

# Reducing Cold Injury to Grapes Through the Use of Wind Machines

**Final Report: CanAdvance Project # ADV – 161;  
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**Hugh Fraser, Agricultural Engineer, OMAFRA  
Ken Slingerland, Tender Fruit & Grape Specialist, OMAFRA  
Kevin Ker, Research Associate, Brock University (CCOVI)  
K. Helen Fisher, Department of Plant Agriculture, University of Guelph  
Ryan Brewster, KCMS Applied Research and Consulting Inc.**

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Researchers heading up the project included Hugh Fraser (Agricultural Engineer) and Ken Slingerland (Tender Fruit and Grape Specialist) from OMAFRA; Kevin Ker from Brock University (CCOVI) and KCMS Consulting, Ryan Brewster from KCMS Consulting; and K. Helen Fisher from the University of Guelph Plant Agriculture. Hernder Farms in Niagara-on-the-Lake and Funk Farms in Lincoln were the cooperating growers working with the above researchers.

### ***Stakeholder Steering Committee***

This Committee was set up early in the project to assist in the information delivery activities. It met three times and included representatives from: GGO, WCO,OTFPMB, Town of Niagara-on-the-Lake, Agricorp, a Virgil resident living beside a wind machine, two grape growers involved in the project and two wind machine suppliers.

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## INTRODUCTION

The trend for the grape and wine industry in recent years has been the planting of more high quality *vinifera* grapes. Unfortunately, many of these cultivars are sensitive to cold injury from early fall through to the last frost in the spring. The winters of 2003, 2004 and 2005 had sufficiently cold temperatures to result in vine and tender fruit bud and plant injury. There were slightly over ten million *vinifera* vines in the province of Ontario (approximately 66% of total commercial vines in Ontario) when winter killing temperatures occurred in January of 2005, with the direct result that overall yield of processed grapes declined 54% (56,787 tonnes in 2004 to 26,198 tonnes in 2005), mainly due to winter injury. Tender fruit crops also suffered crop reduction, especially peaches. This indicated a need for research in the grape and tender fruit industries to minimize cold temperature injury in Ontario.

In November 2005, an innovative 3-year applied research project was initiated. The goals were to study:

- whether grape and tender fruit bud hardiness stages varied throughout the dormant season by doing systematic field sampling
- whether wind machines could take advantage of strong or weak air temperature inversions to prevent/reduce cold injury damage
- where and how best to operate wind machines by intensively studying a vineyard with one
- how effects of machine noise might be reduced, especially near urban encroachment areas, and to
- develop *Best Environmental Management Practices (BEMP)* information.

The project was extended from October 31, 2008 to October 31, 2009.

## COLD INJURY TO PLANTS

Plants may be subject to physical injury when exposed to freezing temperatures during the growing season or during the dormant (overwintering) season. Most people are familiar with frost damage when plant tissues are injured during the growing season (early or late). Visible symptoms include cessation of growth, wilting of shoot tips, the browning of leaf tissue, and in late season, cessation of fruit development and maturation (Figure 1).



**Figure 1.** Leaves injured by early fall frost. These leaves are no longer functional and will not contribute in crop maturity or carbohydrate accumulation for overwintering.

Plant injury in the dormant period is assessed through examination of the buds for any injury, observed as browning or oxidation of the buds (Figure 2). Injury may also be noticed in spring as excessive shoot growth from the base of the plant due to injury to points above on the trunk (Figure 3).



**Figure 2.** Healthy bud (end of white arrow); injured bud (end of red arrow).



**Figure 3.** Dead trunk tissue (brown, oxidized, white arrow) and vigorous shoot growth (red arrow) below the trunk injury location, as seen the spring following winter injury.

Water is the key factor in plant freeze injury, causing ice crystals to form within and between the cells. Cell membranes are damaged, leading to leakage of the cell contents and eventually, cell death. If enough cells die, that portion of the plant will die, leading to significant structural and functional damage. The challenge is assessing existing cold injury during the dormant season and establishing at what critical temperature(s) more injury is likely to take place. Grapes and tree fruits transition from a cold tender to a cold hardy state beginning in the autumn, responding to seasonal changes in temperature, day length and moisture content of the plant tissues.

**Cold acclimation** occurs in two phases, with the first occurring as temperatures decline but remain above 0°C. During this period, chemical changes occur within the cells to enable them to withstand temperatures below 0°C (approximately -5°C to -10°C).

During this **first phase**, a waxy periderm forms and is visible as the progressive maturation and browning of shoots from the base to the tip. This waxy periderm facilitates dehydration of the internal cells, preventing rehydration of the acclimated tissues by external water. In addition, dormant buds on canes are gradually isolated from the vascular system by the development of an additional impermeable layer below the bud, the bud plate. Waxy scales and dense hairs within the buds also aid in keeping the buds dry during the winter. Throughout this period, carbohydrates are stored in canes, trunks and roots. It is important to understand that wood and cane maturation must occur in sequence, commencing well before the leaves are damaged by the first killing frost and in time to anticipate the onset of winter.

The **second phase** of acclimation occurs as temperatures fall below 0°C, with tissue hardiness increasing dramatically as daily temperatures continue to decrease throughout the fall and early winter. During this secondary phase, water content within and around cells decreases dramatically. Physiological changes take place within the cells to withstand low temperatures and minimize ice crystal formation. It has been observed that optimum vine hardiness is achieved in mid winter. This level of hardiness is different among grape cultivars and may be achieved at different rates and maintained for different lengths of time during the dormant season. Plants have an inherent **chilling or dormancy requirement** and must be exposed to specific amounts of cumulative temperatures below 5°C before they will resume growth the following season. This is known as the chilling requirement and for most tender fruit and grapes in Ontario, this requirement is usually fulfilled by early January.

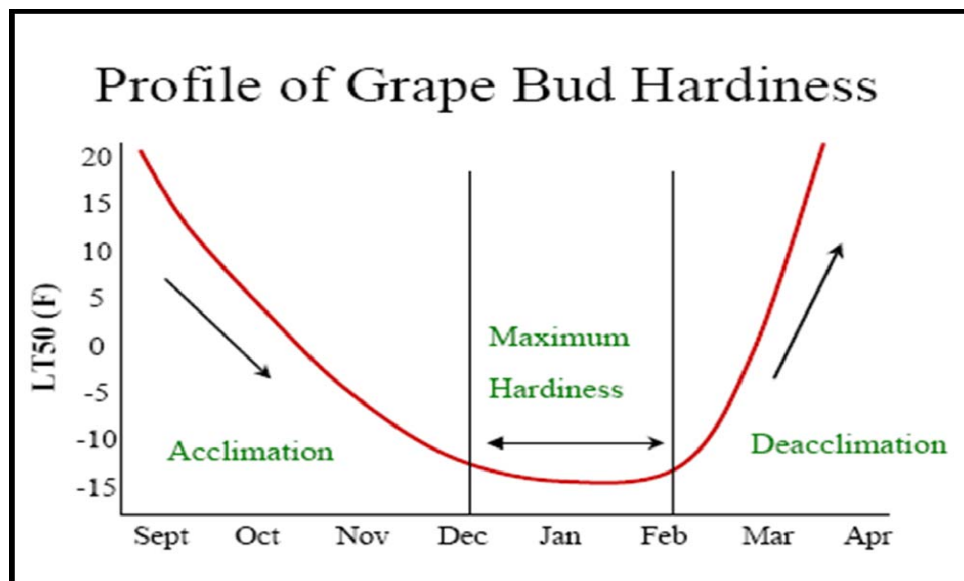
**Deacclimation** is the reversal of acclimation as the plant progresses from a cold hardy to a cold tender state. Deacclimation occurs more rapidly than acclimation, and is primarily dependent on increasing air and soil temperatures. Once vines or trees have achieved physiological chilling requirements to fulfil dormancy, growth could resume if external conditions are suitable for growth. However, each cultivar will resume growth at different rates, which makes it essential to assess multiple cultivars on each sampling date to establish hardiness and bud survival status. Information presented later in this document will demonstrate differences in vine hardiness levels across cultivars and differences of vine hardiness within a cultivar across years.

## FACTORS AFFECTING COLD HARDINESS

As mentioned above, different cultivars will have different rates of acclimation and deacclimation. This is based on vine genotype. This genetic potential determines the optimum level of hardiness that a particular cultivar may achieve. Realization of the hardiness potential is strongly influenced by the environment in which the vine grows (site, soil, topography, proximity to protective geographic features, climatic conditions in season, pest incidence) and grower practices (managing the canopy, fertilization, water management, balanced crop loads, appropriate pruning levels and training systems, rootstock and clonal selection, site preparation and design).

All sites have a different potential vine productivity. It is critical that crop levels and vine care are maintained to ensure vine health is optimized and full fruit maturity is achieved. It has been observed that in sites where vines are over cropped, vine balance is not achieved and greater levels of winter injury are noted. Poor air drainage, poor soil drainage and excessive fertilization also affect winter hardiness. Well managed sites nearby with similar cultivars will overwinter with minimal injury.

Due to the myriad of factors affecting cold hardiness, it is impossible to predict actual hardiness without taking specific samples during the dormant period (Figure 4). Though the hardiness cycle is somewhat ‘U-shaped’ from acclimation through deacclimation, data collected during this study showed that cultivar, location and yearly variability exist. Modelling using temperature indices alone is unreliable and risky.



**Figure 4.** The generalized trend of vine acclimation and deacclimation from late season through to bud break the following spring (Zabadal *et al*, 2007).



## WHY DO GRAPE GROWERS USE WIND MACHINES?

In Ontario, wind machines are primarily used to protect grapes from cold temperature injury (Figure 5). Market demands have encouraged grape growers to plant more cold sensitive *vinifera* grapes today than in the past, as there is little demand for cold tolerant cultivars in traditional growing areas.



**Figure 5.** Wind machine in vineyard near Virgil monitored by authors in this research project

There are three critical times growers need to protect crops against cold injury:

- late spring frosts (early growing season)
- early fall frosts (late growing season)
- mid winter cold (dormant season)

After the significant cold temperatures of January 2005, growers with machines harvested near normal crops that season. Those growers nearby without machines experienced not only total crop failure but also significant plant loss in 2005.

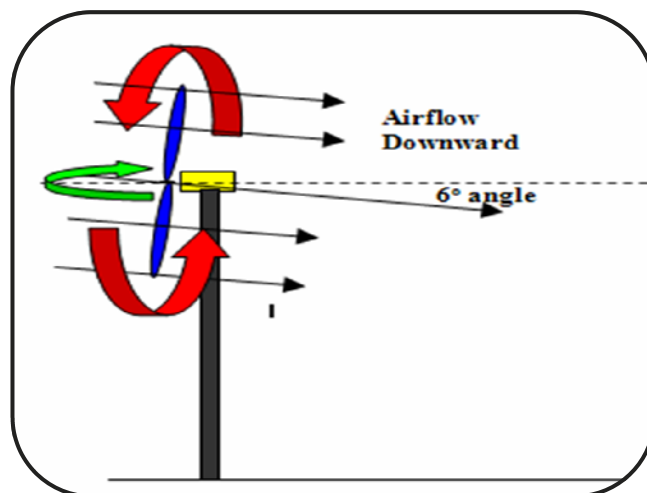
## HOW DO WIND MACHINES WORK?

Wind machines are tall, fixed-in-place, engine-driven fans that pull warm air down from high above ground during strong temperature inversions, raising air temperatures around cold-sensitive perennial crops such as grapes and tender fruit trees. They are not the same machine as wind turbines which are designed to create electricity from wind energy.

Wind machines help reduce cold injury which can affect the following year's crop as well as long-term plant health. Currently, there are four machine types in Ontario. All are about 10.5 m high (34 ft) from the concrete anchor pad to the blade axis. Blades are 5.4-6.0 m in length (18-20 ft). Blade speeds are 400-600 RPM, generating huge airflows blowing outward at least 110-125 m (360-410 ft). Three types of machines have two blades, one has four. The cost to install a wind machine, including the concrete base, is about \$36,000 CDN and fuel costs are about \$25-\$50/h (2009)<sup>a</sup>. Most Ontario wind machines operate on propane, diesel or natural gas, but in some jurisdictions, gasoline or electricity.

All machines work similarly. Fan blades angle 6° down from vertical. During anticipated cold injury periods with a strong temperature inversion, machines pull warm air from at least 15 m (49 ft) above the field then blow it down and out, pushing away and replacing cold air near target crops (Figure 6). This breaks up microscale air boundary layers over plant surfaces, improving sensible heat transfer from the air to plants. Wind machines transfer heat by forced convection. 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.

It costs about \$5,000 (2009) to move a wind machine to a better location, if necessary. This includes the cost of pouring a new concrete pad, dismantling the machine, renting a crane to move it, then reinstalling it. There are extra costs to move a natural gas line.



**Figure 6.** Wind machines pull warm air down from high above crop, blowing it downward and outward.

a. Albert Brooks, Lakeview Harvesters, Niagara-on-the-Lake, ON. Personal Communication. November 2009.

