Chapter 11

Spring Frost Control

To grow more consistent crops and improve your cash flow in years with damaging frost events, this chapter will show you how you can:

1) *identify an active protection system to protect your vineyard during budbreak and early shoot development,*
2) *use the basic principles of frost and frost/freeze protection to deal with complex cold protection scenarios, so that you use your active protection system(s) efficiently, and*
3) *operate the equipment correctly.*

As the North Carolina winegrape industry continues to grow, much of the recent expansion in *vinifera* and hybrid plantings has occurred in the central and western piedmont. Careful site selection as described in Chapter 4 can help you avoid completely unsuitable sites, but even the best vineyard sites in the piedmont and mountains are not completely frost-free. If the economic analysis of the cost of spring frost has you considering an active system of frost protection, this chapter will help you understand the benefits and limitations of wind machines, heaters, over-vine sprinklers, foggers, sprays that inhibit frost, and even the occasional use of a helicopter.

Choosing a Frost Protection System

While people use the terms frost and freeze interchangeably, you need to learn the key differences between a freeze, a frost/freeze, and two types of frost. You must match your frost protection system to the prevailing types of cold events that occur in your vineyard following budbreak. This basic information will help you select the most effective type of active protection system for your vineyard and will be the key to operating that system effectively. Some forms of active frost protection that are highly effective in

Active frost control differs from passive control *strategies and methods* discussed in chapter 4, *Site Selection*, in several important ways:

1) Energy Use. Active control *methods* include energy intensive practices (vineyard heating with fuel, over-vine sprinkling with water, etc.) that are used during the cold event to replace natural energy, or heat losses from the vine (Snyder, 2001).

2) Direct vs. Indirect Method. Active control *strategies* rely on *direct* frost protection methods (e.g. wind machines, heaters, over-vine sprinkling), and involve active control against a cold event (Westwood, 1978). Passive control or protection involves *indirect* practices (e.g. site selection, variety selection, and cultural practices like double pruning), that cause the plant to be less susceptible to cold injury, or decrease the probability or severity of radiation frosts (Evans, 2000).

3) Time of Implementation. Active control strategies and methods must be implemented *just prior to and/or during* the cold event to counteract an immediate threat of a radiation frost or frost/freeze. Passive protection includes strategies and practices that are generally done well ahead of cold events.

certain types of frost can actually damage the vines when used in other types of frost.

Remember, there is no perfect method of active frost control that will be able to counter all of the different types of cold events that may be encountered, especially a freeze when the winds are greater than 10 miles an hour.

FREEZE *(also called advective* or *wind-borne freeze)*

- ❑ Temperature below freezing.
- ❑ Wind usually greater than 10 miles per hour.
- ❑ Little if any stratification of air temperature occurs with changes in elevation.
- ❑ More common in late winter (February or early March) in North Carolina, well before new shoots have emerged.

All mechanical methods of conventional spring cold protection discussed in this chapter (wind machines, heaters, over-vine sprinklers and helicopters) are of very limited value, or no value, under true *freeze* conditions. Do not use active methods for frost control when winds are greater than 10 miles per hour; you can damage the vines (Trought et. al, 1999).

Even good site selection, the basic method of frost protection, can work against a vineyardist in a freeze. Lower lying river-bottom-type areas that are protected from the winds would be the best choice in a freeze, but these areas are not recommended for vineyards because they are highly subject to radiational frost events. Fortunately, freezes are rare after budbreak.

Wind machines and over-vine sprinkler irrigation systems must **not** be used in a freeze. The winds can damage equipment and the vines. Sprinkler irrigation is also risky due to a phenomenon known as *evaporative cooling* under freezes.

Perry (2001) has indicated that heaters may provide some protection under windborne freeze conditions due to radiant energy, which is not affected by wind and will reach any solid object not blocked by another solid object. However, the cost of fuel presently rules out the use of heaters (see chapter 4).

FROST/FREEZE

- ❑ Temperature below freezing.
- ❑ Persistent winds in the range of 5 to 10 miles per hour will prevent the formation of an inversion, so wind machines and helicopters will not provide sufficient protection.
- ❑ A well-designed over-vine sprinkling system can be effective, but you risk extensive crop losses if sprinkling is inadequate, or the irrigation system fails during the night.
- ❑ Vineyard heaters provide some protection, but the cost of fuel may make their use cost-prohibitive.

Frost Warning

The National Weather Service may issue a "Frost Warning," for temperatures *above* 32°F, but this is simply a *warning* of a possible frost event. It does not mean that a radiation frost event has temperatures above 32°F. In fact, Perry (2001) defines a ***radiation frost*** as having temperatures near the surface ***below freezing*** **(32 F).**

Table 11.1 Definition of Frost/freeze Warnings Issued by National Weather Service.

Frost Event	Wind Speed (miles per hour)	Air Temperature (°F)
Frost	Below 10	Above 32
Frost/freeze	Below 10	Below 32
Freeze	Above 10	Below 32

RADIATIONAL FROST

- ❑ Caused by rapid radiational loss of heat.
- ❑ North Carolina has two types of radiational frosts: hoar frost and black frost.
  - *Hoar frost* results when atmospheric water vapor freezes in small crystals on solid surfaces; also called a white frost.
  - *Black frost* has few or no ice crystals because the air in the lower atmosphere is too dry; sometimes called a dry freeze even though it is not technically a freeze.
- ❑ Either type of radiational frost may occur after grapevines have broken bud and commenced spring shoot growth.
- ❑ A black frost is always going to be a killing frost; a hoar frost may or may not damage the crop.
- ❑ Active frost protection can protect the crop under certain conditions, as explained below.

Types of Active Frost Protection

Use Table 11.2 to help you assess the potential effectiveness of different methods of active cold protection under hoar frost, black frost and frost/freeze conditions. As the first column in Table 11.2 shows, wind machines, heaters, over-vine sprinklers, and helicopters *all* may protect against hoar (white) frost conditions. However, as you can see, the method of active frost protection you select matters a great deal when it comes to either a black frost or frost/freeze condition. For example, in a black frost condition (second column) with temperature minimums below 28°F, a wind machine may require supplemental heaters, or possibly even a helicopter (which can adjust to the height of the inversion), to add extra heat to the vineyard when minimum temperatures are going to be too low for a wind machine. Generally, wind machines are not found to be

Table 11.2 Relative Effectiveness of Passive, Active Frost, and Active Frost/freeze Protection Methods Under Different Cold Event Scenarios. [1]

Method	Radiational Hoar Frost; Temperature 28 to 36°F	Radiational Black Frostand/ or Weak Inversion; Temperature- Below 28°F	Frost/freeze (winds 5 to 10 mph)	Comments
Good site selection (passive)	***	**	*	Locations with good air drainage; visualize air flow/and evaluate frost climatology.
Wind machine	***	*	x	**Do not use** if winds are greater than 5 miles per hour.
Wind machine-plus heaters	na	**	*	Can be effective in black frost, weak inversion, and merits further attention. Heaters not needed in a hoar frost.
Wind machine-plus helicopter	na	***	0	Useful when inversion ceiling is high. Not needed in a hoar frost.
Over-vine sprinkling	***	***	**	Incorrect use can cause greater damage.
Helicopter	***	**	x	Very high costs per hour, greater than $825 in 2006.
Heaters	***	**	*	Very limited use in NC vineyards due to high cost of fuel.

