Wind Machines for Minimizing Cold Injury

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Infosheet

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HOW DOES COLD INJURY OCCUR?

Cold or frost injury can occur on sensitive grapevines and tender tree fruits if plant tissue temperatures fall below critical values beyond which there is an irreversible physiological condition causing malfunction or death of plant cells (Food and Agriculture Organization, 2005). Exposure for only a short period can cause damage. Free water in the plant could freeze leading to tissue damage and significant economic effects.

During the growing season (about mid-April to end of October in Niagara) after sap flow begins, but prior to leaf fall, there are two types of frost causing cold injury; *radiative* and *advective* (FAO, 2005). *Radiative* frosts occur due to energy loss by long-wave radiation exchange to clear, calm, dark night skies. Cold air collects near the ground, while temperatures higher up are warmer, creating temperature inversions. *Advective* frosts occur when large cold air masses usually associated with high winds and cold temperatures move into a location. In Ontario, both types of frost occur, often in combination, when *advective* frosty air masses associated with high winds are followed by a *radiative* frost event with cold, clear, calm conditions. Because the plant is growing, it is very susceptible to cold injury, so temperatures just slightly below freezing can cause problems.

During the dormant season (about end of October to mid-April in Niagara) after harvest and leaf fall but before sap flow begins in spring, cold injury can occur to buds, canes and trunk material (in grapes) that should grow the next year. However, it takes much colder temperatures than during the growing season to cause damage. Perennial plants such as grapes or tender tree fruits need to acclimate to prepare for winter dormancy. This happens in response to ambient temperatures and day length. It is also influenced by the physiological state of the vine or tree. It may be delayed by poor health, over cropping or other stresses. The level of winter hardiness varies by cultivar, time of season, location, and many management factors. A critical air temperature is that at which buds or other tissue will be killed, but it is not the same temperature throughout winter. Critical temperatures at which injury may occur become gradually colder during fall until reaching the point at which that cultivar or species is at its optimum hardiness. Critical temperatures become gradually warmer as the plant comes out of dormancy in spring. Different species and cultivars acclimate and de-acclimate at different rates, so different cultivars are sensitive to different temperatures on the same day of the year. This helps explain why one grower might run their wind machine, while neighbouring growers may not.

WHY DO GRAPE GROWERS USE WIND MACHINES?

In Ontario, wind machines are primarily used to protect grapes (Figure 1). Although grape growers are planting more cold-susceptible cultivars than in past, due to market pressures as there is little demand for more cold tolerant cultivars.

Figure 1: Wind machine in vineyard being monitored by authors in a Niagara research project.

Ministry of Agriculture,
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Ontario

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

- Spring's late frosts (early growing season)
- Autumn's early frosts (late growing season)
- Winter's very cold temps (dormant season)

Significant spring damage or early frost damage are not that common for grapes or tender tree fruits in Ontario. Historically, significant winter damage (Figure 1) occurs approximately 1 year in 10 in Ontario. However, the winters of 2003, 2004 and 2005 all had sufficiently cold temperatures resulting in observed vine and tender tree fruit bud injury. Grape yields in Niagara in 2005 were about half the normal, and some tender tree fruit growers also reported reduced crops. Wind machines proved beneficial. Growers with machines harvested near normal crops in 2005. Those growers nearby without machines experienced total crop failures. Other management options help protect these crops from cold injury, but many grape growers consider installing wind machines one of their best long-term management strategies.

Fortunately, conditions that can result in cold injury are uncommon. Although wind machines are infrequently used, it is almost exclusively between midnight and 7 a.m. when most people are sleeping. The authors' research data suggests annual Ontario use is between 25 and 75 hours per machine, operated over a few intermittent days.

WHERE ELSE ARE WIND MACHINES USED?

Wind machines were introduced in the 1920's to the US. Now there are thousands on five continents in the US, Chile, Australia, New Zealand, Portugal, Japan, Spain, Argentina and Mexico. Most machines are used to reduce cold injury during late spring or early fall frosts. Ontario is one of the few places to use them to reduce cold injury during the dormant season when cold mid-winter temperatures occur.

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 crops such as grapes and tender tree fruits. They are different from wind turbines which are designed to create electricity from wind energy. Wind machines **should not operate during windy conditions** because their long thin blades are not designed to handle high wind forces.