Different machine types have different airflow rates, airflow travel distances, times to sweep around the field and sector angle coverage (Figure 7). This is the wedge of land area 'feeling' air mixing from the fan at any one time. It is calculated by measuring the time air movement occurs at one location compared to one full rotational cycle of 360°. For example, stand a short distance away from a machine and start a stop watch when first feeling air hit your face. Stop it when you no longer feel the air. If the time is 1 minute and total cycle time is 5 minutes, this is 20% of time, or 20% of 360°, or 72° sector angle coverage. Greater angles are better as this gives less time for cold air to resettle.

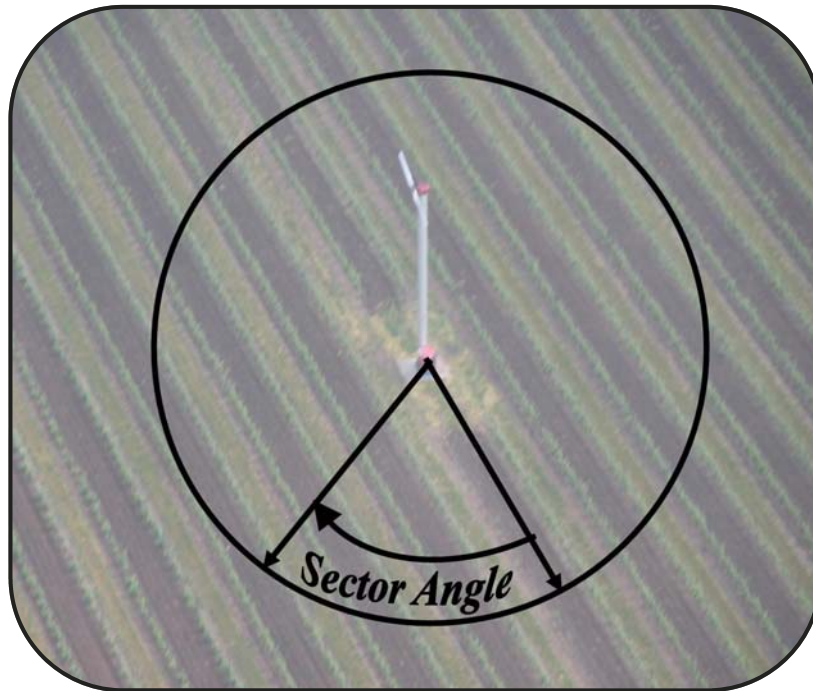
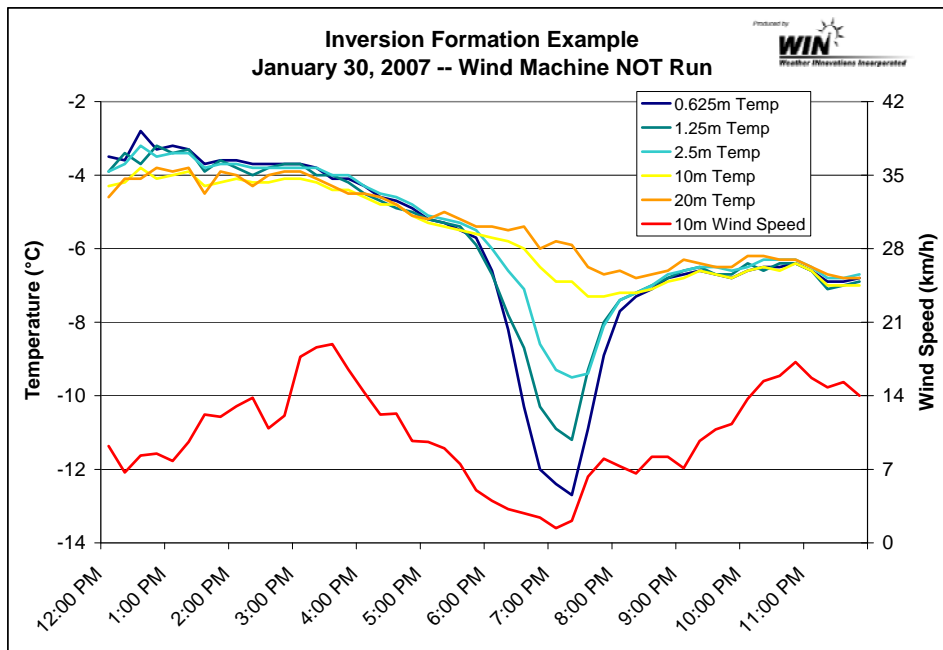


Figure 7. Sector angle describes wedge of land 'feeling' fan air at any time from a wind machine.

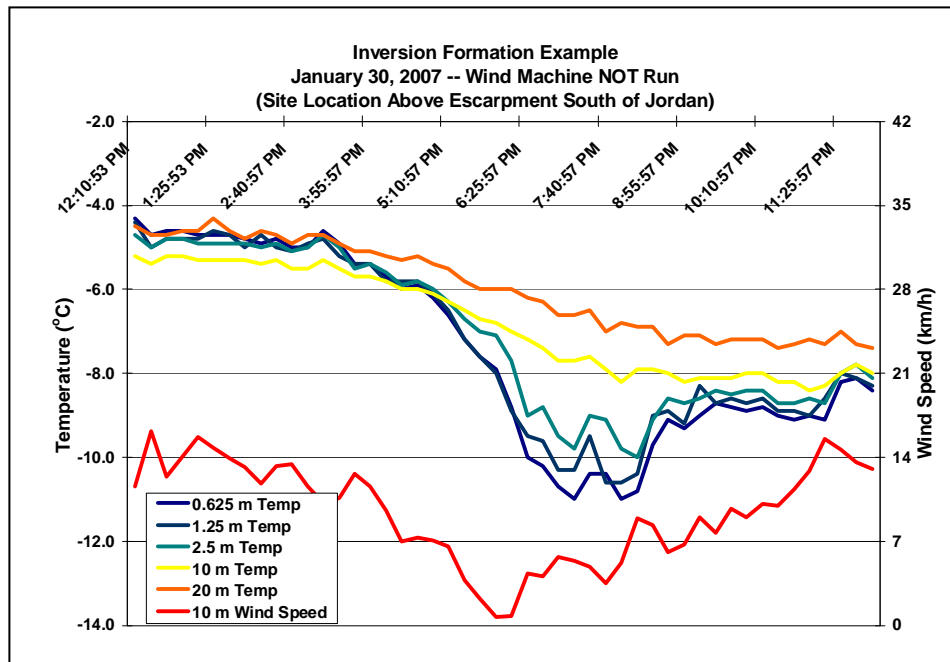
## TEMPERATURE INVERSIONS

Temperature inversions are *strong* if air temperatures 20 m (66 ft) above the field are at least 3°C (5.4°F) warmer than at vine level 0.625 m (2 ft). Strong night-time radiative temperature inversions were confirmed during periods when wind machines might be used below and above the Niagara Escarpment. This occurred when skies were clear and starlit, with minimal wind movement.

Inversions are greatly affected by atmospheric wind, even if it is only a slight wind. Wind speeds less than about 7 km/h (4 mph) are necessary for inversions to form and greater than 7 km/h to break up again (Figures 4, 5). Temperature inversions just before wind machines were turned on during this project were generally in the range of 5-7°C (9-13°F), but inversions as great as 10°C (18°F) were observed. Inversions can develop, dissipate, then redevelop all in the same night as winds rise or fall. So, on rare occasions wind machines might operate for a time, then go off, then operate again in the same night. Wind machines can raise air temperatures around plants by about half the temperature inversion difference. So, in Figure 8, if at 7:15 pm the air temperature at 20 m above the vineyard was -6°C and the air temperature at 0.625 m vine level was -13°C and a wind machine was turned on, you might expect the air temperature at vine level to rise to as high as about -9.5°C. We also observed that strong temperature inversions occurred above the Escarpment (Figure 9).

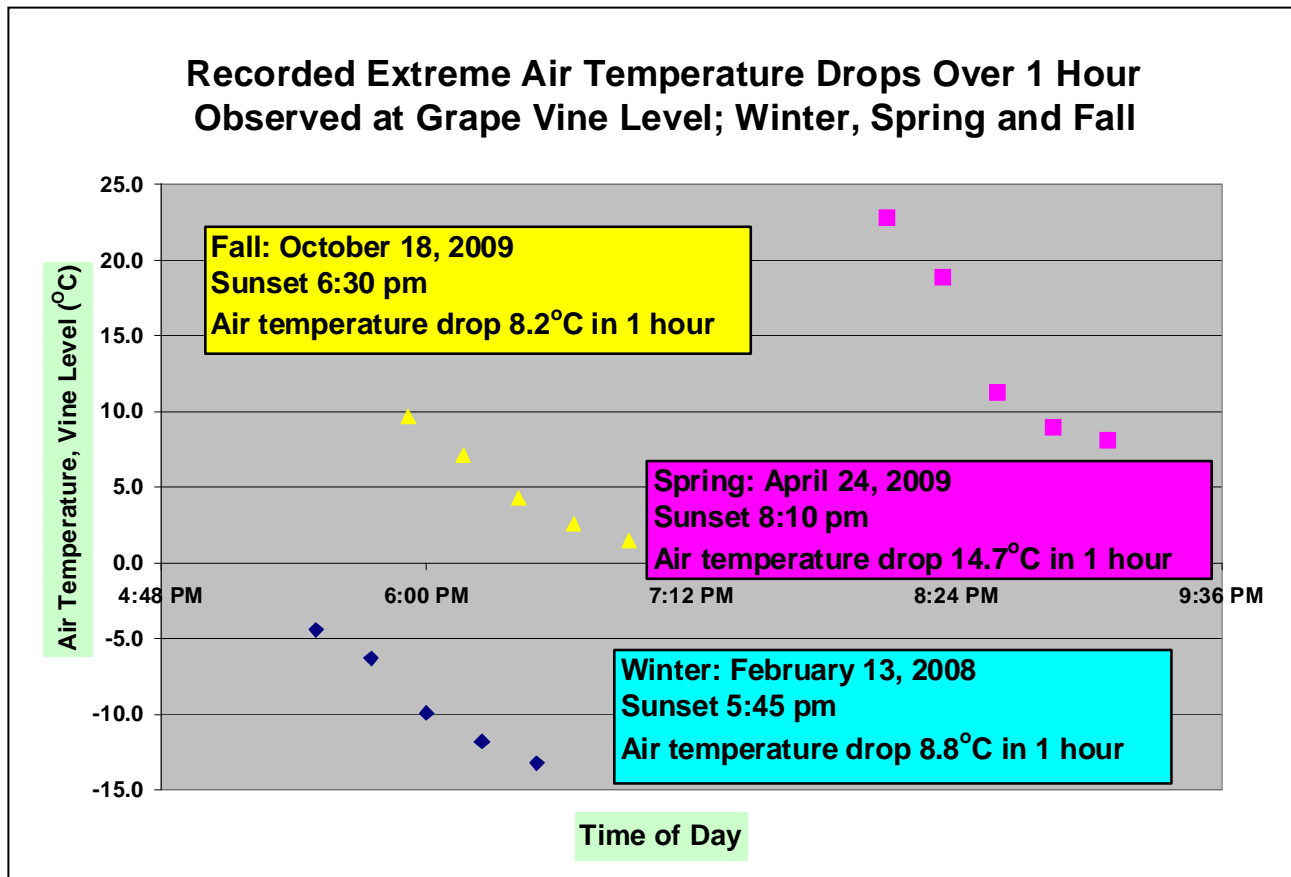


**Figure 8.** This strong temperature inversion below Escarpment near Virgil of about 7°C between 20 m above and 0.625 m above ground started forming as winds dropped below 7 km/h at 5:30 pm. The inversion ended when wind speed rose above about 7 km/h at 8:00 pm. A date was chosen when the machine was not operated so the true impact of atmospheric wind would demonstrate its affect.



**Figure 9.** This strong temperature inversion above Escarpment south of Jordan of 4.5°C between 20 m above ground and 0.625 m above ground, started forming as winds dropped below 7 km/h at 5 pm the same evening as in Figure 8 (about 23 km SW of other site in Virgil). The inversion at this site was not as strong as the inversion below the Escarpment south of Virgil, a trend noted on other occasions. The inversion dissipated when wind speeds again rose above about 7 km/h at 9 pm.

Vineyard or orchard air temperatures are often very different from the local or regional forecasts. They don't predict temperatures close to the ground where grape buds or fruit are located and they don't account for low areas where temperatures are often much colder. Temperatures can drop very abruptly, many degrees in just an hour, often right at sunset or sunrise, so predicting exactly if and when a wind machine might need to be operated can be difficult. See Figure 10.



**Figure 10.** Three events (spring, fall, winter) demonstrate how quickly air temperatures can drop at the 0.625 m (2 ft) level in a vineyard. In the most extreme case, the air temperature dropped 14.7°C in one hour on April 24, 2009.

## SPRING, WINTER AND FALL EVENTS

### Spring Events

The effect on ground air temperatures is almost instantaneous after a wind machine is turned on, but air temperatures will vary slightly throughout the area. See Table 1.

**Table 1:** Air temperatures over 35 minutes at several vine level locations (0.625 m above ground) compared to 20 m above the vineyard before and after a wind machine started during potential spring frost 18 May 2009. Vineyard was below Niagara Escarpment SE of Virgil.