[1]*highly effective = ***; effective = **; limited effectiveness = *; ineffective = 0; and, potentially damaging = " x "; not applicable = "na"*

practical when you need to raise the temperature more than 1 to 3 degrees. Keep in mind that wind machines require an inversion to be effective. Also, they are not effective if winds are greater than 5 miles per hour. Wind machines are not an appropriate choice for sites subject to frost/freeze conditions following bud break. Wind machines will provide no protection in freeze conditions, and their use may increase injury to vines and damage the equipment as well.

For vineyards subject to black frosts and/or frost/freeze conditions, over-vine sprinkling can be very effective. Over-vine sprinkling can be designed to provide enough heating capacity to protect vines in cold events with minimums in the low 20s. But, you must be aware of the greater complexity of operation of sprinkler irrigation, especially under winds in the 8- to 10-mile an hour range.

Ultimately, the proper choice of protection equipment will depend on many factors. A detailed economic analysis of each frost protection system is beyond the scope of this chapter, as is a full consideration of the environmental impacts of the various protection systems. Here are some general points regarding the general utility, relative cost effectiveness, and environmental impacts of these systems outside the area being treated.

WIND MACHINES may prove profitable on sites where there is a 20 percent or higher probability of spring frost during early stages of new shoot growth (see investment analysis in Chapter 4). Wind machines use the inversion that develops in a radiation frost. Seven to 10 acres is the minimum size vineyard for a wind machine.

The experiences of several commercial vineyards in North Carolina's over the last decade have affirmed the value of wind machines on piedmont sites with chronic radiational frost problems. In some instances, the sites helped are near valley floors or creek bottoms that are very prone to frost. Although wind machines do not provide more than 1 to 3°F of warming, they are particularly well suited for managing the dominant kinds of cold weather events that occur in North Carolina vineyards after bud break–radiational frosts.

Although hourly operating costs are higher than for over-vine sprinkling, these costs are still substantially below operating costs for return-stack oil heaters and standard propane heaters. In 2005, the initial cost of a fully installed wind machine was approximately $2,800 per acre in North Carolina.

Other benefits not widely reported have to do with using them for moisture control during harvest in August and September, when heavy dews in lower lying areas can cause significant delays in harvest and increase fruit rot pressure. Wind machines started at 6 a.m. can have the grape canopy dry and ready for harvest by as early as 9 a.m.

Wind machines may also be appropriate for use to protect a grape crop from fall frosts in higher elevation areas with shorter growing seasons, and they may also be useful for protecting the vineyard canopy from frost damage shortly after harvest. Leaf damage from fall frost may delay cane hardening and render the vines more susceptible to winter damage (Sugar et al., 2003).

Wind machines produce a very loud noise, and you should be conscious that any nearby neighbors may strongly object to their use!

HEATERS may be the sole source of protection for radiation frosts, but the rising cost of fuel may make the use of 40 to 50 heaters per acre prohibitively expensive. No heaters are being used in North Carolina vineyards at this time, but a limited number of heaters arrayed near the perimeter of the vineyard and in portions of the vineyard farthest from the wind machines may merit consideration under colder radiational frost conditions. Air pollution by smoke can be a significant problem, and the use of oil-fired heaters is banned in many areas.

OVER-VINE SPRINKLING – Sprinkling for frost and frost/freeze protection has been very successful in North Carolina for years on low-growing crops like strawberries, but it has not been very popular with vineyard operators in the state for a number of reasons, including:

- the cost of materials, installation, and development (usually including a pond);
- not having enough water resources to safely provide three consecutive frost/freeze nights of protection (about 150,000 gallons of water for each acre of vineyard),
- complexity of operation and high risk of vine damage if the system fails in the middle of the night, and
- even though sprinkler irrigation offers the highest level of protection of any single frost control system, their fixed-rate design delivers more protection than generally necessary (Perry, 1998). They can only be turned on or off, so you can't vary the irrigation rate.This contributes to over-watering, which can waterlog soils, leach fertilizers, and may increase disease pressures.

If your vineyard is highly prone to frosts and frost/freezes, one of the real advantages of over-vine sprinkling is its very reasonable cost for operating. Evans (2000) has reported that over-vine sprinkling was about 12 percent of the cost per hour of wind machines (requiring fuel), and only about 4 percent of the hourly cost to operate a return-stack oil heater system (40 per acre).

If you decide to invest in over-vine sprinklers for frost/freeze control in the vineyard, it is much more convenient to install the system before the vineyard is planted than it is to add it to an existing vineyard.

HELICOPTERS are another option that may be economically justified under special circumstances, despite the fact that charges started at $825 an hour in 2006. Currently, helicopter services are used in Virginia vineyards, but not in North Carolina.

FOGGERS – When the dew point temperature is close to the air temperature, the fog that can form can act as a barrier to radiative heat losses from plants at night. Fog lines that use high pressure lines and nozzles to make fog droplets have been reported to provide excellent protection under calm conditions. Little water is deposited, minimizing the potential for ice-load damage (a concern with over-vine sprinkling). However, containing and/or controlling the drift of fogs and potential safety/liability problems (if fogs cross a road), are factors that may seriously limit the usefulness of fogging systems (Evans, 2000). Dew point temperature is discussed in Principles of Cold Protection.

ICE NUCLEATION BACTERIAL INHIBITORS – A few vineyards in North Carolina are using special foliar nutrient sprays to change the freezing point of the plant tissue, but more research on this technique is needed. In trials conducted in Oregon (Sugar et al., 2003), little or no frost protection was obtained from treating vines with substances that are supposed to depress the freezing point or inhibit bacteria that can serve as nucleators for ice formation.

Principles of Cold Protection

With a clear understanding of the frost and frost/freeze management principles in this section, you will be better able to deal with complex cold protection scenarios. You will also know when active protection is likely to have success as well as understand when it can lead to greater crop damage. Since there is very little that you can do to protect against a freeze, this section focuses on frost and frost/freeze events.