Wind machines help protect crops from 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 with different features. All are about 10.5 m high (34 ft) from the concrete anchor pad to the blade axis. Blades are 5.4 to 6.0 m in length (18 to 20 ft). Blade speeds are 400 to 600 RPM generating large volumes of air blowing outward at least 110 to 125 m (360 to 410 ft). Three types of wind machines have two blades, one has four. Wind machines cost $30,000-$40,000 CDN to install, including the concrete base, and then $30-$40/h to run using propane, diesel, gas, or natural gas as fuel. All four work under similar principles. Fan blades angle 6^{o} down from the vertical. During a temperature inversion, they pull warm air from above and blow it down and out, pushing away and replacing cold air near target crops (Figure 2). This air movement also breaks up microscale air boundary layers over plant surfaces, improving sensible heat transfer from the air to plants (FAO, 2005). Wind machines transfer heat by forced convection. While the blades spin, the head of the fan rotates around the tower's vertical axis. Air is circulated north then east, south, west, then back where it started 4.5 to 6.5 minutes earlier, depending on machine type. Air flows in all directions over time, covering at least 4 hectares (10 ac). If a wind machine completes this circuit too slowly, cold air could resettle, 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 done for logistical reasons.

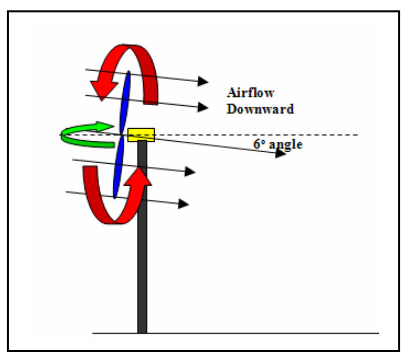

Figure 2: Wind machines pull warm air from high above the crop, blowing it downward and outward

Different machine types have different airflow rates, airflow travel distances, times to sweep around the field, and sector angle coverage (Figure 3). Sector angle coverage is the wedge of land area that 'feels' wind machine air movement at any one time. It is calculated by measuring the time air movement occurs at one location compared to one rotational cycle. For example, assume you are 100 m from a machine and you start a stop watch when first feeling air hit your face then stop it when you no longer feel the air. If it was 1 minute 15 seconds, and rotational cycle time was 5 minutes, this is 25% of time, or 90^{o} sector angle coverage. Greater angles mean less time for cold air resettling.

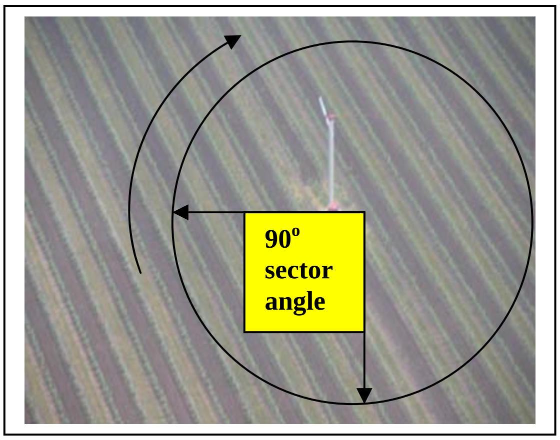

Figure 3: Sector angle coverage describes the wedge of land 'feeling' air movement at any one time.

The ground area affected by wind machines is not a circle. In Niagara, below the Escarpment where most wind machines are located, there is a natural airflow down hill north to Lake Ontario. This skews the circle so it more resembles an oval longer to the north and shorter to the south of the wind machine, with some variations due to topography (Figure 4).

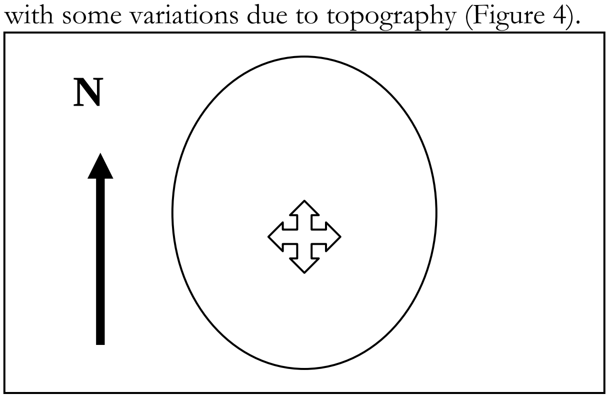

Figure 4: Areas protected by wind machines in Niagara resemble ovals longer north than south.