Time of Day	Wind Machine Status	20 m (66 ft) above vineyard	150 m (500 ft) South of WM (0.625 m level)	75 m (250 ft) South of WM (0.625 m level)	115 m (375 ft) North of WM (0.625 m level)
2:20 am	Off	6.1°C	1.6°C	1.7°C	1.5°C
2:25 am	Started	6.2°C	1.4°C	1.7°C	1.4°C
2:30 am	On	6.1°C	1.2°C	1.5°C	1.5°C
2:35 am	On	5.8°C	1.0°C	1.0°C	1.7°C
2:40 am	On	5.8°C	0.9°C	1.0°C	2.0°C
2:45 am	On	6.1°C	0.9°C	1.3°C	2.2°C
2:50 am	On	6.0°C	0.8°C	1.2°C	2.5°C
2:55 am	On	6.2°C	0.8°C	1.2°C	2.7°C

Note the strong temperature inversion of 4.8°C just before the wind machine started (6.2–1.4 = 4.8°C). At 2:20 am temperatures were almost equal around vineyard (1.5-1.6°C). From 2:30 to 2:55 am, the following observations can be made:

- At 150 m south of the machine temperatures continued to get colder as no ‘warm’ air could reach there
- At 75 m south of the machine temperatures dropped, but not as much because of the machine
- At 115 m north of the machine temperatures were higher because of its influence

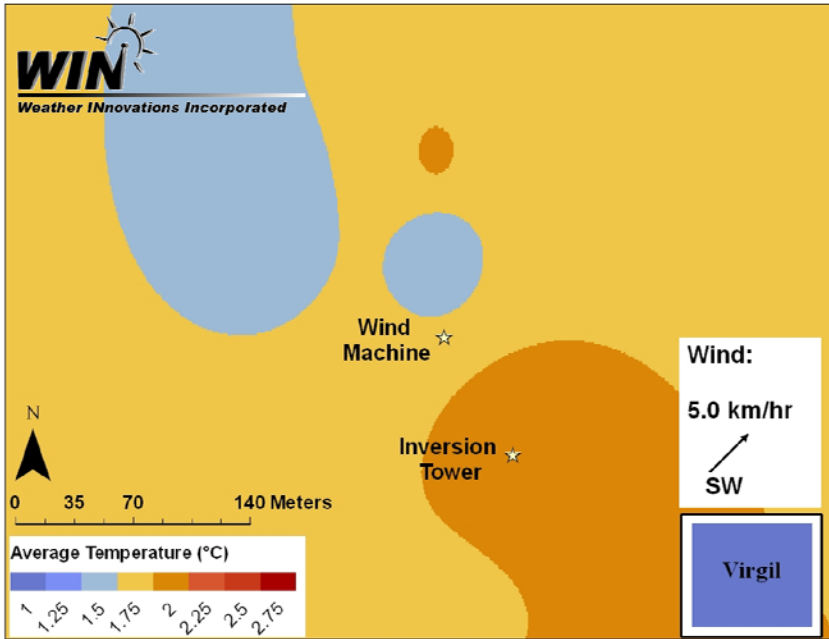
Note air temperatures high above the vineyard remained almost constant, indicating what might be considered ‘an ocean of warm air’ above the vineyard.

The machine was set to start at 1.5°C using a sensor 15 m (50 ft) away at 0.5 m (1.6 ft) above ground (sensors can be set in 0.5°C intervals). The differential was set at 2°C (3.6 °F) so the machine would turn off if the temperature rose to 3.5°C (1.5° + 2° = 3.5°C, differentials can be set at 2, 3, 4 or 5°C). The smaller the differential, the less time the machine operates after temperatures rise. There was a slight SW wind of 4-5 km/h pushing air NE. The vineyard site was level.

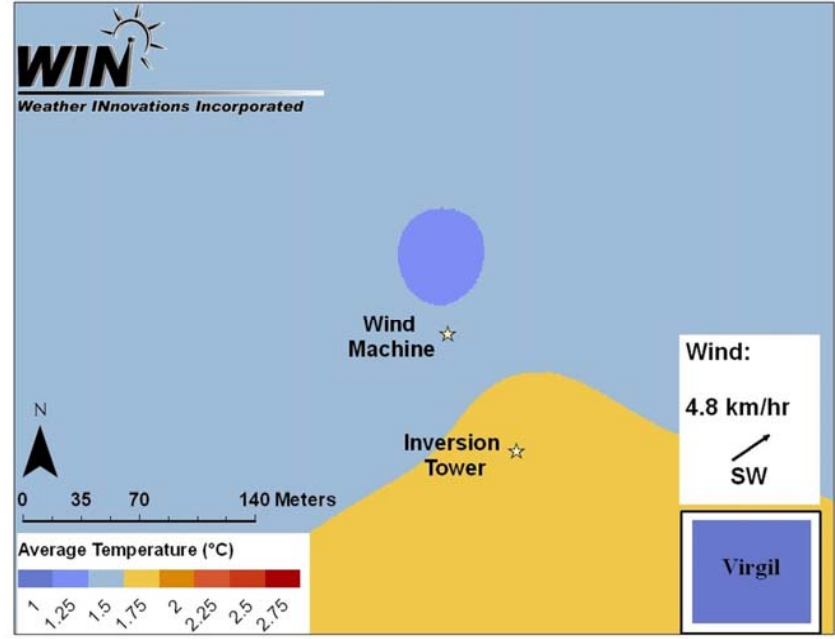
Figure 11 is a visual look at what happened during the 18 May 2009 spring frost event described above. The following eight maps have coloured temperature contours, showing the effects on air temperatures 0.625 m above ground around the vineyard before and after the wind machine was started. Each map is 18 ha (44 ac) of land. The wind machine location is noted, but there are adjacent wind machines to west and east just off the map. Air temperatures were taken five minutes apart. View pictures left to right.

**Figure 11.** (Following two pages). Dark blue is coldest at 1°C at 0.625 m above ground; dark red is warmest at 2.75°C, with six variations between. For comparison, the air temperature at Virgil, 2 km away, where there was no wind machine is shown in the bottom right corner, which remained at 1°C (dark blue) throughout the event. Note the wind direction (southwest) and speed (4-5 km/h). Before and just after the machine was turned on, the entire vineyard hovered around 1.5°C to 2°C. The wind machine took a few minutes to revolve around the vineyard, but after 15 minutes (2:40 am), the vineyard warmed considerably. The area of influence was recognizable as downstream of the machine to the north and east since the observed atmospheric wind direction was from the southwest, causing drift (Figure 12)

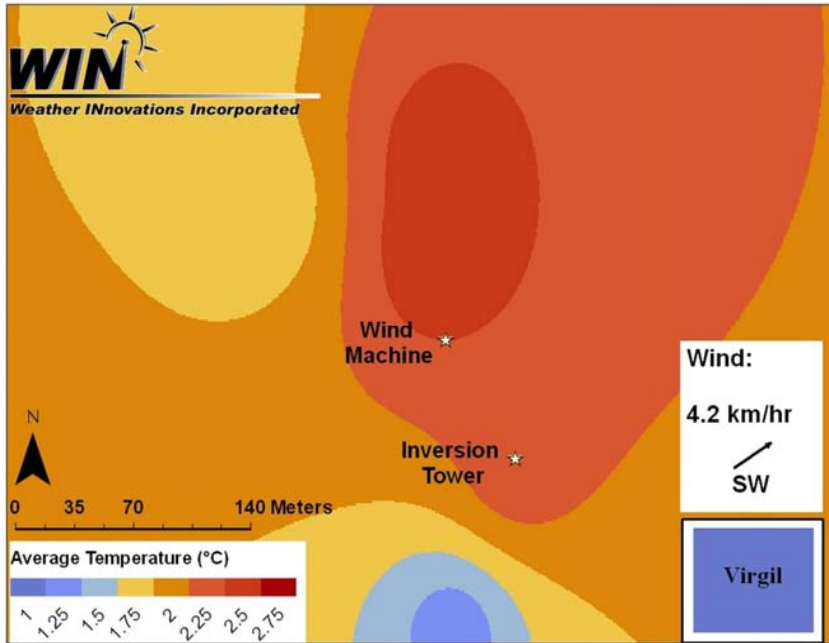
2:20 am: Before wind machine started



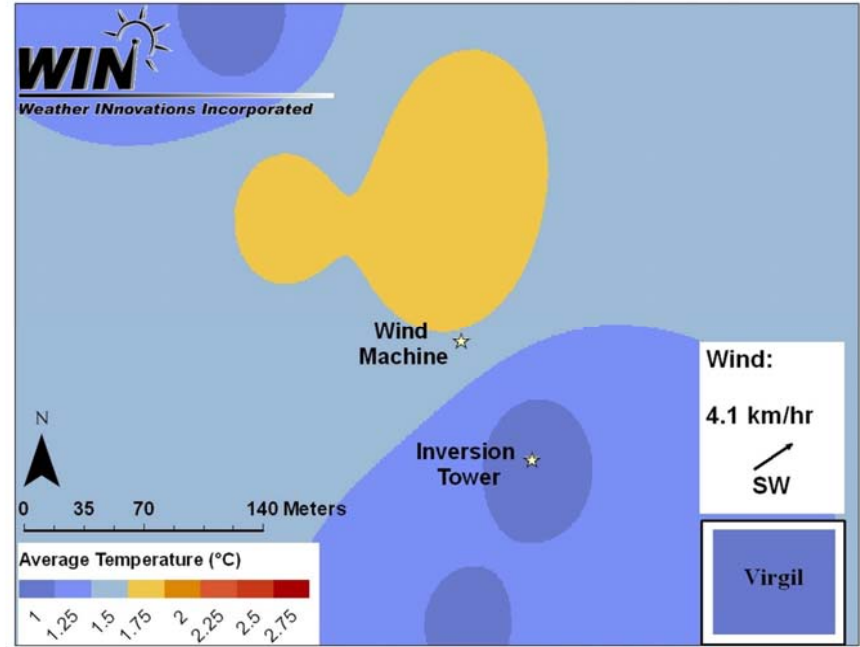
2:25 am: Wind machine started up warming for few minutes



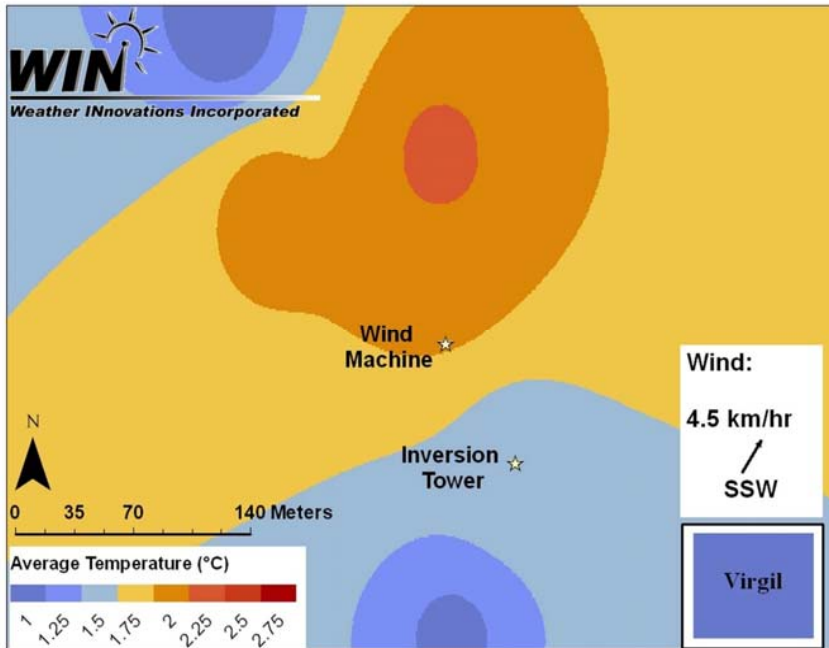
2:30 am: Wind machine running full speed



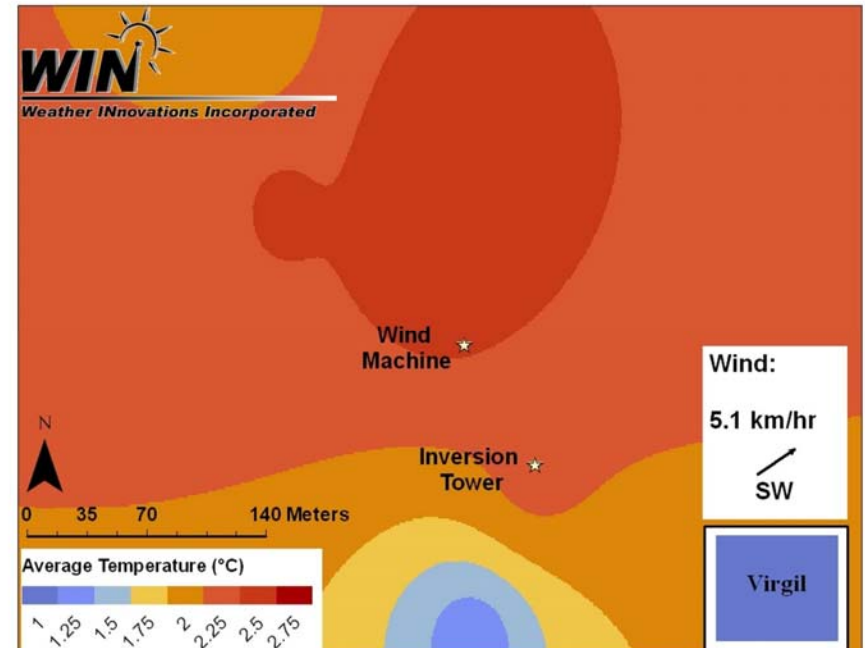
2:35 am: Wind machine running full speed