1. Cold Damage Mechanisms

If the plant tissue in developing shoots spend just 30 minutes at 31°F, or lower, significant damage can occur (Sugar, 2003). On thawing, cold damaged grape shoots lose turgor, completely darken and become water soaked–completely limp grape tissues may be observed within a few hours following the cold event (Sugar et al., 2003). Thus, one very important goal of *active frost protection* is to provide enough supplemental heating to keep tender shoots above 31°F. As *a general rule*, start your frost protection system to keep plant tissues safely in the range of 31.5 to 32°F (Sugar et al., 2003).

Obviously, you must begin countermeasures before the critical temperature is reached and an irreversible freezing strain has occurred, but there is one very serious catch: you cannot rely on air temperature alone. When atmospheric conditions are relatively dry, you need to monitor *both* vineyard air temperature and humidity using dew point (DP)[1] temperature.

2. Monitoring Atmospheric Moisture Using Dew Point Temperature

To protect your crop, you need to know the dew point (DP) temperature. The DP temperature is unquestionably one of the most valuable pieces of information you get as a subscriber to and advance weather forecast service. A relatively low DP temperature indicates drier air, and thus the potential for a killing *black* frost. Conversely, a relatively high DP indicates the potential for a *hoar frost,* which may or may not injure succulent grape tissues.

MOIST ATMOSPHERIC CONDITIONS AND ICE CRYSTALS. Dew point temperature is an excellent indicator of whether the lower atmosphere is moist enough for ice crystals to form on plants. Essentially, a forecast for DP temperatures near or above the freezing point (in the upper 20s and low 30s), indicates that the lower atmosphere is relatively moist, and you need to pay very close attention to the start of ice crystal formation on plant tissues. *Your goal is to prevent ice crystals from forming on young grape shoots.*

Although DP temperature is an excellent indicator of the potential for a hoar frost, you should also be aware of other important conditions, including calm winds and clear skies. Natural factors that will help keep ice crystals from forming include winds greater than 5 miles per hour, cloud cover, and potentially drier soil conditions (Table 11.3). Thus, in cloudy, breezy

[1] The dew point (DP) is also defined as the temperature at which water vapor in the air becomes saturated, and then condenses as dew, fog or frost (Westwood, 1978).

Table 11.3 Natural Factors That Favor and Counteract Frost

Favor	Counteract
Calm winds	Winds greater than 5 miles per hour (slows radiative cooling of solid objects)
Clear skies	Cloud cover (acts as a blanket; the thicker the cloud cover, the slower the cooling rate)[1]
Surface air temperature at 32°F, or below	Surface air temperature above freezing
Dew point temperature in upper 20s and lower 30's	Dew point temperature in mid 20s and lower (atmosphere is too dry)
Soils containing abundant water	Drier soil conditions

[1] Since heat loss from the ground and plants at night is in the form of long wave radiation that does not pass through clouds, clouds act as a blanket over the earth, and in most cases hoar frost will not occur on cloudy nights (Sugar et al, 2003).

weather, frost will not occur and observed low temperatures will likely be very close to forecast values. But under clear calm conditions with DP temperatures in the upper 20s to lower 30s, there is potential for heavy frost.

Researchers have found that a hoar frost sometimes actually helps protect the plant from frost damage. In practical terms, it is much too difficult to determine if a hoar frost will injure grape tissues. Be proactive and *start frost protection at the first appearance of frost (ice crystals) forming on young grape shoots.* Use wind machines or any other frost protection method (over-vine sprinklers, heaters, and helicopters) to prevent ice crystal formation on plant surfaces. A potential *hoar frost scenario* in North Carolina would be:

- ❑ air temperature forecast in the mid- to low 30s
- ❑ dew-point temperature forecast in the low to mid-30s
- ❑ calm wind forecast of less than 3 miles per hour
- ❑ clear to mostly clear skies (no cloud cover)

DRY ATMOSPHERIC CONDITIONS AND BLACK FROST. When speaking with growers across North Carolina, we have found that many are unfamiliar with *black frosts.* Few or no ice crystals form on plant surfaces in a black frost. The crystals do not form because the lower atmosphere is too dry. If the DP is in the mid-20s (relatively low), for example, you will not be able to see (or feel) any ice crystals forming on the plant surface until the air temperature drops into the mid-20s–this is the frost point.[1]

[1] The frost point is the temperature to which the air must be cooled to cause atmospheric moisture to change from a gas to solid (Perry, 1998).

Table 11.4 Characteristics of the Two Types of Radiational Frosts[1]

Hoar (White) Frost	Black Frost
Calm winds	Calm winds
Clear skies	Clear skies
Temperature drop is gradual through the night due to high relative humidity	Temperature drop can be rapid after sunset (more than 2°F per hour) due to relatively dry atmosphere
Dew point may be above the critical tempera-ture for buds and shoots, and hoar frost is not necessarily injurious to plant tissues	Relatively dry air (low dew point); dew point temperature is below critical temperature of sensitive plant tissues, and black frosts are always *killing frosts*
Ice crystals form on surface of solid object from water vapor (not dew)	Development of ice crystals depends on dew point, or frost point of air
Frost formation may trigger ice nucleation and possibly plant freezing	Plant freeze injury may occur in absence of ice crystals forming on plant surface
Initiate frost protection at first sign of ice crystal formation on plant tissues	Frost protection is more complicated as plant tissue temperatures may be several degrees colder than air temperature under low humidity atmospheric conditions; use the dew point temperature to determine when to begin frost protection

[1] Perry (2001) defines a *radiation frost* as having temperatures near the surface below freezing (32°F), and winds of less than 5 miles per hour.

By the time you see crystals on blades of grass, your pickup truck hood, or tender grape shoots, the damage has been done. Grape tissue temperatures will have already dipped below their critical point, and irreversible crop injury will be the outcome. *You cannot wait until you see frost if the DP is low.*

Another confusing characteristic is that plant tissues radiate their own heat back into space under dry atmospheric conditions. So the plant becomes progressively colder than the surrounding air, **and air temperatures may be several degrees *warmer* than the actual crop temperature** (Evans, 2000). To keep tender shoots above 31°F, frost protection procedures using wind machines, heaters, or helicopters must begin at air temperatures that are 1 to 6 degrees higher than the expanding grape shoot's critical temperature. The exact start-up temperature for cold protection will depend on the dryness of the lower atmosphere, as indicated by dew point temperature.

If the DP is in the

- ❑ teens, start frost equipment when the air temperature is around 35 to 37°F.
- ❑ low- to mid-20s, start frost protection equipment when the air temperature is around 34°F.
- ❑ upper 20s, start frost equipment when the air temperature is around 32 to 33°F.

If you do not use dew point temperatures, you are simply guessing at when to start cold protection on radiational frost nights with low atmospheric humidity.

Use Table 11.4 to distinguish hoar frost from black frost events. You will note that both types of radiational frost events occur under calm winds. Under the next principle of cold protection, we consider your cold protection options when winds are sustained and exceed 5 miles per hour, but are less than 10 miles per hour.

