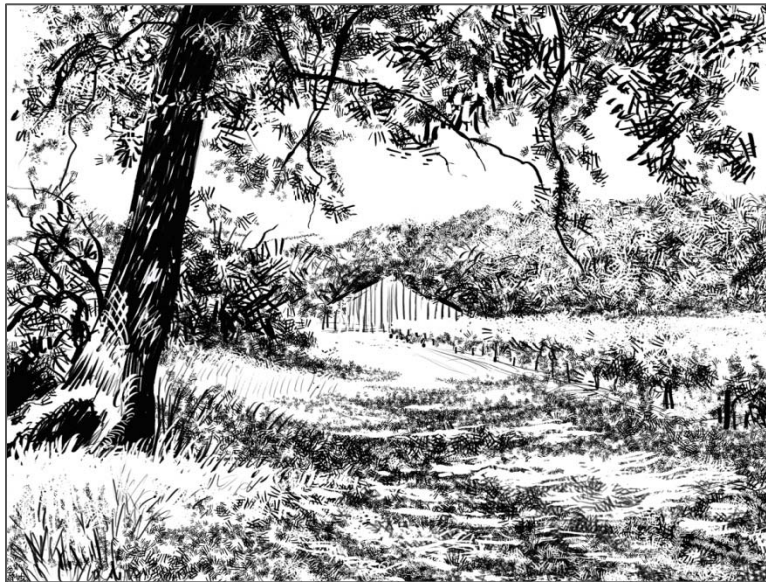


Vineyard Frost Protection

a Guide for Northern Coastal California



ACKNOWLEDGEMENTS

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VINEYARD FROST PROTECTION: A GUIDE FOR NORTHERN COASTAL CALIFORNIA

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INTRODUCTION

Spring can be a risky time in vineyards, when bud break has occurred, but the risk of frost has not yet passed. For vineyards whose climate conditions include the risk of frost during this period, there are many different methods that can be used to protect vines from frost damage. Local Resource Conservation Districts and Natural Resources Conservation Service Centers can provide assistance to growers looking to develop or modify their frost protection systems.

This set of guidelines summarizes frost protection methods specific to Northern Coastal California vineyards. It includes a summary of the different types of frost, descriptions of frost protection methods, examples of equipment manufacturers, and a review of management tools. ***Lists of manufacturers are only partial lists and do not indicate endorsement of any product or company by the Sotoyome RCD or NRCS.***

TYPES OF FROST

There are two types of freezes that occur in California vineyards: advective freezes and radiation freezes.

Advective freezes are rare in California winegrowing areas, and are most likely to happen during the winter dormant season. These freeze events occur when large arctic air masses blow across the landscape, covering entire areas. Advective freezes are generally accompanied by very strong winds. In severe advective freezes, it is unlikely that all crop damage can be prevented.

Radiation freezes are more common in California winegrowing areas, and can occur frequently during the spring season. Radiation freezes occur on calm, clear nights when the heat from the ground radiates upward. The cold air is heavier than the warm air, and subsequently settles in areas of lower elevation. As the cold air stays low and the warm air rises, the air becomes stratified and a temperature inversion forms. Multiple frost protection methods are designed to raise ground level temperatures by mixing the stratified warm and cold air layers.

Most frost protection methods will not protect against all types and severities of frost, but having an idea of the conditions that occur most frequently on the vineyard, one can better select what frost protection methods to use. Data collected from onsite weather stations can be used to determine what type of freezes are occurring, what type of frost protection system will be effective, and where to apply frost protection methods. Weather station data can also be used per frost event to determine when and for how long protection is required. By managing frost protection based on site data, rather than regional weather forecasts, resources can be used more efficiently.

Creating a frost protection plan is a good first step in determining frost protection needs. A site map outlining areas with varying conditions (e.g. elevations, temperature extremes, timing of bud break), and historical frost protection methods used, if any, serves as a great planning tool. Such maps should be based on weather data, topographic information, personal observations of past frost conditions, and vine management records. Combining the site map with knowledge of vine requirements and working guidelines of the different frost protection systems, the appropriate frost protection system(s) can be selected.

There are two categories of frost protection; active and passive. Descriptions of the different methods are provided in the following sections. Active and passive frost protection methods can be combined for increased protection.

PASSIVE FROST PROTECTION METHODS

SOIL WATER CONTENT

Increasing soil water content improves the soil's ability to absorb and hold heat. When soil holds more heat, the severity of frost events is decreased because the soil keeps low-lying air warmer for a longer time. To take advantage of the frost-buffering capabilities of soil moisture, wet the top foot of soil to field capacity 2 to 3 days before a frost event.