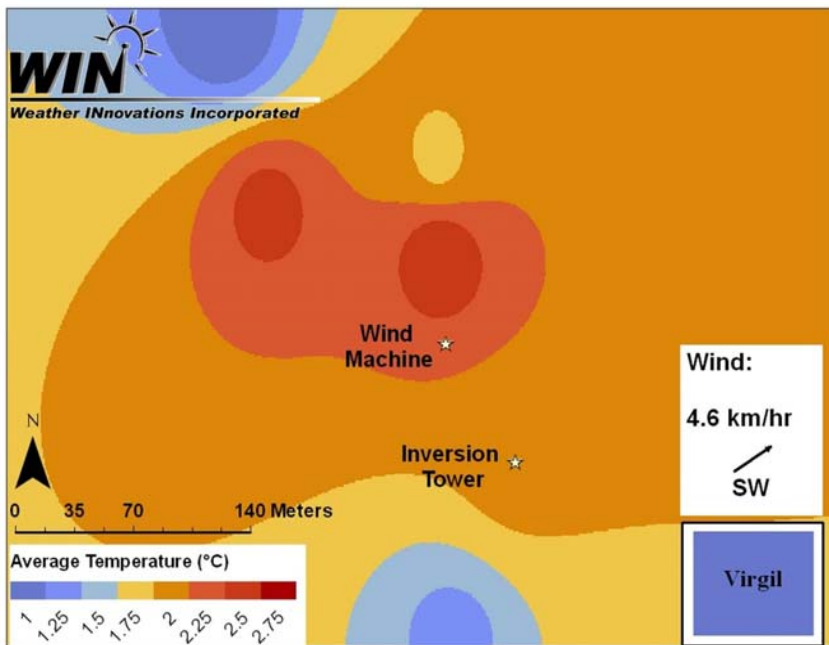
2:40 am: Wind machine running full speed



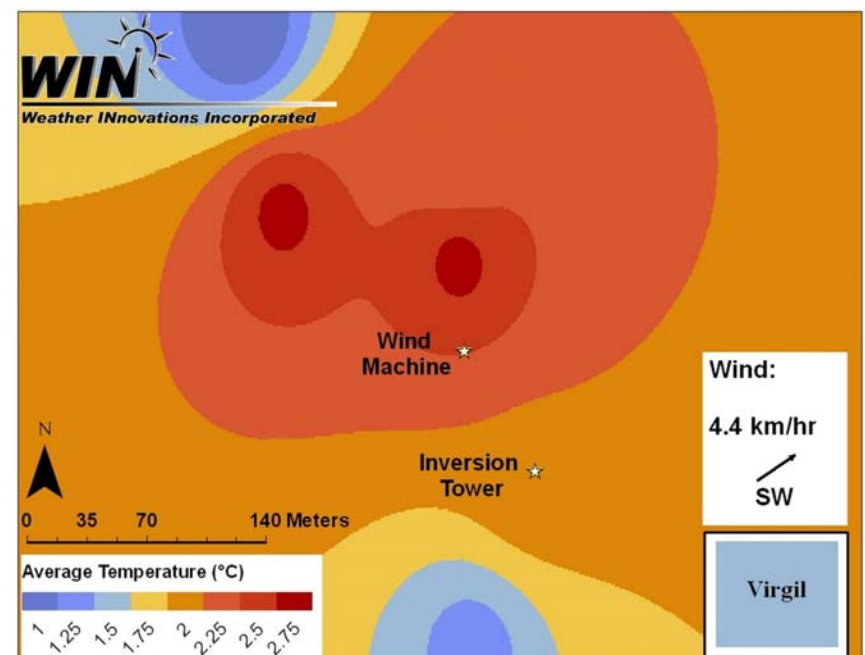
2:45 am: Wind machine running full speed



2:50 am: Wind machine running full speed

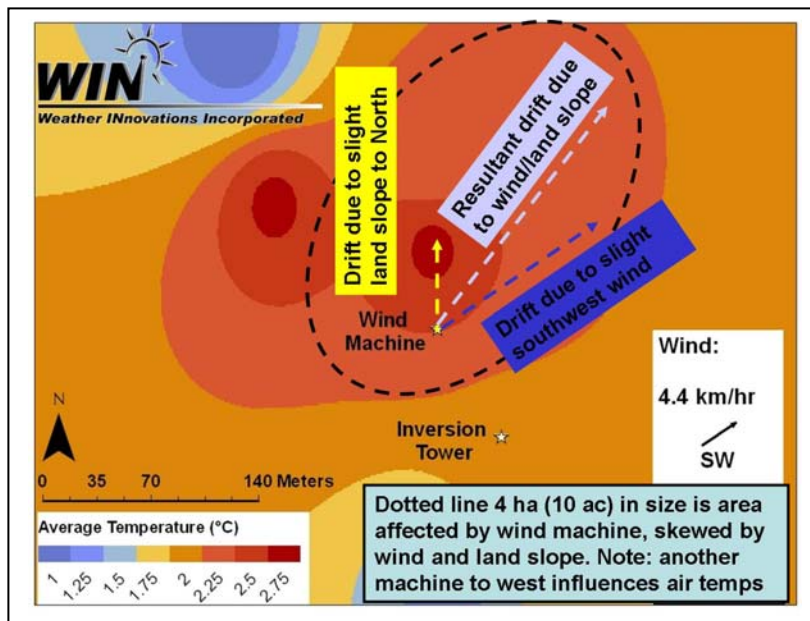


2:55 am: Wind machine running full speed





Even though wind machines blow air outward, mixing it in all directions, their area of influence is not circular as one might expect. The area of influence can be distorted by a combination of land slope and wind direction. Cold air flows down slope like the ‘flow of molasses’. In Niagara, below the Escarpment, there is a natural airflow from the base of the Escarpment to Lake Ontario which naturally skews a wind machine’s area of influence into an elliptical shape. Even though winds are quite calm when wind machines operate, wind direction appears to also skew the area of influence. If both land slope and wind direction are in the same direction areas of influence will be take on an elliptical shape in that direction. If land slope and wind direction are in opposite directions or at right angles to each other, this again changes the shape of the area of influence. From our research, it appears most of the time when wind machines are used in Niagara winds are from the SW creating the area of influence shape as in Figure 12.



**Figure 12.** In this 18 May 2009 spring frost event map, the area influenced by a wind machine is not always a circle but skewed by the combined effect of the slope of the land and wind direction/speed even though winds are generally very calm when a wind machine is operated. The dotted line is 4 ha (10 ac).

### Winter Events

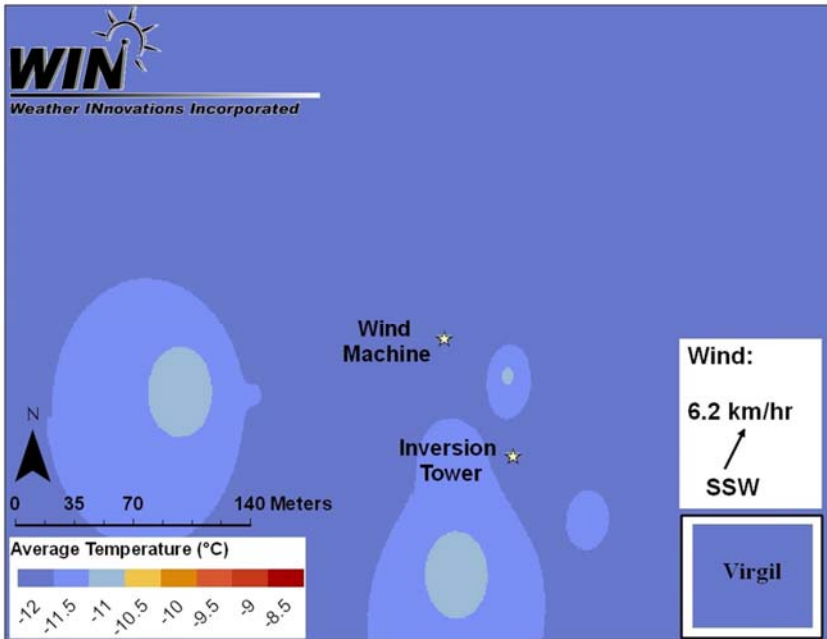
Similar effects on air temperatures 0.625 m above ground occur in winter with wind machines as seen in this 13 February 2008 event (Figure 13).

In Figure 13, dark blue is the coldest temperature  $-12^{\circ}\text{C}$  at 0.625 m above ground, dark red is warmest at  $-8.5^{\circ}\text{C}$ , with six variations of colour in between. For comparison, the temperature at another site at Virgil (2 km away) where there was no wind machine is shown in the bottom right corner, remaining at  $-12^{\circ}\text{C}$  (dark blue) throughout the event. Winds at the test site were consistently from the SSW between about 4 - 6 km/h.

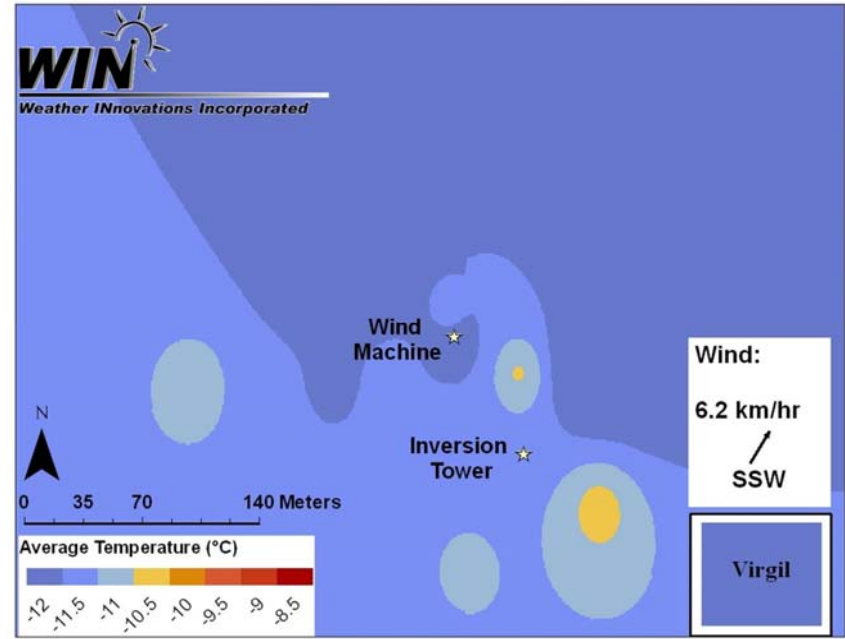
Before the wind machine was turned on at 7:00 pm and just afterward, the entire vineyard hovered around  $-11^{\circ}\text{C}$  to  $-12^{\circ}\text{C}$ . Within about 15 minutes at 7:15 pm the vineyard had warmed up considerably and the main area of influence is recognizable as being downstream of the wind machine to the north (mainly) and east since winds were from the SSW. See Figure 14.