3. Cold Protection Principles Under Windy Conditions (Frost/freeze)

Advance weather forecasts will often contain information on **wind speed,** which can be especially helpful information. Persistent winds of 5 to 10 miles per hour prevent an inversion, so there would be no warmer air for a wind machine or helicopter to return to the plants. Heaters work in *frost/freeze* conditions, but the cost of fuel may make them prohibitive. Over-vine sprinkling systems offer a high degree of cold protection relative to other systems of cold protection and are relatively cost-effective (Sugar et al, 2003), but they are risky when sustained winds are greater than 7 miles per hour. Damaging evaporative cooling effects are promoted by winds and low humidity.

Adequate over-vine sprinkling rates in windy conditions. The success of over-vine irrigation for frost/freeze protection is critically dependent on having adequate delivery rates to keep grape shoots safely at 31.5 to 32°F (Sugar et. al, 2003); the grower should not attempt sprinkling unless he or she is sure that their system can provide adequate sprinkling to offset wind-related, evaporative cooling demand.

A final point about cold protection under windy conditions: if the atmosphere is dry (DP is low), swollen buds and grape shoots may not be injured until the air temperatures are several degrees below the temperature thresholds that are normally considered critical for cold protection activities. Under very dry atmospheric conditions in the vineyard, Wolf and Boyer (2003) report that injury to grape shoots may not occur until air temperatures reach 25 to 26°F, which is several degrees colder than the critical temperature points reported for young shoots (30°F). When the humidity is low and cooling is gradual, newly developing grape shoots have the ability to supercool (drop below their normal freezing points) and may not freeze at 30°F. Thus, the best strategy may be to take no action at all in a number of *frost/freeze* situations. Fortunately, frost/freeze events are more likely to occur before spring budburst, and they are *not* considered a "prevailing condition" for most winegrape growing areas in North Carolina. However, be sure to consult a qualified climatologist if you are unsure about the potential for frost/freeze events in your general area and vineyard location, especially in colder sections of the mountains (see chapter 4).

4. Cold Protection Principles—Be Proactive in Planning Your Strategy!

As stated in the milestone extension bulletin, *Frost and Frost Control in Washington Orchards* (J.K. Ballard, 1981), the grower, "… must know the kind of frost confronting him each time the frost alarm rings," and today's advance weather forecast allows the modern day vineyard producer to make an educated guess about what can potentially happen several days, or more, before the cold event occurs. You can then revise control options and strategies as more information becomes known about the event in 48-hour and 24-hour updates.

If you decide to use a commercial provider for specialized weather forecasts, be sure to use one of the more farm-specific services. They may provide twice daily reports on the Web or send you reports via e-mail or fax. Weather forecasts for your vineyard should provide the following information:

- ❑ When a cold event is coming.
- ❑ How cold it will get (minimum air temperature at the weather shelter level of 5 feet).
- ❑ How long the cold may last (duration).
- ❑ Wind speeds and direction.
- ❑ Whether the humidity will be low or high and specifically the dew point temperature.

Unfortunately, the current methods for predicting wind speeds coupled with widely varying terrain for mountain zones of North Carolina, greatly limit the capability of various weather forecast services to provide meaningful wind forecast products for this region of the state.

Know Your Vineyard

Conditions specific to your growing site can affect temperature, humidity, wind speed, and inversion strength during radiational cooling. Knowing what has happened in the past when the forecast was similar can help you to predict what is likely to happen in your vineyard during a cold event.

Keep a Weather Journal

Organizing a journal can help you develop a successful cold protection strategy. A weather journal should include the following information for each cold event:

- ❑ Date of the event and type of event (freeze, frost/freeze, or frost).
- ❑ The minimum dry bulb temperature (at 5 feet) and at the canopy level.
- ❑ Wind speeds and directions.
- ❑ Amount and type of cloud cover.
- ❑ Dewpoint temperature (frost point)
- ❑ Inversion strength

In summary, take full advantage of regional and localized weather forecast products, and key information on *wind speeds*, *dew point temperatures* and *minimum temperatures.* Then use your personal knowledge of your vineyard site's microclimate, and past experiences and "lessons" in frost and frost/freeze protection, to determine a strategy that will give you the best chance of success.

Operating Frost Protection Systems

This section provides in-depth information on the actual operation of several conventional frost control systems (wind machines, over-vine irrigation, and heaters), and also explores scenarios where combination approaches may be a better choice, such as the use of both wind machines and heaters. Information is also provided on helicopters, which are another option that may be economically justified under special circumstances, despite their high hourly charges (starting at $825 per hour).

Wind Machines

Choose this method for your vineyard when:

1) most spring cold events during grape budbreak and early shoot development are likely to be radiational;
2) there is a 20 percent probability, or higher, that you will lose 50 percent of your yield an average of twice every 10 years; and
3) the frequency and strength of low-level inversions during the budbreak and early shoot development will make over-vine wind machines effective.

INSTALLATION. Typically, an 18-ton crane is required for installation, but a 14-ton truck crane can often suffice, as long as the boom-out is at least 60 feet. The heaviest part of the wind machine is the steel tower, which weighs about 4,000 pounds. Also, the ground-mounted unit requires a concrete pad (about 7.5 yards of concrete gravel mix with no fly ash). There are well-qualified wind machine vendors serving North Carolina. Your county Extension agent can provide you contact information. Wind machine suppliers typically have a great deal of field experience, and they will be able to help you with the appropriate placement of the wind machines in your vineyard.

PRINCIPLES OF OPERATION. Ground-mounted wind machines with heavy-duty industrial engines, combined with high-strength 18-foot fan blade mounted approximately 30 feet from the ground, can move large volumes of air through the vineyard. *These machines rely on the principle that a large, slow moving cone of air can produce the greatest temperature modification around the vines by mixing warmer air above the vineyard with cooler air around the vines.* The propeller revolves at approximately 590 revolutions per minute and rotates 360 degrees about its vertical axis every 4½ minutes. The motor should be strong enough to drive the air turbulence into the vineyard 300 to 400 feet under windless conditions. You will notice in Figure 11.1 that the protected area is usually an oval pattern. This is because the machines are located to take best advantage of natural patterns of air movement in the vineyard during frosty nights. In Figure 11.1, you can see that a single wind machine may drive the air 500 to 600 feet with the air drift, but that the effective turbulence is only 250 to 300 feet on the upwind side. *The effectiveness of a wind machine depends on a temperature inversion so that there is a source of warm air for mixing* (Sugar et al. 2003). One Davidson County vineyard, where a wind machine has been recently installed, quite commonly experiences inversions of 7°F from the ground level to 50 feet in elevation. (This would be considered a strong inversion with 1.4°F per 10 feet). The general rule is that with a typical inversion layer at 40 to 50 feet, wind machines can be expected to increase the temperature around the vines by one-fourth to one-half of the difference in temperatures between air around the vines and the warmest air in the range of the wind machine.