ARE THERE TEMPERATURE INVERSIONS?

Previous research (Shaw, 2001) reconfirmed by these authors, shows strong night-time radiative temperature inversions during periods when wind machines might be used, both below and above the Niagara Escarpment. At 20 m (66 ft) above ground it can be 5 to 10^{o}C warmer (9 to 18^{o}F) than at 0.625 m (2 ft) above ground at vine level. Temperature inversions are *strong* when temperature differences are at least 3^{o}C (5.5^{o}F) warmer (Figure 5).

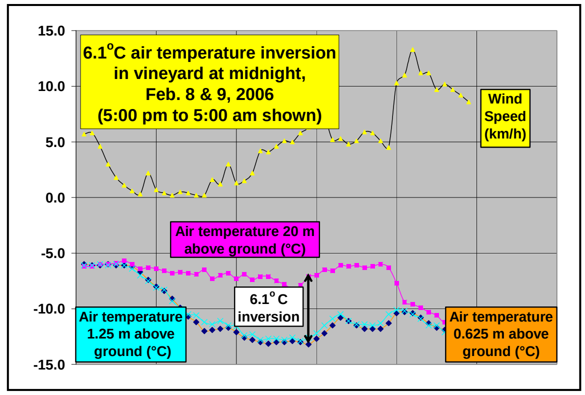

Figure 5: Air temperatures high above ground can be much warmer than near the ground during inversions as shown in the authors' research data above.

The authors have shown wind speeds must be less than about 6 km/h (4 mph) in Niagara for temperature inversions to occur (Ker *et al*, 2007). If air temperatures near the crop are expected to be in the critical range and there is a strong temperature inversion, wind machines should help prevent cold injury. There is anecdotal evidence that on the very rare nights when it is calm, but with little to no temperature inversion, air movement created by a wind machine can help prevent cold injury. Wind machines can raise air temperatures around plants by about half the temperature inversion difference.

WHEN DO GROWERS DECIDE TO TURN ON/OFF THEIR WIND MACHINES?

Most growers decide to operate wind machines by monitoring air temperatures about 0.6 m (2 ft) above ground compared to air temperatures as high as 20 m (66 ft) in the air (Figure 6). Each wind machine has its own air temperature sensor placed at vine level nearby since conditions vary site to site due to elevation differences, proximity to the lake, obstructions, etc. Monitoring is becoming more sophisticated and many growers now monitor air temperatures at many locations in real-time through computers and/or cell phones (Figure 7).

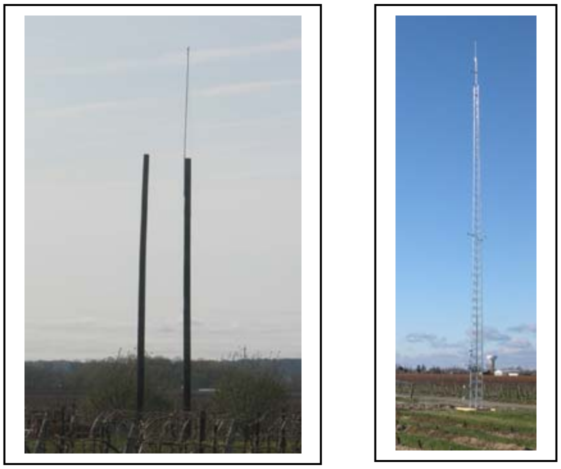

Figure 6: Most growers monitor air temperatures 0.6 m (2 ft) above ground and high above ground so they know when air temperatures are reaching critical levels and a temperature inversion is developing

Neighbours ask why growers operate machines in spring when weather reports predict temperatures of 2°C. Rural areas are usually colder than forecast locations. Wind machines must warm up and run <u>before</u> critical cold temperatures arrive. Also, weather stations measure and predict temperatures about 1.5 m (5 ft) above ground. Air temperatures at vine levels 0.6 to 1.2 m (2 to 4 ft) are often colder than slightly higher at 1.5 m, especially on calm clear nights when cold air settles during temperature inversions. During a monitored temperature inversion from 8:00 pm to 2:30 am (Figure 5), the air temperature at 1.25 m above ground was consistently warmer than at 0.625 m, averaging 0.4°C warmer.