**Figure 13.** (Following two pages)

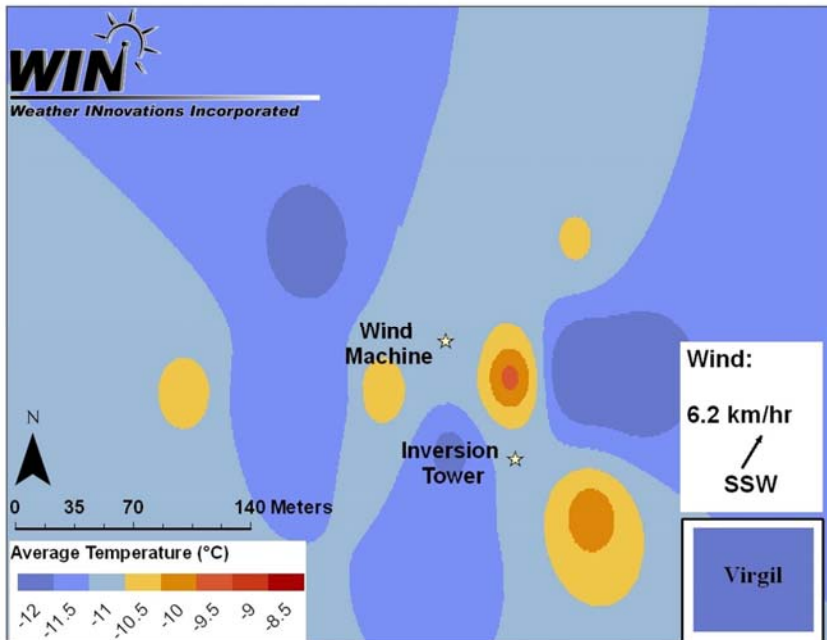
6:55 pm: Before wind machine started



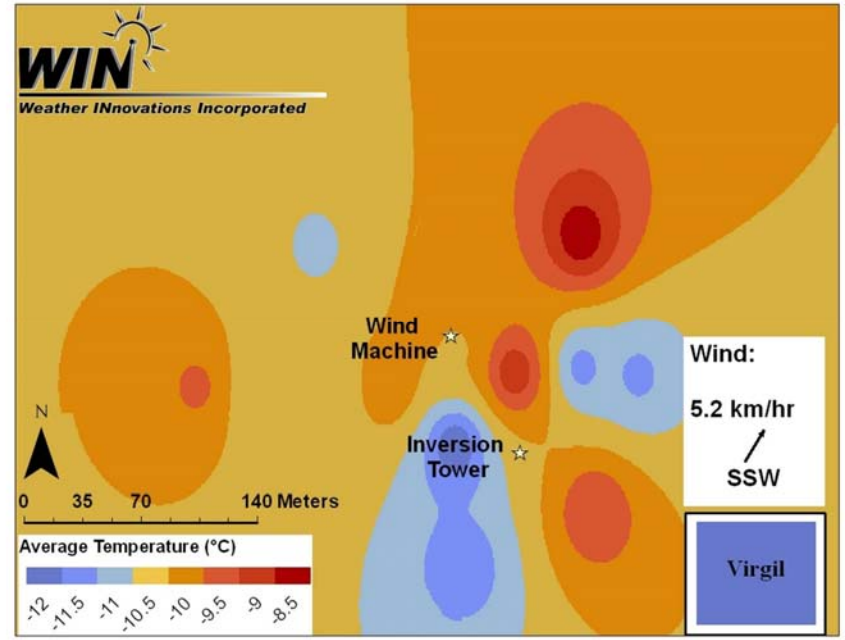
7:00 pm: Wind machine started up; warming for a few minutes



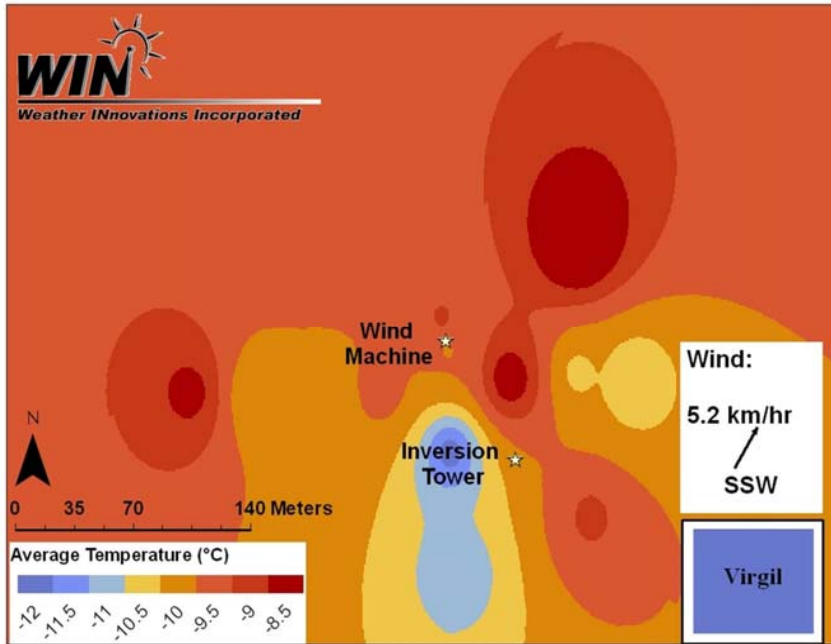
7:05 pm: Wind machine running full speed



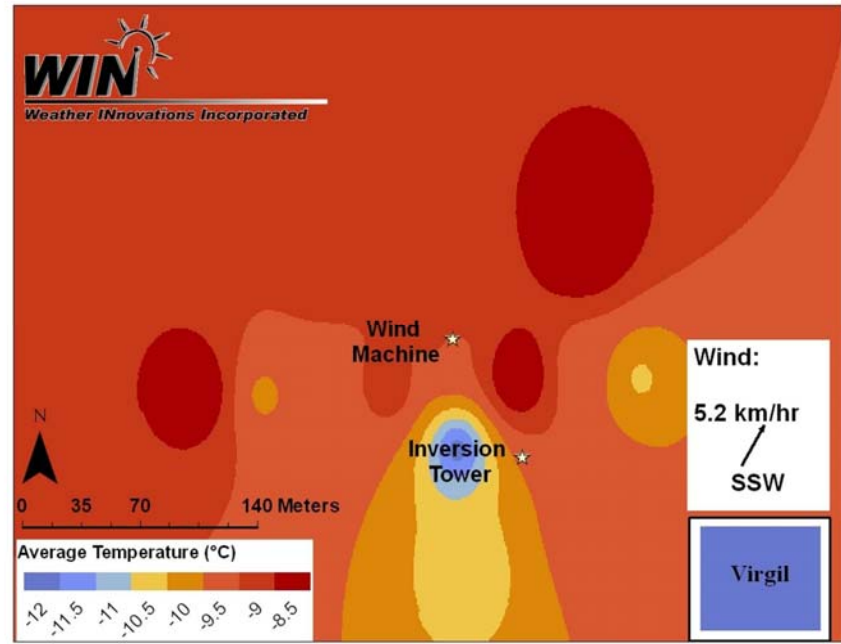
7:10 pm: Wind machine running full speed



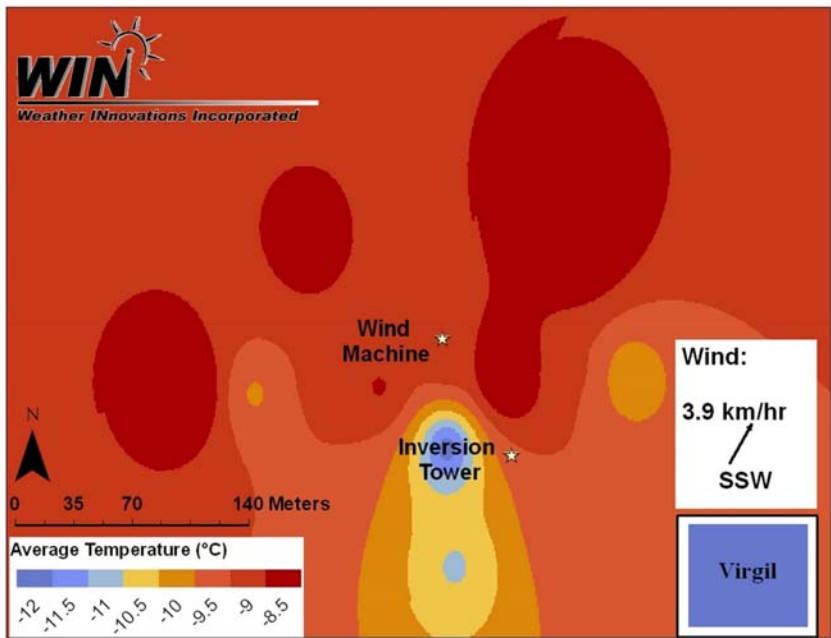
7:15 pm: Wind machine running full speed



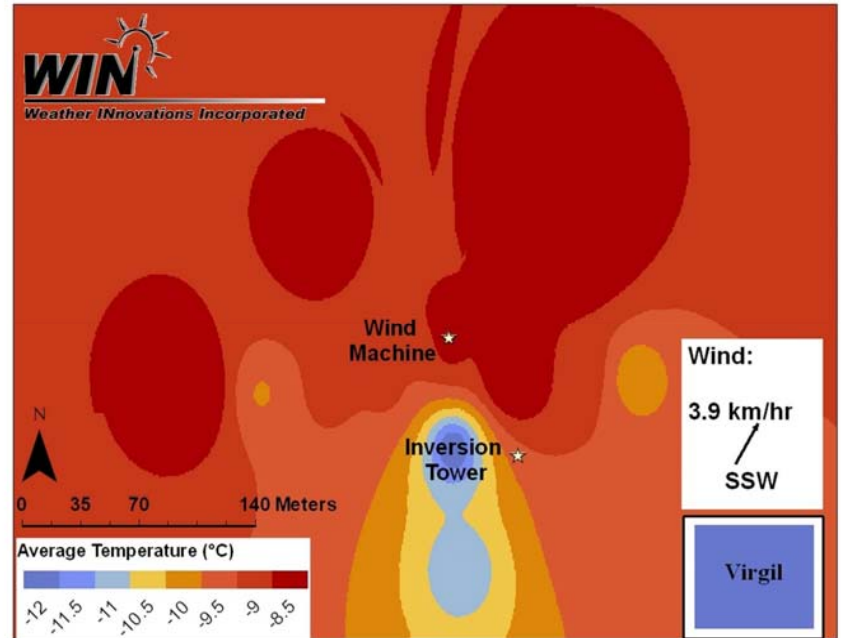
7:20 pm: Wind machine running full speed

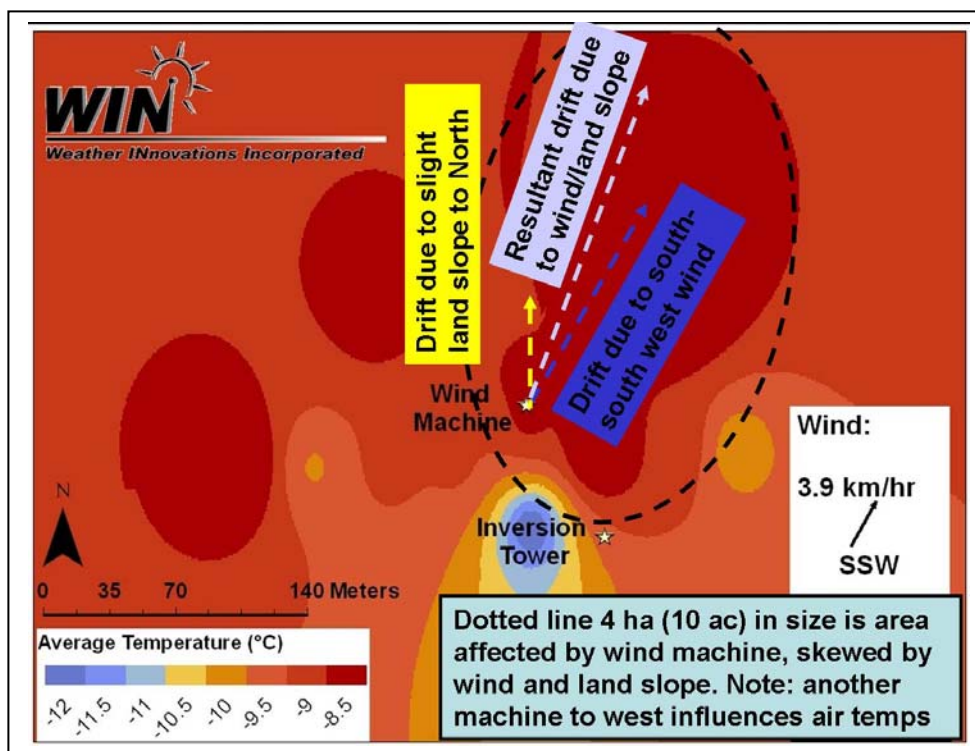


7:25 pm: Wind machine running full speed



7:30 pm: Wind machine running full speed





**Figure 14.** In this 13 February 2008 winter cold event, the area of influence of the wind machine is skewed by the combined effect of the slope of land and wind direction/speed, even though winds are generally very calm when a wind machine is operated. However, because the wind direction was more from the SSW, the area of influence aligns more with the NNE direction. So, despite winds appearing quite calm, it appears its speed and direction has a great influence on what is protected. The dotted line is about 4 ha (10 ac) in size.

### Fall Events

Wind machines may be operated to prevent early frost injury in fall to extend harvest dates. At the test site, the wind machine was not used for this purpose during the project. However, the effect of the use of a wind machine to prevent early frost injury at another site in October 2009 can be seen in Figure 15. Grape leaves were still green where protected from frost by the wind machine a few days earlier, while leaves are dead and brown just beyond reach of the wind machine, past about 120 m (394 ft). This protection allowed leaves to continue to photosynthesize for another three weeks, enhancing the quality of the crop and making it much more marketable. Another Niagara grower used his wind machine in late fall 2008 and reported three concentric rings around his machine; the first with ‘dry’ grape leaves nearest the machine; the second with ‘wet’ grape leaves further from the machine; the third with ‘frosty’ leaves furthest from the machine.

### WIND MACHINE USE DURING RESEARCH TESTING PERIOD

During the four year research project, the wind machine at the test site operated 29 times (Table 2). The number of hours each year was less than originally anticipated, with the range 22 to 48. However, it is likely that during the very cold previous winters of 2003, 2004 and 2005 (before this project commenced), wind machines would have operated for longer periods. Each site is different with its unique needs. With experience, growers operate wind machines more precisely with fewer hours, not more.



**Figure 15.** View from 6 m up wind machine ladder looking north at a St. David’s vineyard. Camera zoomed to look at end of the rows about 137 m (450 ft) from the machine where leaves were frosted.