COVER CROP

Cover crops between rows can reflect sunlight and deplete water in the soil, causing the soil to absorb and hold less heat, increasing the severity of radiation frost events. Cover crops also create roughness and can slow the movement of air, causing cold air to build up rather than moving off the vineyard. Additionally, grass cover crops tend to cause more freezing injury because they harbor ice nucleating bacteria. Due to erosion concerns, it is not recommended that growers completely remove cover crops for frost protection. Instead, cover crops can be mowed early and kept short throughout the frost season. Cover crop management can be combined with other methods for increased protection.

BARRIER MANAGEMENT

During radiation frosts, the denser cold air will flow towards areas of lower elevation and will 'pool' upon contact with a barrier. Examples of barriers include vegetation, buildings, fences, hillsides, and berms. As the cold air accumulates in these areas, frost conditions intensify. Depending on the location of the vines relative to locations of cold air pooling, barriers can either be installed to prevent exposure to cold air or barriers can be removed to promote the flow and reduce pooling of the cold air. For these reasons, an understanding of air flow and addition or removal of barriers can be helpful in reducing the severity of frost events.

Barrier management can be combined with other frost protection methods, and is commonly applied with the use of Cold Air Drains®, which are described under the Active Frost Protection Methods section in this document.

ACTIVE FROST PROTECTION METHODS

WATER –OVERHEAD IMPACT SPRINKLERS



APPLICABILITY

Standard overhead impact sprinklers that apply water at a rate appropriate for frost protection require between 35 and 90 gallons per minute per acre (depending on air temperature, wind speed, and sprinkler rotation interval) and a minimum pressure of approximately 50 psi. These requirements limit the feasibility of this method for growers who have limited water supply. Overhead sprinklers, when used properly, can protect vines at temperatures down to 23°F.

OPERATION GUIDELINES

When water freezes, heat energy is released. Overhead impact sprinklers use this concept to keep vines at a temperature of 32°C as long as there is ice on the vines and water dripping off the ice. If there is no water dripping off of the ice, then too little water is being applied, and the sprinklers may actually be causing more harm than the frost event would alone cause.

The term wet-bulb temperature refers to the temperature that air can be cooled through evaporation alone (evaporation of water takes energy out of the air, causing the air to cool). If relative humidity is very low, water will evaporate quickly, causing the air to be cooled to a very low temperature. Therefore, low humidity means a low wet-bulb temperature. The term dew-point refers to the temperature at which air will become saturated and will stop being cooled by evaporation. This concept is important when frost protecting with sprinklers, because if there is very low humidity and sprinklers are turned on or off when the air is already very cold, evaporation of the sprinkler water can cause the air temperature to dip down even lower and cause crop

damage. Dew points below 30 degrees usually indicate that there will be a fairly rapid drop in temperature when sprinklers are turned on. Therefore, sprinklers must be turned on earlier when dew points are low.

Provided in Appendix A are tables that correlate air temperature and relative humidity to dew point and frost protection starting temperatures. Table A1 provides dew points based on measured relative humidity and air temperature. Table A2 provides appropriate frost protection starting temperatures based on the dew point found in Table A1.

It is important to test sprinkler systems prior to frost events. Testing can highlight malfunctions in the system, including problems with individual sprinkler heads. Pre-season testing also provides an opportunity to determine the time required to get the sprinklers up to operating pressure. The amount of time for establishing operating pressures should be factored into decisions regarding when to turn sprinklers on.

MANUFACTURERS

Jain Irrigation Systems, (800) 695-7171, www.jains.com

Netafim, (800) 695-4753, www.netafimusa.com

Rain Bird, (800) 724-6247, www.rainbird.com

WATER - MICROSPRAYERS

APPLICABILITY

Microsprayers provide frost protection using approximately one third the amount of water used by standard overhead impact sprinklers (based on an average of 16 gpm/acre for microsprayers and an average of 50 gpm/acre for standard overhead impact sprinklers). Microsprayers apply water only to the vines, rather than applying to the whole field including areas between vines. Pulsating microsprayers also require less water pressure than standard overhead sprinklers, because they can build up pressure in a chamber within the sprinkler and pulse the water out rather than requiring

constant pressure for constant flow. Microsprayers can be less costly than standard overhead sprinklers, as they can be installed by adding a line to an existing drip system rather than having to build in new pipes to accommodate the level of water required for standard sprinklers. Microsprayers, when used properly, can protect vines at temperatures down to 26°F.