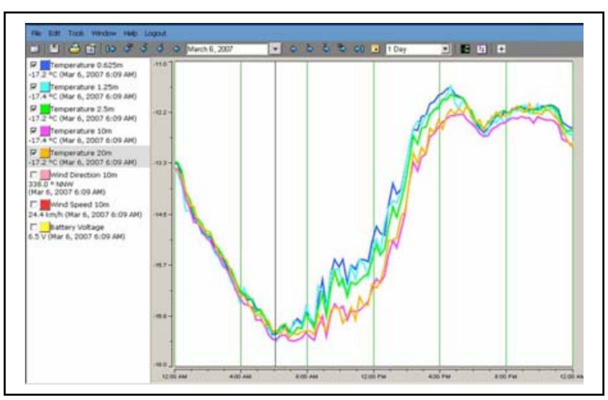

Figure 7: Some growers monitor air temperatures in real-time at several farm locations using sensors that beam data over the Internet to their cell phone and/or computer, so wind machines only operate when needed (from the authors' research project through co-operator *Weather Innovations Inc.*)

Most wind machines have auto-start controls based on air temperatures around vines. Alternatively, when temperatures approach critical levels, operators can be automatically alerted via cell phones so they can turn machines on manually. Many operators prefer manual start as it provides more control if an air temperature sensor has failed, or if ambient winds are too high. Few growers have wind speed sensors (Figure 8) but machines should <u>never</u> operate during wind speeds over 20 km/h (12 mph) as this can damage machines. Also, operation is futile under these conditions as there is no temperature inversion. Advancements in technology are optimizing wind machine control and use.

Figure 8: Wind speed sensors like this one used by the authors are not common, but it should be used along with air temperatures to decide if wind machines should be turned on/off, or if winds are favourable for operation.

DETERMINING GRAPE BUD HARDINESS

Grape hardiness is estimated by cutting live buds from vineyards periodically (Figure 9), taking them indoors, placing them on thermo-electric modules hooked to data acquisition systems (Figure 10), then subjecting them to artificial freezing regimes.

Figure 9: Every two weeks, the authors cut grape canes and prepare buds for lab freezing.

Cooling starts at 4°C, then air temperatures are dropped slowly 3°C/h over 13 hours to -40°C. When water freezes, it releases heat, so as buds are gradually subjected to colder, freezing temperatures, two small 'heat' spikes appear. The first is when *external* water in the buds freezes and the second is when *internal* water freezes (Figure 11). Predictions can then be made about air temperatures that may cause cold damage in subsequent days. This information helps decide whether wind machine use makes sense.

However, in absence of specific acclimation data, one can assume wind machines will be used for grapes in Ontario during the months in Table 1.

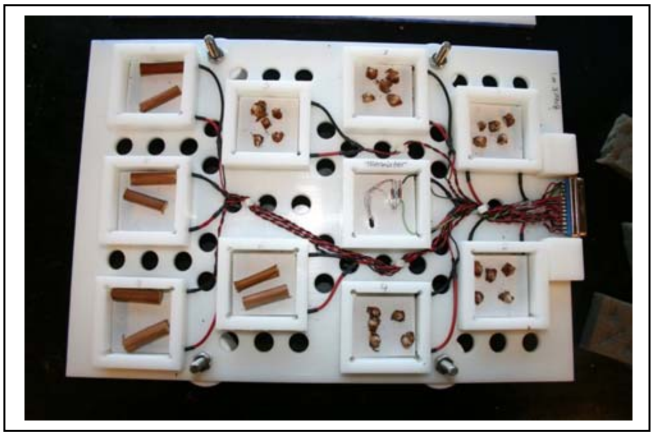

Figure 10: The authors use a freezer unit utilizing a programmable Tenney ™ chilling chamber with a capacity to hold 4 fabricated sample trays like the one shown. Each tray has 9 thermo-electric modules used to detect temperature gradients generated by exotherms (freeze episodes), 5 of which are shown with Cabernet Franc buds and 4 with Cabernet Franc grape cane material.