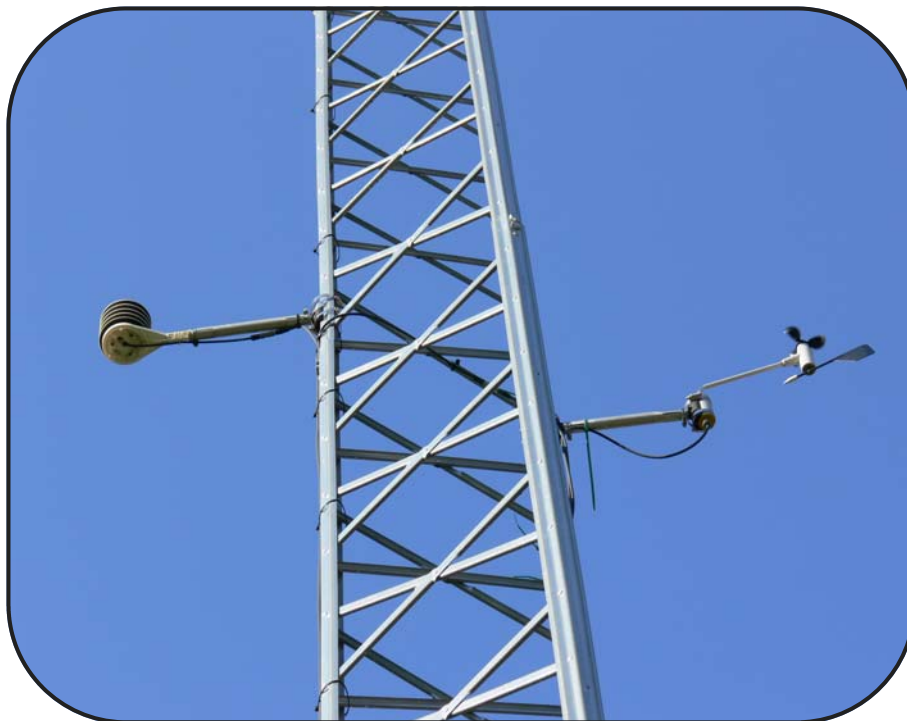
**Table 2:** Operation of wind machine over four year period December 2005 to November 2009

	<b>Winter</b>	<b>Spring</b>	<b>Fall</b>	<b>Totals</b>
<b>Number of uses</b>	8	15	6	29
<b>Hours used</b>	29.5 hours	72 hours	39.5 hours	141 hours
<b>Average uses/year</b>	2	4	2	8
<b>Average hours/year</b>	7.5 hours	18 hours	10 hours	35.5 hours

## **FACTORS AFFECTING WIND MACHINE OPERATION**

### ***Wind Speed***

Wind speed is best measured with a tower and an anemometer placed at 10 m (33 ft) above ground. This is the standard height used by weather forecasters (Figures 16, 17), but they are expensive and impractical for many growers. However, there is a simple rule of thumb for measuring wind speed. In 1805, Sir Francis Beaufort, a British Admiral, created the *Beaufort Wind Scale* to help sailors estimate wind speeds based on visual observations. It is still used today (Table 3).



**Figure 16.** This 20 m tower held air temperature and wind sensors in the test vineyard. Real time air temperatures were monitored every 15 minutes for the first half of the project, every 5 minutes in the latter half, at 0.625 m, 1.25 m, 2.5 m, 10 m and 20 m above ground (2 to 66 ft) and real time wind speed and direction at 10 m above ground (10 m temperature sensor on left, 10 m wind speed sensor on right).



**Figure 17.** The location of the 20 m tower used to monitor air temperatures and wind speed/direction can be seen as a shadow in this picture and was 55 m (180 ft) southeast of the wind machine. The wind sensor was 10 m (33 ft) above ground on the tower, but because the wind machine fan hub was also at about the same height but blowing air 'downward', it did not appear to affect the wind sensor readings.

**Table 3:** The Beaufort Wind Scale can help estimate wind speeds in order to better understand when not to operate a wind machine

Wind; km/h	Beaufort Description	Visual Observations	Use Wind Machine?
2 – 5	Light air	Wind direction is shown by smoke drift, but not by wind vanes	Yes
6 – 12	Light breeze	Wind is felt on face; leaves rustle; ordinary wind vanes move	Yes; but may not be effective
13–20	Gentle breeze	Leaves and small twigs in constant motion; wind extends light flag	No; could damage the blades
21–29	Moderate breeze	Raises dust and loose paper; small branches are moved	<b>Never operate machine</b>

### Dew Point Temperature

One tool for understanding when to turn on a wind machine is to be familiar with *dew point temperature*. It is defined as the temperature at which condensation of water vapour in air first condenses from a gas to a liquid. This is the general property of the air mass in the region<sup>a</sup>. Dew point temperatures occur at all air temperatures we experience from above 30°C (86°F) to below -30°C (-22°F). If the dew point occurs above 0°C (32°F) it is called dew point, but if it occurs below 0°C this temperature it is called frost point. If there is a large difference between outside air temperature (called the dry bulb temperature) and the dew point, the air is ‘dry’. Conversely, if there is a small difference between outside air temperature (dry bulb temperature) and the dew point, the air is more ‘humid’. At 100% relative humidity, the dew point and outside air temperature (dry bulb temperature) are the same. See Table 4.

**Table 4:** Dew point temperatures vs dry bulb temperatures at different relative humidity %

Dew Point Temperature, °C	Dry Bulb Air Temperature, °C (measured on your thermometer)			
	0°C	2°C	4°C	6°C
-6°C	63.9%	55.4%	48.0%	41.8%
-4°C	74.4%	64.4%	55.9%	48.6%
-2°C	86.4%	74.8%	64.9%	56.5%
0°C	100%	86.6%	75.1%	65.4%
2°C		100%	86.6%	75.5%
4°C			100%	87.0%
6°C				100%

For example, using Table 4, if a temperature sensor reads 6°C and the relative humidity is quite dry at 41.8%, dew point (or frost point) temperature is below freezing at -6°C. However, if the same air is more humid at 75.5% relative humidity, the dew point temperature is above freezing at 2°C. During a radiative freeze, infrared radiation is constantly exchanged between the earth and the atmosphere. When the sun sets, objects on the earth’s surface, such as grape vines, emit infrared radiation to the atmosphere. This is known as radiational cooling. If the skies are cloudy, the water vapour in the air absorbs and re-emits the infrared radiation back to the earth’s surface. However, if overnight skies are clear, and winds are calm, more infrared radiation is emitted from the vines than back from the atmosphere. As a result, the vine surfaces become cooler than the air surrounding it.

a. Dr. Robert Evans, USDA, Agricultural Research Service, Sidney, MT. Personal communication on dew point. 17 Dec. 2009.

***It is important to understand that when water condenses on a surface (such as a grape bud), it releases a lot of heat and this is helpful in protecting your crop from cold temperature injury.*** This heat is called the latent heat of condensation and the air is literally filled with a reservoir of this heat that can potentially provide great quantities of free heat to a crop. When water condenses, 2510 kJ/L at 0°C (9000 BTU/US Gal at 32°F) is directly released on the object or into the air where that condensation occurs. This heat is often more than enough to sufficiently replace the heat lost through radiation to the dark night time sky, and averting further temperature decreases, at least temporarily. Exposed plant tissues only have to be very slightly below the dew point temperature in order for water to condense on these tissues. If these tissues are exposed to the dark, night time clear sky during a radiative freeze, they can be 1°C to 2°C colder than the surrounding ambient air and so will reach the dew point before the air surrounding them. So, water condenses on these tissues, releasing heat and keeping the tissues at, or very near, the dew point temperature. This condensation of water/release of heat from that water continues to occur throughout the night and heat continues to radiate out to the clear sky. You might consider this condensation/release of heat energy on the tissue surfaces as Mother Nature's spontaneous assistance to plants in fighting frost.

If the dew point is only a few degrees above the critical crop damaging temperatures, there is little likelihood of damage to that crop. The dew point basically establishes the minimum expected air temperature for the night period because once you reach the dew point, it drops very slowly as more water is condensed and releases heat to the air and anything else it is in contact with, such as a grape bud.

However, if the dew point is at, or a few degrees below the critical crop damaging temperatures, this is different. Some intervention method to protect the crop through the use of wind machines, or even adding heat to make up the difference between dew point and critical temperatures may be needed. You do not always reach the dew point temperatures during these events, but you need to be ready to intervene if necessary. Fortunately, most radiation frosts in spring and fall have fairly high dew points near the critical crop damaging temperatures, so heat released through condensation may be all that's needed.

Wind mixes the colder air mass near the crop caused by radiation cooling with the warmer air mass high above the crop. It evens out the air temperature profile so air is warmer near the crop, even as the crop continues to radiate heat to the night time sky. Water vapour content of air between the ground and 30 m (100 ft) above ground does not vary much, even with natural wind or air movement by a wind machine.

Low, damaging dew points occur more often in drier climates where grapes are grown in California or Washington because the air is very dry, but they can also occur in Ontario. If the dewpoint is below the critical crop damaging temperature, you may want to turn on a wind machine sooner to keep the plant as warm as possible to reduce the 1 to 2°C cooler temperatures of plant surfaces compared to air around it as described above. Hopefully, this will keep the plant as close to the air ambient temperature as possible, and allow you to outlast the rate of temperature drop throughout the night until the sun comes up.

Measuring dew point temperature accurately is not easy and expensive. It can be calculated knowing the relative humidity (RH) and dry bulb temperature, but RH is also not easy to measure accurately especially at low dry bulb temperatures. If dew point temperature was predicted on a site specific or regional basis, this would assist growers in better knowing if and when they might operate their machines. If forecasted dew point was below critical air temperatures, wind machines might need to be operated. If forecasted dew point was above critical air temperatures, wind machines might not need to be operated. An alternative is to measure *wet bulb temperature*, the lowest temperature reached by evaporation of water only. It's the temperature you feel when your skin is wet and exposed to moving air and is between dry bulb and dew point. In Table 3, at -2°C dew point, 0°C dry bulb and 86.4% RH, the wet bulb temperature is -0.8°C. This is about 40% of the difference between dry bulb and dew point, lower than dry bulb. That is, the difference between dry bulb and dew point is 2°C, so the wet bulb at -0.8°C is 40% of this 'less'



than dry bulb. At temperatures around 0°C and at typical RH values, wet bulb temperature is consistently about 35% to 45% of this difference less than dry bulb. Wet bulb temperature is easier and less costly to measure than dew point, using sophisticated but available equipment, so this might be a viable alternative.

## MEASURING BUD HARDINESS AND BUD SURVIVAL

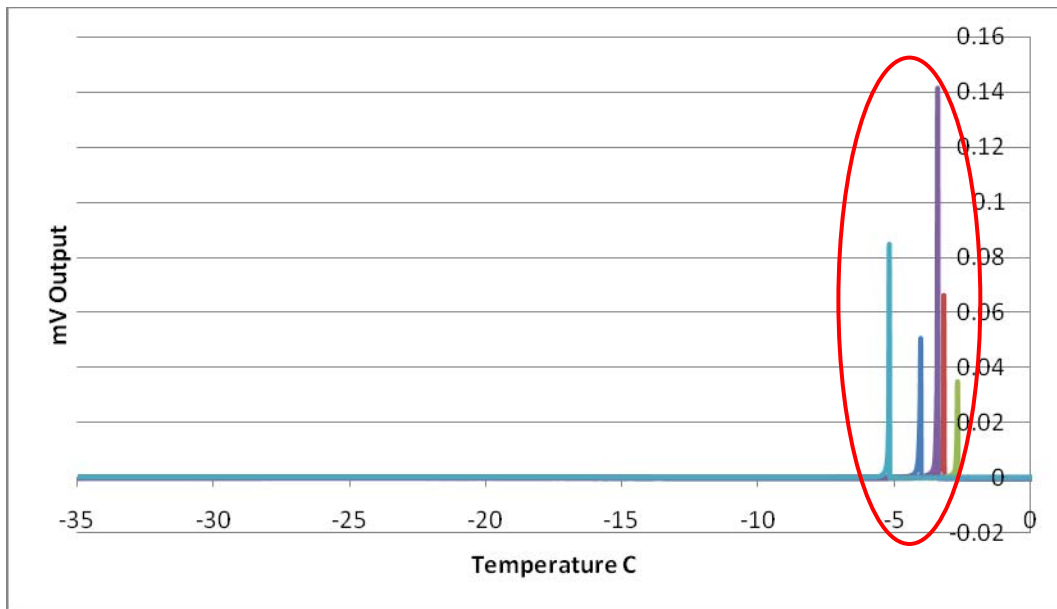
### *Thermal Analysis/Freezing Studies*

A system for differential thermal analysis (DTA) was constructed to assess cold hardiness of grapevine buds (Figure 18). The system was based upon one developed and used at Washington State University, Prosser, WA, with similar systems being used at other research facilities in the US and Canada. This unit incorporates a specially designed sample chamber with a commercially available programmable freezer and a data acquisition system (DAS).