Operation

1. A reliable **weather prediction system** will allow you to decide in advance of the cold event if frost protection with a wind machine will be adequate. Start checking weather forecasts at least 48 to 72 hours in advance of the event. Once you know what type of cold event is coming, you can start making plans to use your wind machine or to add a backup system if supplemental heating may be needed. On the night of the cold event, make sure your frost alarm is correctly set (usually at 37°F).

2. **Calculate the strength of the inversion.** Wind machines work well under hoar frost (white frost) conditions, but you may need to use

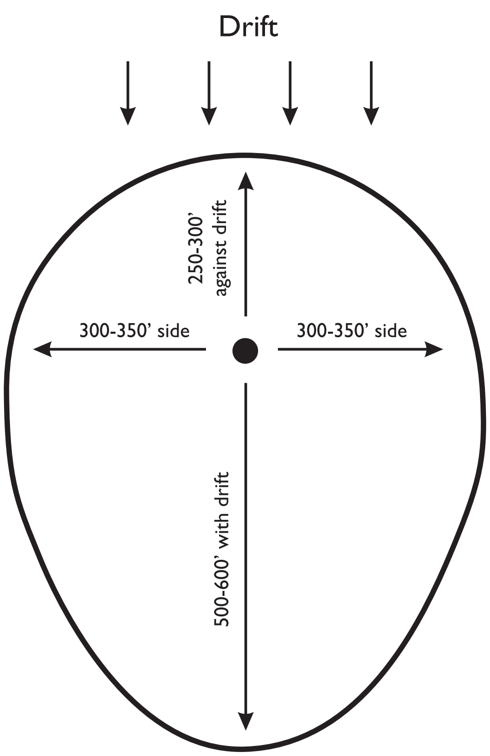
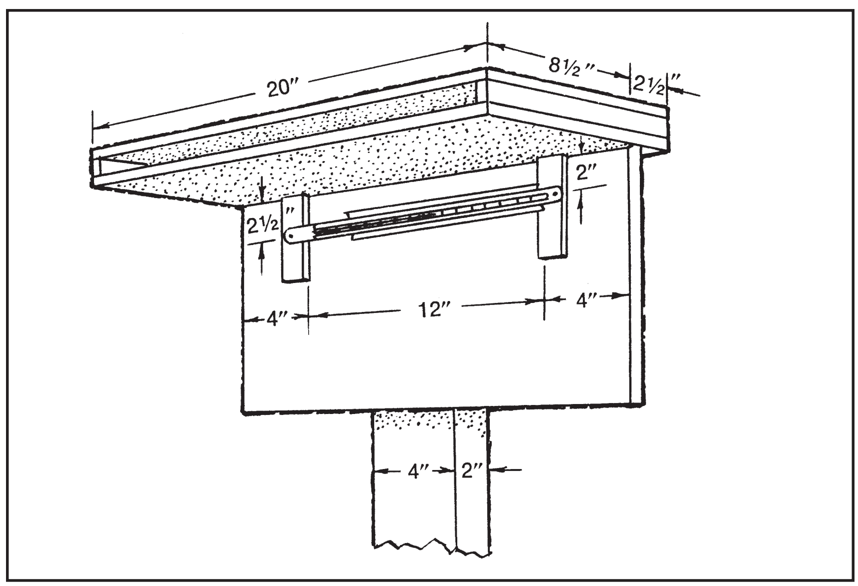


Figure 11.1. Oval pattern of protection provided by wind machines.

an additional method in *black frost* conditions when more than 2 or 3°F is needed to keep developing new shoots above their critical temperature. Remember that wind machines bring in warmer air from the thermal inversion, but these machines are not very effective when the inversion strength is small. Calculate the strength of the inversion by multiplying the difference in air temperature at 50 feet and the vine level by a factor of ¼ to ½ (e.g., if the difference in temperature is 4°F, then the inversion will only provide about 1 to 2°F of warming of the air around the vines). Advance information about the likely strength of the inversion may be obtained from your weather forecast service.

3. **The critical temperature** will vary with the stage of plant tissue development and environmental conditions. For the most part, an air temperature of 31°F or lower for 30 minutes or longer, may be considered critical beyond budbreak (Sugar et al. 2003) for frost and frost/freeze protection.

4. **Air temperature measurment.** By definition, the critical temperature of 31°F is the *air temperature* as read on a properly sheltered, correctly calibrated vineyard thermometer. A well-managed frost protection system depends on accurate temperature readings and also on having thermometers properly distributed. At least one is needed in the coldest location in the vineyard, and the number of other thermometers required will be a function vineyard size. The idea is to have enough to keep you posted on the temperature behavior throughout the protected area (Ballard, 1981). The thermometers must be sheltered and not exposed to the sun during the day or sky during the night (Fig.11.2).



5. **Know your dew point temperature!** When your frost alarm clock has awakened you, begin checking temperatures in the vineyard. Many growers will automatically turn on the wind machines at about 32°F (based on the temperature of the thermometer in the coldest vineyard location), but this may or may not be a good decision. A better strategy takes into account

Figure 11.2 Properly sheltered air temperature thermometer. (Illustration courtesy of Washington State Cooperative Extension)

both air temperature *and* dew point temperature.[1] When the dew point is low, temperature can drop very rapidly, and it is not unusual to see the air temperature drop more than several degrees in the first hour. The U.S. Weather Service reports that dew points of 30°F are considered **high** and those of less than 20°F are considered **low** (Ballard, 1981). Evans (2000) recommends that if the weather forecast is for subfreezing temperatures accompanied by low dew points (less than 20°F), that you should turn on the wind machine(s) at 35 to 37°F to start moving the warmer air through the vineyard even with weak inversions. This will at least partially replace radiative losses and strip cold air layers away from the buds and shoots. If the dew point is in the low- to mid-20s and air temperatures are dropping at an average of 2°F per hour, turn on the wind machine when the temperature is around 34°F. If the dew point is in the upper 20s, 32 to 33°F should be satisfactory.

If the dew point is near or above the critical temperature for grape tissue (around 31°F), it is important to be aware that the heat released at the dew point may provide sufficient heat to avoid reaching damaging temperatures, or at least may delay the temperature fall and postpone the need to turn the wind machine on (Sugar et al. 2003). HOWEVER, as soon as you detect any frost forming on exposed grape plant tissues, TURN THE WIND MACHINE ON! By stirring up the air, wind machines can interfere with ice crystal formation. As discussed in Principles of Cold Protection, the formation of ice crystals on succulent grape shoots can be very damaging.

6. **Heaters** may be lit to supplement the wind machines on nights when temperatures are expected to go below 27 to 28°F. See the section on *Heaters* for additional information.