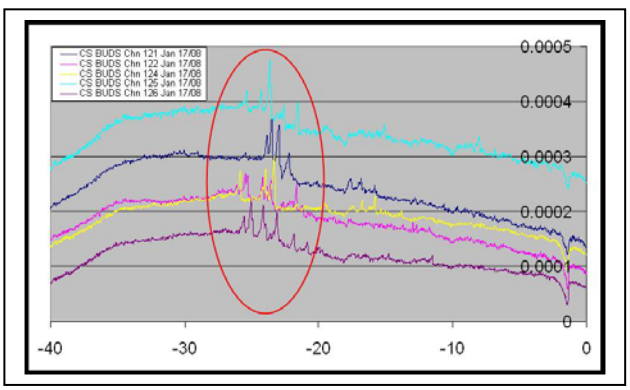

Figure 11: Heat spikes are recorded at temperatures when; (first) external water freezes around the bud cells (downward facing spikes found at -2^{o}C); (second) when intracellular water freezes in cells surrounding buds (smaller spikes to right of circle); (third) when intracellular water freezes in buds (spikes within circle) resulting in bud death. (Chardonnay bud freezing data shown from authors' research project)

Table 1: Potential air temperatures at vine level when one could expect wind machines to operate in Ontario.

Month(s)	**Air Temperatures (winds < 6 km/h)**
Winter (dormant season) January and February	-17^{o}C to -20^{o}C (1.4^{o}F to -4.0^{o}F)
Winter December and March	-10^{o}C to -12^{o}C (14^{o}F to 10.4^{o}F)
Spring April, May	0^{o}C to 1^{o}C (32^{o}F to 33.8^{o}F)
Fall (crop not harvested) (September - November)	0^{o}C to 1^{o}C (32^{o}F to 33.8^{o}F)

WHY ARE WIND MACHINES NOISY?

Wind machines need large engines operating at high RPM, and long pitched blades to blow a lot of air a long distance. It is difficult to make wind machines quieter. Sound comes from the engine and blades as they rotate (Fraser *et al*, 2006). Slower blade speed reduces noise, but reduces airflow, meaning more machines would be needed to cover the same area.

Some people do not like wind machine sound. They describe it like a *helicopter*, *whining*, or *thumping* sound or that their windows or dishes vibrate. It takes 4.5 to 6.5 minutes for the head of the blades to make its full 360^{o} sweep around the tower (depending on make), so sound oscillates in intensity in a sinusoidal fashion (Figure 12). 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 can affect the spread of sound waves (Figure 2).

Conditions *outside* a house that complicate and affect sound movement and affect intensity include:

- 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 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. Sound is generally less 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 from wind machines 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 (Gambino and Fraser, 2006). These travel long distances and may penetrate, or excite, building components of residential structures. Low frequency sound is like 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 that is perceived as a nuisance to some people.

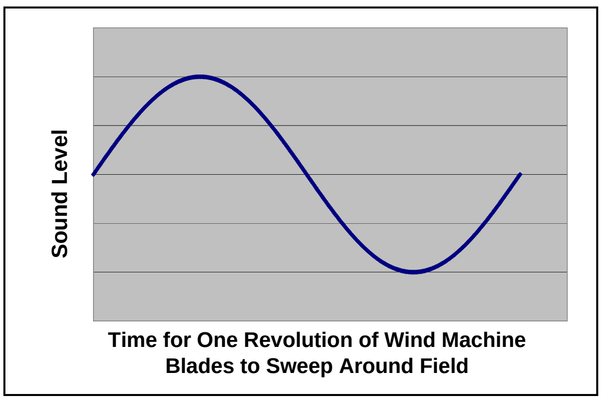

Figure 12: The authors discovered wind machine sound varies sinusoidally over time as the blades sweep around the field. Some people find this irritating, since it makes them wait in anticipation for the sound to grow louder.

WHAT RESEARCH IS BEING DONE?