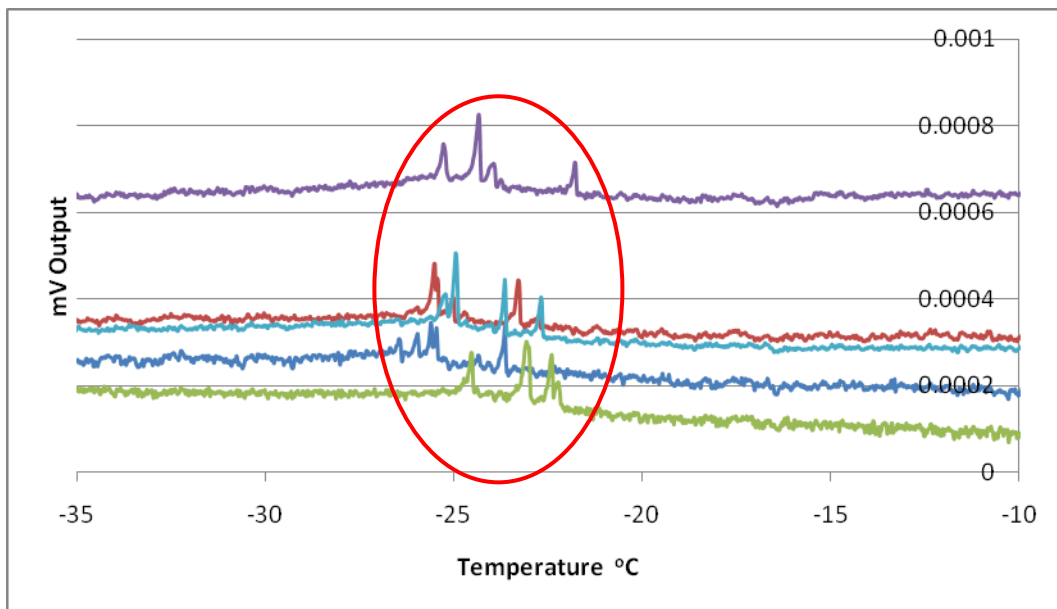
Grapevine buds avoid cold temperature damage by avoiding ice crystal formation. Damage quickly occurs when ice crystals form. The conversion of supercooled water to ice (latent heat of condensation) is being measured using this system. When water freezes, heat is released in an exothermic reaction. By using sensitive thermoelectric modules (TEM), we are able to identify these heat loss or freezing episodes during a controlled freezing test. A high-temperature exotherm (HTE) is when the inter-cellular (between cells) water freezes. This freezing event often occurs at temperatures between -2°C and -8°C and does not cause bud injury (Figure 19). As the temperature declines, a low temperature exotherm (LTE) occurs and indicates the freezing of intracellular water (within cells). These LTEs contain much smaller exotherm spikes (less water freezing), but typically result in bud death (Figure 20).



**Figure 18.** Differential thermal analysis (DTA) system programmable freezing chamber and loaded sample tray. Note the freezer is holding the maximum six sample trays per cycle. Cooling started at 4°C, then air temperatures were dropped slowly (4°C/h) over 12 hours to -40°C. Signals from the sample trays are transmitted to a multimeter (located on the top of the chamber), automatically converted to temperatures and loaded into an Excel spreadsheet.



**Figure 19.** High Temperature Exotherms (HTE) from a Chardonnay sample on December 4, 2008. Graph represents five sensors (TEMs) containing five buds. The height of the spikes is relative to the amount of water freezing. Buds are placed on a moist membrane which contributes to the HTE.

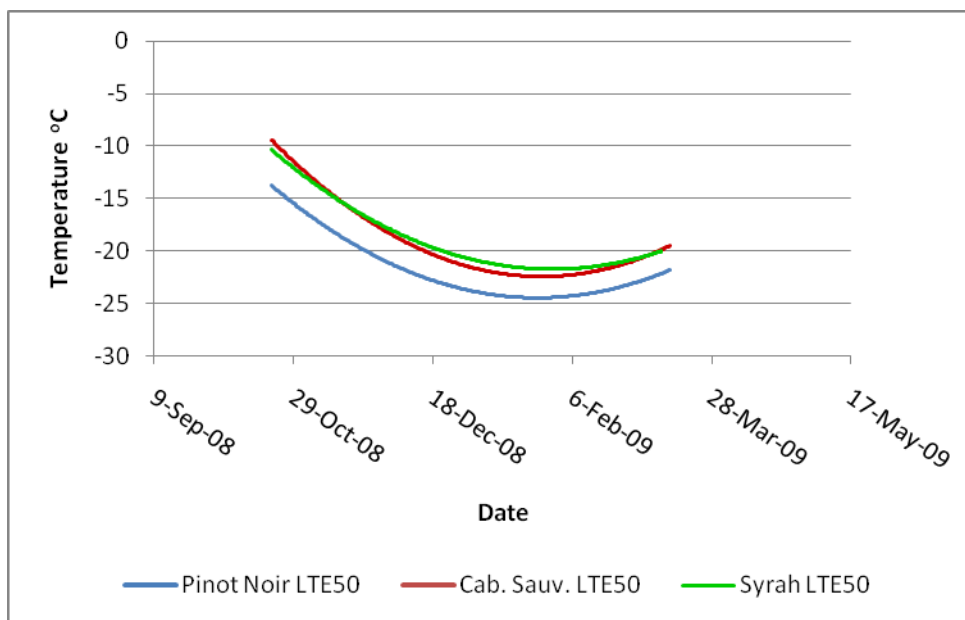


**Figure 20.** Low Temperature Exotherms (LTE) from a Chardonnay sample collected on December 4, 2008. Much smaller spikes with each spike indicate a bud killing event. Data from this sample resulted in a LTE<sub>50</sub> of -23.1°C.

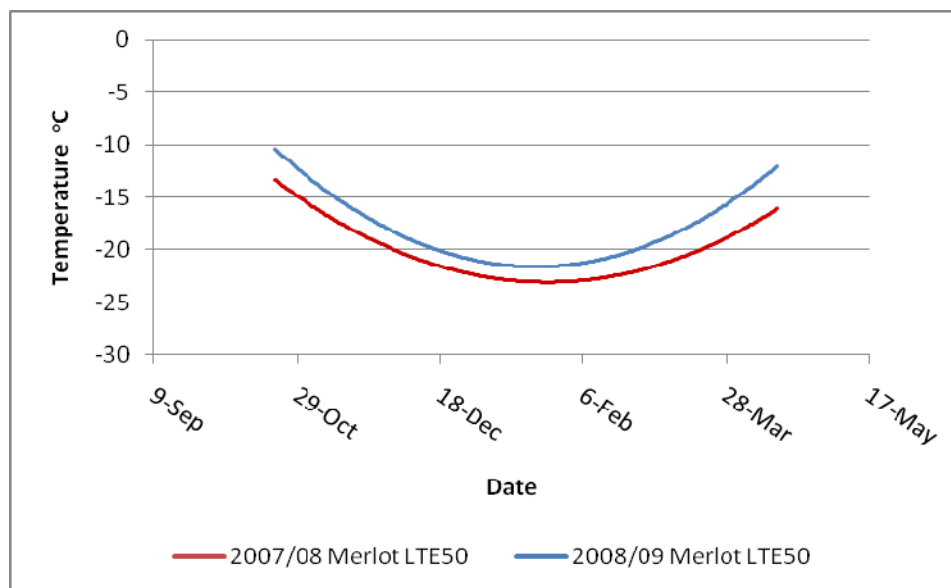
This DTA system was designed to test up to 54 samples of five buds simultaneously (6 sample trays with 9 wells available per tray) in the programmable freezer. For this study one cultivar sample was analysed per tray. Therefore, with one DTA system, we had capacity to analyse 6 cultivars per sequence. The data was analysed and recorded as LTE<sub>50</sub> which is the temperature at which 50% of the buds are killed.

### Cultivar and Annual Differences in Hardiness

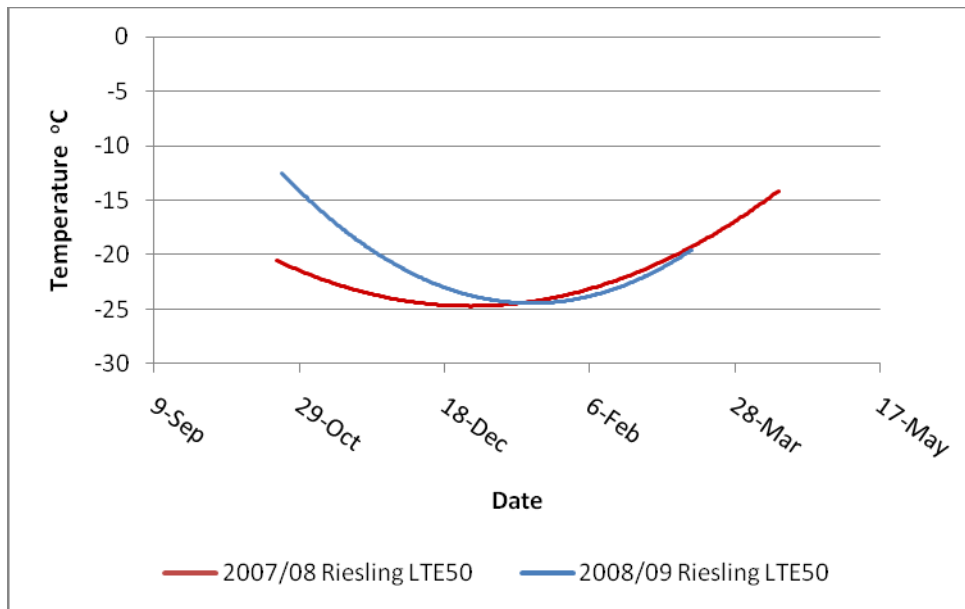
Grapevine genetics play an important role in the level of cold hardiness a particular cultivar can achieve (Figure 21). The lineage of a particular cultivar can give clues to its potential cold hardiness, however several environmental factors are also involved in determining their eventual mid-winter hardiness. Furthermore, management decisions can significantly impact cold hardiness. Environmental conditions can range dramatically year to year in Ontario and many of the critical management decisions are based heavily on the environmental conditions experienced during each growing season. Since these two factors fluctuate each year, it is not surprising to see annual differences in bud hardiness (Figures 22 and 23).



**Figure 21.** LTE<sub>50</sub> values of three cultivars sampled from the same vineyard in 2008/09. Trend lines were generated from 16 sample dates. Note that Pinot Noir is the hardiest cultivar of the three displayed and the rates of acclimation are all similar.



**Figure 22.** LTE<sub>50</sub> values of the same cultivar (Merlot) and vineyard location. Graph representing annual hardiness difference between 2007/08 and 2008/09. Trend lines were generated from 19 sample dates. Similar acclimation and deacclimation rates were achieved however maximum hardiness differed between years.



**Figure 23.** LTE<sub>50</sub> values of the same cultivar (Riesling) and vineyard location. Trend lines were generated from 19 sample dates. Very different rates of acclimation occurred, however similar mid-winter hardiness levels and de-acclimation rates were achieved.

When reviewing multi-year data in the tested cultivars, it appears buds were generally capable of withstanding lower absolute winter temperatures in 2007/08 compared to 2008/09. The 2007 growing year was hot and dry with drought-like conditions in most areas. Many vineyards and vines had below average crop levels, but the grapes were high in quality. The lower crop load may have enabled the vines to store more reserves in shoots, trunks and roots and resulted in good hardiness for the winter of 2007/08. The 2008 growing season was cooler than average with precipitation levels for the entire year being 15% above normal levels. This resulted in greater disease problems and barely adequate fruit quality. In addition, the 2008 yields per vine were higher than average. High crop yields and adverse weather patterns in 2008 appeared to have a negative impact on bud hardiness (less tolerant of low temperatures) when measured during the winter of 2008/09 (Table 5).

**Table 5:** Grapevine cultivar bud hardiness ratings based on LTE<sub>50</sub> data collected using differential thermal analysis from Jan. 1 to Feb. 15, 2009. Dates were selected to indicate maximum bud hardiness.

Cold Hardiness Class	Range of Critical Low Temperatures °C	Cultivars
Very Tender	-17.5 °C to -20.5 °C	Sauvignon Blanc, Syrah, Merlot
Tender	-20.5 °C to -23.0 °C	Cabernet Franc, Cabernet Sauvignon, Gewurztraminer, Chardonnay
Hardy	-23.0 °C to -26.0 °C	Gamay, Pinot Blanc, Pinot Gris, Pinot Noir, Vidal, Riesling
Very Hardy	-26.0 °C to -28.0 °C	Baco, Foch

### Assessment of Wind Machine Effectiveness (Bud Sampling)

Grape bud survival was estimated by cutting buds sampled at frequent intervals throughout the dormant season. During this period, we collected 112 samples every two weeks at 31 vineyards across 8 identified growing regions in Niagara (Figures 24 and 25). This was also an opportunity to collect samples from a number of vineyard locations to assess the effects that wind machines may have had after cold events. This method is very commonly used and is based on discolouration (browning or oxidation of injured cells) of bud meristems (growing points) that occurs after low temperature injury. Healthy bud meristems maintain their green colour, while injured cells rupture from ice crystal formation and turn brown after being exposed to above freezing temperatures. Samples were collected in the field then placed at room temperature for 24 - 48 hours to allow the oxidative browning process to take place. Results were posted on various industry websites for anyone to review (Table 6).