7. **Using a helicopter service as back-up.** In colder radiational frost conditions, some Virginia vineyards will use both wind machines and also have helicopters on standby in case temperatures may fall below the capacity of wind machines. This can be relatively expensive, but growers faced with devastating black frost losses find them very effective. Information about helicopters is provided in a later section.

8. **Shut-down of wind machine.** *Monitor air temperatures after sunrise, and continue to run the wind machine until the temperature is above 32°F in the lowest area of the vineyard.* Technically, you could safely turn off the wind machine before an air temperature of 32°F is reached, as the air temperatures will warm more slowly in the morning than the grape shoot tissues. If you own a device for monitoring actual tissue temperatures (e.g. digital thermometer with thermocouple inserted in grape shoot tissue), you will see that as the crop tissues receive direct rays from the sun in the morning and they will warm up more rapidly than the surrounding air. You would need an instrument for monitoring this, and since few grape growers own these devices, it is recommended that you continue to run the wind machine until the air temperature is safely above 32°F in the lowest area of the vineyard.

Over-vine Sprinkling Systems

This is the most complicated method of active frost protection and should only be chosen if you have established that your vineyard site is highly prone to frost and frost/freezes and that you have enough water to provide three consecutive frost/freeze nights of protection (about 155,000 gallons of water per acre).

[1] Dew point is predictable from the difference between the wet- and dry-bulb thermometer readings. Grape growers who do not have a weather forecast service that provides hourly dew points may find it to their advantage to determine their own dew points with a sling psychrometer. Your Extension agent can tell you where you can purchase a sling psychrometer and obtain a copy of psychrometric tables for obtaining the dew point.

PRINCIPLES OF OPERATION. The overhead sprinkler irrigation system relies on two key principles: *heat of fusion* and *heat of vaporization***.** As water freezes, heat is released by the freezing process (heat of fusion). The amount of heat generated when water freezes is 1,200 British thermal units (btu) per gallon or 80 calories per gram of water frozen. This heat keeps plant temperatures safely at 31.5 to 32°F (Sugar et al. 2003) when air temperatures are colder. Evans (2000) indicates that the ice and water mixture is at about 30.9°F.

As long as an *adequate layer of freezing water* covers the buds and shoots, the temperature will stay above the critical damaging temperature.

With very low air temperatures, greater rates of water are required for adequate protection. Also, the presence of wind while sprinkling over the vines can lead to extensive crop loss if sprinkling rates do not offset evaporative cooling heat losses. Since the heat taken up by evaporation at 32°F is about 7.5 times as much as the heat released by freezing, at least 7.5 times as much water must freeze as is evaporated. Thus, relatively high sprinkling rates are required under windy compared to calm wind conditions (see Table 11.5), and this is needed to both supply heat to warm the vineyard as well as to satisfy heat losses through evaporation. Keep in mind that under cold conditions evaporation is happening all the time from the liquid and frozen water, and if the system should fail at anytime during the night, it goes *immediately* from a heating system to a very good refrigeration system, and damage can be much worse than if no protection has been used at all (Evans, 2000).

Furthermore, there may be what is called an "evaporative dip," or "cold jolt," due to evaporative cooling of the sprinkler drops when the system is first turned on. This 15- or 20-minute dip can push temperatures of the grape tissues below their critical point and cause serious cold injury at the outset of the sprinkling operation. Under conditions favoring evaporative cooling (winds and low humidity), it is very important to **turn on the sprinklers** on the basis of **wet bulb temperatures,**[1] and **not ambient temperatures**.

Operation

1. Start-up. Under low dew point and/or windy conditions, ***start watering <u>before</u> the wet-bulb temperature reaches the critical grape shoot temperature of 31°F***. The wet-bulb temperature governs the turn-on time, not ambient temperature. Except when the air is saturated with moisture, the wet-bulb temperature is normally lower than the air temperature but higher than the dew-point temperature. For example, when the air temp is 33°F and the wet-bulb is 30°F, the dew point is 25°F (Ballard, 1981). But, by waiting to turn on the irrigation system until the wet-bulb temperature is below 31°F, you are running some risk of plant tissue injury due to the 'cold jolt' phenomenon. It is far better to waste 30 or so minutes of irrigating early in the evening than to risk damaging grape shoots. Under higher dew-point conditions and winds, it will still be important to monitor wet-bulb temperatures and turn on sprinkling before the wet-bulb temperature reaches the critical grape shoot temperature of 31°F. Under low wind speeds (less than 2 miles per hour) and/or no winds, along with relatively high dew points (upper 20s and low 30s), *start frost protection procedures at the first sign of ice crystals forming on the plant surfaces under hoar frost conditions.*

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[1] Knowing wet bulb temperature is especially important to growers who use over-vine sprinkler irrigation for frost/freeze protection of grapes. (It is not critical to know wet bulb temperatures when using other types of frost protection, such as wind machines, heaters, or helicopters). The wet bulb temperature determines when you turn the irrigation system on and off. Wet bulb temperature is a measurement of the evaporative cooling power of the air and can be measured using a sling psychrometer, an instrument comprised of two thermometers. The wet bulb temperature has a gauze wick attached to the bulb end; and to measure wet bulb temperature, the gauze wick is immersed in water, and the instrument is swung in a circular motion for a few minutes. (The above information on wet bulb temperature and how to take a wet bulb temperature reading is taken from *Priniciples of Freeze Protection for Fruit Crops,* ANR-1057A, March 2000, Arlie A. Powell and David G. Himelrick.)

2. **Once sprinkling starts** and an ice coat has built up, the system must operate continuously through the night until the vines are free of ice the next morning, or at least until the wet-bulb temperature of 32°F, or above, has been reached. Be especially cautious about stopping the application of water during the night if the temperature rises because of a light breeze or a few clouds. Once the breeze falls or the clouds disappear, the temperature will probably drop rapidly again. With sprinkler irrigation for frost protection in vineyards, the system must be designed for worst-case conditions.There are several excellent irrigation suppliers in North Carolina who can design a vineyard sprinkler system to provide protection down to a target temperature of 20 to 22°F. In Oregon, it is reported that an application rate of 0.19 inch per hour can protect grape buds and shoots down to 22°F (Sugar et al., 2003). However, it should be noted that under relatively high wind conditions and with temperatures approaching 22°F, you may need to apply more than 0.19 inch per hour (see Table 11.5). In North Carolina it would be better to design a vineyard sprinkler irrigation system that can deliver precipitation rates of up to 0.25 inch per hour to take into account evaporative cooling heat losses when winds are in excess of 5 miles per hour at an air temperature of 22°F. Less water is required for protection to 26°F, and in Oregon it is recommended that an application rate of 0.12 inch per hour will be sufficient at this temperature (Sugar et al., 2003). Water should slowly but continuously drip from the vine when the sprinkling system is working properly (Evans, 2000). The application rate is not sufficient if the ice has a milky color (from occlusion); ice should be clear at all times.