Organizations of growers using wind machines in Ontario are being proactive. In November 2005 an innovative 3-year applied research project began sponsored by the Grape Growers of Ontario (GGO) and the Wine Council of Ontario (WCO). The project is scheduled to run until October 2008. The authors are doing the research and are working with two grape growers at two vineyards:

- Near Virgil on the flat plain below the Niagara Escarpment (95.5 m above sea level) in Niagara-on-the-Lake area where most wind machines are located, and where there is little climate modification from Lake Ontario/Escarpment

- Near Rockway on a slightly rolling farm higher in elevation above the Niagara Escarpment (172.5 m above sea level) where there are fewer grapes/wind machines, and average daily wind speeds are slightly higher than at Virgil location.

This project has many funding partners:

- *CanAdvance*, through the Agricultural Adaptation Council of Agriculture and Agri-Food Canada
- *CRESTech* through the Ontario Centres of Excellence
- Grape Growers of Ontario
- Wine Council of Ontario
- Orchard-Rite Wind Machines
- Chinook Wind Machines
- Agricorp
- Ontario Tender Fruit Producers' Marketing Bd
- Niagara Peninsula Fruit and Vegetable Growers

In-kind contributions were made by the Ontario Ministry of Agriculture, Food and Rural Affairs, KCMS Applied Research and Consulting, Brock University (CCOVI) and University of Guelph.

The objective is to establish best environmental management practices for wind machines, and find ways to use them less often and more effectively. A Stakeholder Steering Committee of citizen neighbours, growers, industry, suppliers, and government assists researchers (authors) so more informed decisions can be made.

There are several specific objectives to the project:

- To provide growers with tools to improve their decision process for turning on, or turning off their wind machines;
- To provide estimated acclimation temperatures throughout dormant winter season (Figure 11)
- To study temperatures near grape vines before, during and after wind machine use (Figure 13)
- To study temperature inversions;
- To study wind machine noise (Figure 14)
- To keep rural community informed (Figure 15)

Figure 13: A 20 m (66 ft) tower lets researchers monitor air temperatures from vine level to the top, plus wind speeds in real-time over the Internet.

Figure 14: During research, sound levels were monitored inside and outside homes to understand sound movement and its effect on neighbours.

Figure 15: The authors have held several meetings, given many presentations, and held demonstrations and discussions with growers and rural citizens since the research project commenced.

IS THE RESEARCH MEETING OBJECTIVES?

Although the research is not yet complete, grower management of wind machines has improved through some of the information discovered by:

- operating wind machines only when needed
- checking the many sets of bud sampling data; January 2006 to February 2008 at www.omafra.gov.on.ca/english/crops/hort/news/tenderfr/tf1004a5.htm and www.brocku.ca/ccovi/pages/news/section.php?id=6
- setting wind machine start up temperatures based on acclimation data from freezing trials
- grower knowledge that there are no temperature inversions with winds > 6 km/h
- industry is using real-time temperature and wind speed data at several Niagara vineyards
- managing wind machines close to neighbours using the Last On, First Off principle
- industry interest in extending the research project beyond the scheduled end date
- the spread of the knowledge base through the multitude of articles, presentations, TV stories, open houses, and conversations on the project keeping the industry and others informed

ARE THERE WIND MACHINE SETBACK RULES?

Currently, no municipality has a by-law establishing setbacks for wind machines. Growers can strategically place wind machines anywhere on their property to optimize the effective coverage area since wind machines are costly to install and operate. Growers should always take into account the location of neighbours to minimize possible noise affects. This means avoiding placement such that a house might be within the approximate 4 ha protected area. This isn’t always easy. However, it is predicted that in most years, wind machines will only operate 25 to 75 hours. In 2006/2007 some were used less than 10 hours total. At the time of writing, wind machines have not operated over the dormant winter season of 2007/2008.

ARE WIND MACHINES 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

ARE MORE WIND MACHINES STILL COMING?

There are many properties that might benefit from using wind machines but on others, installing one would be impractical especially on properties with:

- crop cultivars that are less temperature sensitive
- odd-shapes or small sizes
- good air 'drainage' already
- proximity to the relative warmth of large bodies of water when they are ice-free
- locations that have extreme temperatures too cold to benefit grapes or tender fruit trees

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