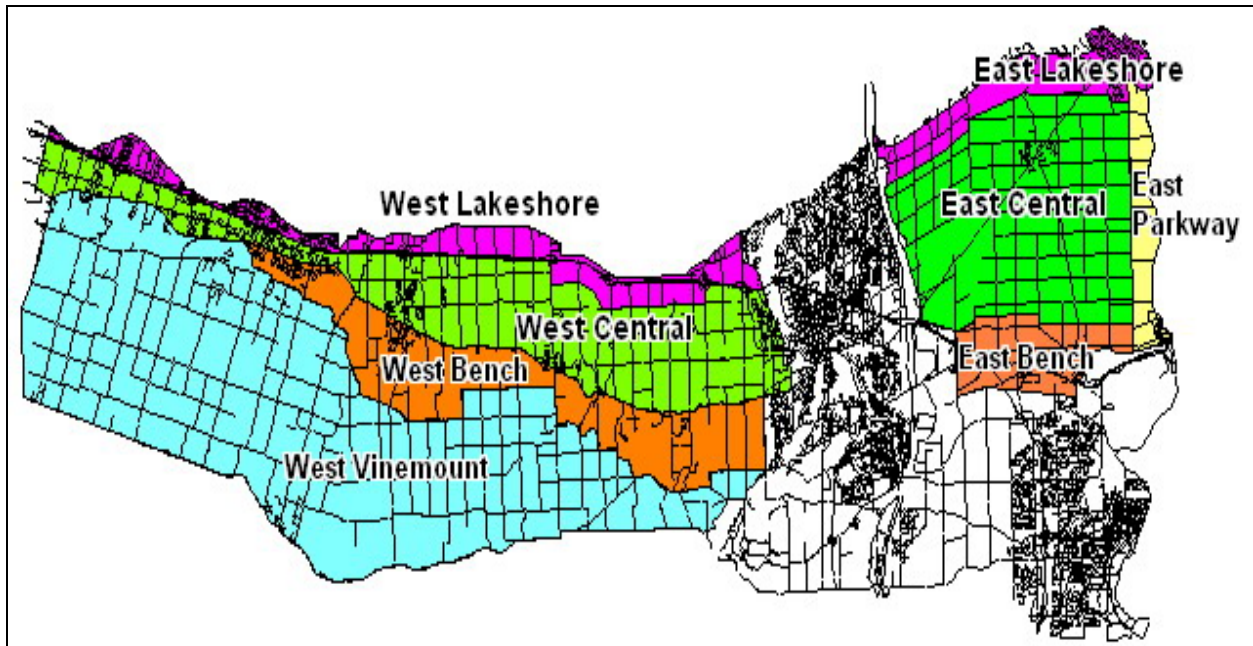


Figure 24. Niagara regional sampling zones used for bud survival sampling.



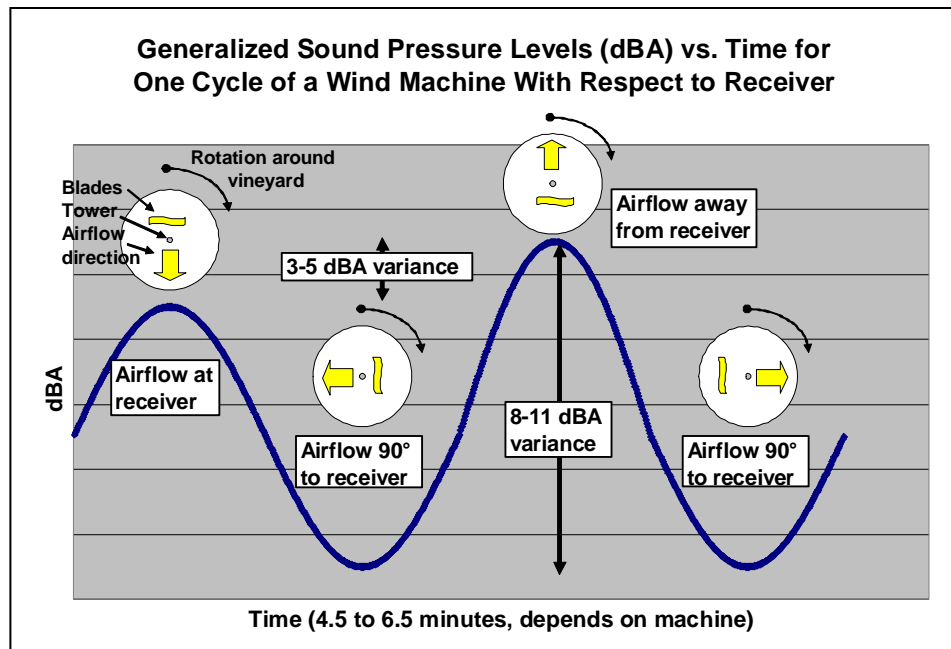
Figure 25. Every two weeks, representative grape canes were harvested and their buds were prepared for freezing.

**Table 6:** Vinifera bud survival results (% live primary buds) from samples collected during the week of April 13, 2009. NS means no samples taken from that area. Some results are displayed as a range since more than one sample was analysed from that sampling zone.

Cultivar	Location	East of Canal	West of Canal
Cabernet Franc	Bench	70 - 92%	33 - 56%
	Central	56 - 78	58 - 61
	Lakeshore	69	62
	Parkway	63 - 77	NS
	Vinemount	NS	46
Cabernet Sauvignon	Central	NS	87
	Lakeshore	NS	77
	Parkway	80	NS
Chardonnay	Bench	75 - 93	47 - 63
	Central	72 - 77	62 - 86
	Lakeshore	81	NS
	Parkway	89 - 96	NS
	Vinemount	NS	62
Merlot	Bench	72 - 88	35 - 38
	Central	65	21 - 68
	Lakeshore	78	56
	Parkway	66	NS
	Vinemount	NS	83
Pinot Noir	Bench	80 - 99	61 - 65
	Central	82	63 - 95
	Lakeshore	85	65
	Parkway	94	NS
	Vinemount	NS	62
Riesling	Bench	72 - 98	55 - 60
	Central	55 - 82	55 - 89
	Lakeshore	69 - 80	72
	Parkway	84 - 87	NS
	Vinemount	NS	82
Sauvignon Blanc	Central	75	30
	Lakeshore	80	NS
Syrah	Lakeshore	NS	43

## NOISE FROM WIND MACHINES

Many neighbours do not like the noise of wind machines. They describe it like a *helicopter*, *whining*, or *thumping* sound, or that their windows or dishes vibrate. Wind machines need large engines operating at high RPM and long pitched blades to blow air a long distance. It is difficult to make wind machines quieter. Sound comes from the engine and blades as they rotate. Slower blade speed reduces noise, but reduces airflow, meaning more machines are needed to cover the same area. It takes 4.5 to 6.5 minutes for a wind machine to make a full 360° sweep around the tower, so sound oscillates in intensity in a sinusoidal fashion (Figure 26). Some find this irritating, since it makes them wait in anticipation for the sound to grow louder. Wind machines are *upstream* machines as they operate with blades upstream of the tower. So, air blows past the tower which also affects the spread of sound waves.



**Figure 26.** Tests show neighbours hear wind machine sound as varying sinusoidally over time as the blades sweep around the field. Sound levels are greatest when the blades blow air away from the receiver, next greatest when they blow at the receiver. When air is blown perpendicular to the receiver, the sound is greatly reduced. When sound rises by 10 dB it is subjectively perceived by people to have doubled in loudness. Conversely, if sound drops 10 dB it is subjectively perceived to be half as loud.

Conditions *outside* a house complicate and affect sound movement from wind machines:

- natural quiet of a cold, rural winter night
- absence of normal wind sound
- lack of leafy vegetation on grapes, grass on the ground or leaves in woodlots to muffle sounds
- bouncing of sound waves off the warmer temperature inversion layer high above ground
- hard, non-absorbing ground surfaces in winter for sound waves to travel across
- source of sound being very high above ground
- simultaneous operation of multiple machines
- low relative humidity of the cold air

Conditions *inside* homes that complicate and allow external sound waves to penetrate, or be amplified include; large rooms, large windows, hard floors and light construction. Wind machine sound is generally less offensive in small carpeted rooms with heavy thick walls and in areas of the house on the opposite side to the wind machine(s) or in basements. The sound is sometimes partially masked inside a house if there is 'white noise' present such as a radio, television, or ventilation fan operating.

Wind machine blades also produce low frequency sound and very low frequency infrasound waves . These travel long distances and may penetrate, or excite, building components of residential structures. Low frequency sound is like the low bass music sounds you might hear in your home when someone next door is playing their stereo, even though you cannot hear the rest of the music. Other familiar examples of low frequency sound occur when waves strike a shore or there are high speed winds. Sound from wind machines manifests itself as sound energy perceived as a nuisance to some people.

## **WIND MACHINES AND NORMAL FARM PRACTICE**

Farmers are protected from nuisance complaints, such as noise, by neighbours provided they are following *normal farm practice*. The *Farming and Food Production Protection Act (FFPPA) 1998* defines normal farm practice as one which:

- (a) is conducted in a manner consistent with proper and acceptable customs and standards, as established and followed by similar agricultural operations under similar circumstances, or
- (b) makes use of innovative technology in a manner consistent with proper advanced farm management practices

Whether or not a farm practice is considered normal is determined by the *Normal Farm Practices Protection Board*, a quasi-judicial administrative board appointed by the Provincial Government, but comprised of non-government members. For more information on the Act and the Board, see website:

[www.omafra.gov.on.ca/english/engineer/nfppb/nfppb.htm](http://www.omafra.gov.on.ca/english/engineer/nfppb/nfppb.htm)

## **BEST MANAGEMENT PRACTICES**

The objective of this on-farm research project was to provide the Ontario grape and tender fruit industry with best management practices for operation of wind machines to use them more effectively and minimize nuisance noise for neighbours.

### ***Crop hardiness***

- Plants should be managed to maintain optimum health to ensure they are as healthy as possible going into winter
- The most up-to-date plant hardiness information and critical temperatures should be taken into account when decisions are made to operate a wind machine
- Wind machines should only operate when there is the possibility of cold injury to crops within the area of influence of the machines

### ***Placement***

- Wind machines should be located to take into account the expected skewing effects on their areas of influence by topography and wind direction
- Wind machines should be located to take into account the location of other adjacent wind machines and other features which might provide some additional cold injury protection such as roads, warm buildings, streams, bush
- Growers should consider planting crops that are more sensitive to cold injury as far as practical from neighbours, so wind machines can be located further from homes

### ***Monitoring***

- Growers should use best local weather available such as <http://www.vineandtreefruitinnovations.com/>
- Growers should continually monitor for a strong temperature inversion, greater than 3°C (5.5°F), as close as practical on or near their farm, so they know if operating their wind machine(s) might provide some plant protection from cold injury. This would include a tower at least 10 m (33 ft) high to monitor temperatures high above the crop
- Growers should set start-up temperatures for their wind machines based on sensors located within 15 m (50 ft) of each machine, and below the fruiting wire height



- Growers should monitor and automate the start up/operation/shut down of their wind machines using a combination of real-time remote temperature/wind speed/wind machine operation sensing devices and monitoring via cell phones/computers/pagers, etc.
- Growers should set start-up temperatures as close as practical to expected critical air temperatures:
  - Spring frost: 2 to 3°C (36 to 37.5°F)
  - Fall frost: 1 to 2°C (34 to 36°F)
  - Winter: Variable based on latest bud hardiness data from freezing trials
- Growers should set the differential (wind machine stop) temperature 2°C - 3°C (3.5°F – 5.4°F) on their wind machines higher than start temperatures

### **Wind**

- Growers should monitor wind speeds before and during expected cold injury events
- Growers should not operate wind machines if wind speeds are much higher than 7 km/h (4 mph) as there is unlikely to be a strong temperature inversion or ‘heat’ above the field to pull down anyway
- Growers should not operate wind machines if wind speeds are 13 km/h (8 mph), or higher, as this can damage their long, thin blades
- Growers should never operate wind machines if wind speeds are 21 km/h (13mph), or higher, as this can seriously damage their wind machines

### **Maintenance**

- Growers should maintain machines in good condition with checkups at least annually by;
  - changing gearbox oil (at tower base and top)
  - lubricating drive lines and inspecting seals
  - checking tension of all bolts on tower
  - inspecting blades and attaching hardware
  - performing regular engine maintenance; and
  - keeping booster cables handy for quick use

### **Noise**

- Wind machines should be located as far as practical from the edge of neighbouring homes within agricultural areas, but not closer than 125 m unless best management practices are in use
- For neighbours living within 125 m of a machine, growers should:
  - discuss the need for wind machines and how and why they operate
  - consider creating an early warning system about possible machine on certain nights
  - give them a 24-hour cell phone number to call
  - use a ‘Last On, First Off’ principle for machine(s)
- Growers should be more diligent in operating wind machines on farms where they do not live, as they are not always there to hear if and how their machines are operating
- All wind machine engines should have mufflers

### **On-going learning**

- Growers should train and educate all employees who will operate wind machines on the latest best management practices to minimize machine operation

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