Large amounts of water are required for over-vine irrigation, so you should size your pond(s) to provide for three continuous nights of protection at 10 hours per night. You would need 5.7 acre-inches of water (27,152 gallons equal 1 acre-inch) for sprinkling at the rate of 0.19 inch per hour (for control down to 22°F), for 10 continuous hours each night over 3 nights. Or, 1.9 inch/night (10 hours x 0.19 inch) x 3 nights = 5.7 acre-inches. An irrigation pond would need to hold about 155,000 gallons of water for each acre of vineyard production under these conditions (5.7 inch x 27,152 gal per acre inch = 154,766 gallons).

3. **Shut-down of irrigation system.** Operate continuously after sun-up until you can see free water running between the ice and the grape buds and shoots, or until ice falls easily from the

Table 11.5. Required Irrigation Rates (Inches per Hour) in Fruit Crops to Maintain a Temperature of 28°F and Relative Humidity of 70 Percent [1]

	Wind Speed			
Minimum Temperature (°F)	0 to 1 mile per hour, apply	2 to 4 miles per hour, apply	5 to 8 miles per hour, apply	9 to 14 miles per hour, apply
27	0.10	0.11	0.14	0.16
26	0.10	0.13	0.16	0.17
25	0.10	0.14	0.18	0.21
22	0.10	0.18	0.24	0.29
20	0.11	0.21	0.28	0.34
18	0.12	0.23	0.31	0.38
16	0.13	0.26	0.35	0.43

[1] This table illustrates the affect of wind speed on precipitation rates in fruit crops; it is not specific to grapes.
Source: Perry, Katherine (1998, Feb.). Guide to deciding when to start and stop irrigation frost protection of fruit crops, *Hort. Information Leaflet 713*

vine structures (spurs, cordons). It is not necessary to run until all the ice has melted after the warm sunlight "takes over" (Ballard, 1971). But, if the morning should turn cloudy after sunrise and/or if there are chilly winds, CONTINUE TO RUN THE IRRIGATION UNTIL THE **WET BULB** TEMPERATURE IS **ABOVE 32°F** IN THE COLDEST PORTION OF THE VINEYARD.

Heaters as a Supplement to Wind Machines[1]

For years the principal method of frost protection in fruit crops was by burning fuel to create heat. But burning these fuels (e.g. diesel, propane) as the sole means of frost protection is prohibitively expensive. Burning 40 heaters per acre with a diesel price of $2.50 per gallon would cost $100 per hour. There is the additional cost for labor to light the heaters and put them out in the vineyard, as well labor to refill them with oil for the next night of frost protection. *However, in North Carolina, heaters can be considered as an effective method of adding extra heat during nights when temperatures may fall below the capacity of wind machines wind machine protection*.

PRINCIPLES OF OPERATION. The hot gases emitted from the top of the heater initiate convective mixing in the crop area, tapping the important warm air source above in the inversion. About 75 percent of a heater's energy is released as hot gases. The remaining 25 percent of the total energy radiates from the hot metal stack. Radiated heat is not affected by wind and will reach any solid object not blocked by another solid object. *Heaters may thus provide some protection under windborne freeze conditions.* A relatively insignificant amount of heat is also conducted from the heater to the soil.

[1]This section is partially adapted from Horticultural Information Leaflet 705, *Frost/freeze Protection for Horticultural Crops* by K.B. Perry, North Carolina Cooperative Extension Service, 2001.

Operation With Wind Machines

Using heaters with wind machines is more energy efficient than relying on heaters alone. The number of heaters is reduced by at least 50 percent by dispersing them into the peripheral areas of the wind machine's protection area (Evans, 2000). In Oregon vineyards, when heaters are the sole source of protection, 40 to 50 heaters burning at the rate of 0.5 gallons per hour per acre is recommended (Sugar et al., 2003). There do not seem to be any absolute formulas to follow on this, but by lighting 20 to 25 heaters per acre you may expect approximately 3°F protection (Sugar et al., 2003). The lightest heater concentration should be nearest the wind machine tower to minimize vertical current interference with the fan blast (Ballard, 1981). Grower testimony in North Carolina has further revealed that heaters are not usually necessary within a 150- to 200-foot radius from the base of the wind machine. Heaters give you the option of delaying protection measures if the temperature unexpectedly levels off or drops more slowly than predicted. There is no added risk to the crop if the burn rate is inadequate; whatever heat is provided will be beneficial (Perry, 2001).

Helicopters

Because of the great expense, helicopter use for frost protection is limited to special cases and emergencies, such as when a black frost in the mid-20s is forecasted at a critical growth stage and only a wind machine is available for protection, which is not likely to be adequate under such conditions. (Wind machines usually provide 1 to 3°F protection. In this scenario, at least 5 or 6°F protection is required.) Helicopters are generally hired for particular events, and will remain on standby either in the vineyard or close by. This is a relatively expensive operation, with hourly costs ranging from $825 to $1,600 per hour (depending on the size of the helicopter, and availability). The grower is also asked to guarantee at least 3 hours of work.

PRINCIPLES OF OPERATION. Helicopters are an expensive variation of wind machines (Evans, 2000), but they can be considerably more effective than a wind machine since they can adjust to the height of an inversion. A single large helicopter can protect more than 50 acres under the right conditions (Evans, 2000).

Operation

Contact the helicopter service well in advance of any serious frost/freeze event to make appropriate arrangements. The only company servicing our region in 2006 already has many long-standing commitments with vineyards in Virginia. (See Resources at the end of this chapter.) Since frost/freeze protection on some nights will last 6 hours or more, it is usually also necessary for the company to dispatch a jet fuel truck to the vineyard for refueling. Typically, you will be given a two-way radio so that you can talk with the helicopter. You and your workers must walk the vineyard during the cold event, checking vineyard thermometers with flashlights, so you can give the helicopter operator information on cold spots in the vineyard. A rapid response thermometer in the helicopter helps the pilot adjust the flying height for the best heating effect (Evans, 2000).

Summary

The cost effectiveness of active frost control depends on how prone a particular vineyard site is to radiation frosts (and possibly frost/freezes) in the spring from budbreak through early shoot development. Good site selection is still the best method of passive cold protection, but as more winegrape vineyards are planted in frost-prone areas of North Carolina, growers need to consider active methods of frost control. A number of growers in the piedmont and mountains are using wind machines to control radiation frost events in their vineyards. Radiation frosts occur on clear nights with calm winds (less than 5 miles per hour) and temperatures near the surface below freezing. When either a hoar frost or black frost threatens, they turn on the wind machines to break up the temperature inversion (warm air above the cold air close to the ground) by mixing warmer air with cold air.

Once ice forms in the plant tissue, there will be damage. Growers are advised to be proactive in their use of wind machines or any other frost protection method (over-vine sprinklers, heaters, and helicopters) in preventing ice crystal formation associated with a *hoar (white) frost.* In a *black frost* few or no ice crystals form because the air in the lower atmosphere is too dry, and the grower cannot wait for "evidence" of ice crystals to start up frost protection measures in these conditions. Advance weather forecasts from a subscription service can provide information on *dew-point temperatures* (DP), which can help the grower assess whether he or she may be dealing with a *hoar frost* (DP in the upper 20s and low 30s), or *black frost* (DP in the mid 20s or lower). If the DP is in the low to mid-20s, for example, turn on the wind machines when the air temperature is around 34°F. When the dew point (DP) is below the critical temperature of 31°F, expect that plant tissue temperatures will fall more rapidly than the surrounding air temperature, and the amount of *upward adjustment* in the start-up air temperature is going to be related to the dryness of the lower atmosphere, as indicated by dew point temperature. In dry atmospheric radiation frost conditions, be conscious of the need to monitor *both* vineyard air temperature and humidity (*using dew point temperature*).

On a *frost/freeze* night, the best strategy may be to take no action at all. Five- to 10-mile-per-hour winds will prevent the formation of an inversion, so wind machines and helicopters will not be effective. Over-vine sprinkling can be designed to provide enough heating capacity to protect vines exposed to *frost/freeze* conditions. The system must be carefully engineered specifically for use under windy conditions that promote evaporative cooling. If the grower has any doubt about the capacity of the irrigation system to provide adequate heating in *frost/freeze* conditions, the best strategy may be to take no action at all as an ice-covered vine will cool below the temperature of a comparable dry vine if freezing stops and evaporation begins.

Use the details for operating several conventional frost control systems (wind machines, overvine irrigation, and heaters), and the discussion of some cold event scenarios to help you determine which system(s) might be best for your vineyard. Regardless of the system(s) you use, remember that successful cold protection must be approached with a sound understanding of frost and frost/freeze management principles, a good knowledge of your vineyard site's microclimate and weather conditions that are favorable for the operation of your cold protection system, and careful attention to the details contained in specialized weather forecasts on air temperature minimums, dew point temperatures, wind speeds, cloud cover, and inversion strength.

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Resources

Climate Information

Ryan Boyles, Associate State Climatologist
State Climate Office of North Carolina
1005 Capability Drive, Suite 240
Research III Building, Centennial Campus
Box 7236, North Carolina State University
Raleigh, North Carolina 27695-7236
ryan_boyles@ncsu.edu
919-515-3056, 877-718-5544
Fax: 919-515-1441
http://www.nc-climate.ncsu.edu

Jan Curtis, Applied Climatologist
NRCS - National Water & Climate Center
1201 NE Lloyd Blvd, Suite 802
Portland, OR 97232-1274
jan.curtis@por.usda.gov
503-414-3017, (503) 956-4609 (cell)
FAX: 503/414-3101
http://www.wcc.nrcs.usda.gov/

County Extension Agent
http://www.ces.ncsu.edu/
index.php?page=countycenters

Heaters (HY-LO Return Stack Heater and similar heaters)

Plummer Supply
Agricultural Irrigation & Orchard Supply Co.
2875 Plummer Park Place
Bradley, MI 49311
269-792-2215, 800-632-7731
http://www.accn.org/~plummer

Helicopter Frost Control Service

HeloAir, Inc.
5733 Huntsman Road
Richmond International Airport, VA 23250
804-226-3400, 888-FLY-HELO
www.heloair.com

Over-vine Irrigation System Suppliers

B.B. Hobbs
PO Box 437
Darlington, SC 29540
843-395-2120
sales@bbhobbs.com
http://www.bbhobbs.com

Berry Hill Irrigation
3744 Hwy 58
Buffalo Junction, VA 24529
434-374-5555, 800-345-3747
sales@berryhilldrip.com
http://www.berryhilldrip.com

Gra-Mac Irrigation
2310 NC Hwy 801 N.
Mocksville, NC 27028
336-998-3232, 800-422-35600
gramacirr@yadtel.net

Johnsons & Company
PO Box 122
Advance, NC 276006
800-222-2691, 336-998-5621
henry.johnson@johnsonandcompanyirrigation.com
http://www.johnsonandcompanyirrigation.com

Mid-Atlantic Irrigation Co.
PO Box L, Farmville, VA 23901
434-392-3141
mairrigation@cstone.net
http://www.irrigationparts.com

W.P. Law Co.
Sales: Brad Scease, Tom Plumlee
303 Riverchase Way
Lexington SC 29072
803-461-0599
Fax: (803) 461-0598
http://www.wplawinc.com/

Weather Forecasting Services

AcuWeather.Com
Online subscription weather forecasting service
State College, PA
http:// wwwa.accuweather.com/

AWIS Inc
Agricultural Weather Information Service Inc.
PO Box 3267
Auburn, AL 36831
888-798-9955, ext 1 or 334-826-2149
info@awis.com
http://www.awis.com

SkyBit, Inc.
369 Rolling Ridge Drive
Bellefont, PA 16823
800-454-2266
info@skybit.com
http://www.skybit.com

Weather Instruments (thermometers, sling psychrometers, frost alarms, digital thermometers, portable weather stations)

B.B. Hobbs
PO Box 437
Darlington, SC 29540
843-395-2120
sales@bbhobbs.com
http://www.bbhobbs.com

Berry Hill Irrigation
3744 Hwy 58
Buffalo Junction, VA 24529
434-374-5555, 800-345-3747
sales@berryhilldrip.com
http://www.berryhilldrip.com

Forestry Suppliers (http://www.forestry-suppliers.com/)

Gempler's
PO Box 44993
Madison, WI
800-382-8473
http://www.gemplers.com/

Omega Engineering
PO Box 4047
Stamford, CT 06907
800-848-4286, 203-359-1660
sales@omega.com
http://www.omega.com

Spectrum Technologies, Inc.
12360 South Industrial Dr., East
Plainfield, IL 60585
800-248-8873, 813-436-4440
info@specmeters.com
http://www.specmeters.com

Wind Machine Suppliers

Orchard-Rite Ltd.
Contact: Rod Robert
PO Box 9308
Yakima WA 98909
509-457-9196
Fax: 509-457-9186
sales@orchard-rite.com

Plummer Supply (distributor for Orchard-Rite Ltd.)
Sales: Lee Deleeuw
PO Box 117
2875 Plummer Park Lane
Bradley MI 49311
800-632-7731
Fax: 269-792-6637
plummer@accn.org

W.P. Law Co. (distributor for Orchard-Rite Ltd.)
Sales: Brad Scease, Tom Plumlee
303 Riverchase Way
Lexington SC 29072
803-461-0599
Fax: 803-461-0598