OPERATION GUIDELINES

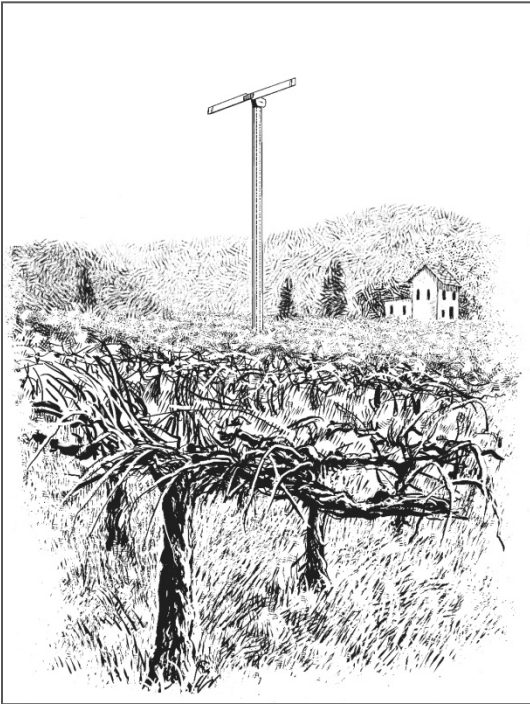
Microsprayers work based on the same principles of overhead sprinklers. Because they are made of plastic and are somewhat fragile, they require more maintenance than metal impact sprinklers. Because microsprayers use smaller tubing than conventional overhead sprinklers, the system must be designed properly so that the end sprinklers are oversized for increased water flow to minimize freezing of the supply lines. It is also often recommended that microsprayers be turned on earlier than conventional overhead sprinklers to prevent freezing of the lines. Refer to the manufacturers' specifications for proper system design and operation.

MANUFACTURERS

Netafim, (800) 695-4753, www.netafimusa.com

Pulsating Irrigation Products, (760) 347-6800, www.pippulsators.com

WIND MACHINES



APPLICABILITY

Conventional wind machines (tower wind machines) work with temperature inversions to mix warm air with lower-lying cold air. Tower wind machines are best suited for flat, evenly shaped square or rectangle vineyards. Wind machines require no water, and can be powered through a variety of means (propane, natural gas, diesel, electric, PTO). They are generally quite loud, which should be a consideration in vineyards with nearby residences. Wind machines generally provide frost protection down to approximately 28°F, though they can protect to lower temperatures if the inversion is very strong (i.e. if the warm air up high is much warmer than the low-lying cold air). The temperature increase produced depends on the strength of the inversion layer. A rule of thumb is that the temperature achieved will be roughly the average of the temperature 5 feet above the ground and the temperature 33 feet above the ground. Wind machines vary in horsepower and different models can protect from 5 to 15 acres

per machine. Different models are available in stationary and portable configurations.

OPERATION GUIDELINES

Wind machines should be turned on when the temperature 5 feet above the ground is above the critical damage temperature for the crop, and before a strong inversion layer has formed. Most wind machines can be equipped with temperature sensors and automatic start features. When placing or siting a wind machine, proximity to potential wildlife nesting habitat should be considered.

MANUFACTURERS

Amarillo Wind Machine Co., (559) 592-4256, www.amarillowind.com

H.F. Hauff Company, Inc. (Chinook Wind Machines), (509) 248-0318, www.hfhauff.com

Orchard Rite, (509) 248-8785, www.orchard-rite.com

COLD AIR DRAINS®

APPLICABILITY

Cold Air Drains® (also called towerless wind machines) are most effective in vineyards with low-lying areas where cold air drains or pools. These machines are designed to break up the stratified warm and cold air layers by use of a horizontal propeller. Underlying cold air is thrust vertically into the atmosphere and mixed with the overlying warm air. Cold Air Drains® can be powered by various options (PTO, gas, electric), they are portable, and are quieter than tower wind machines. Cold Air Drains® vary in horsepower and can protect from 2 to 16 acres per machine.

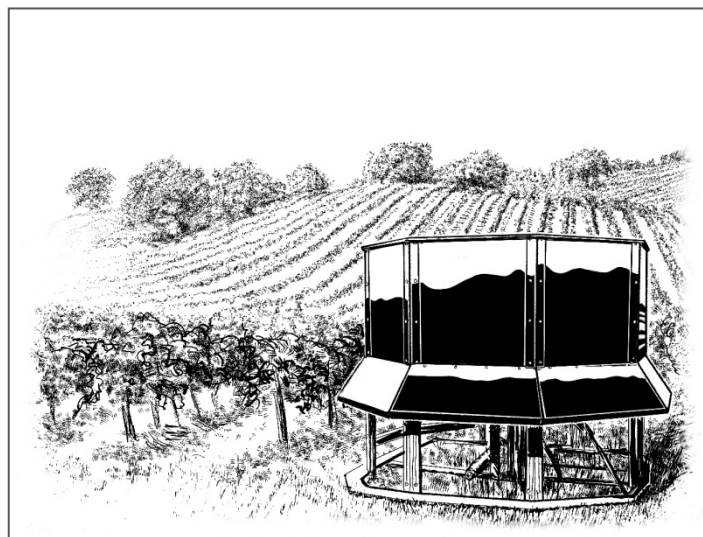
Depending on topography of site, barriers can be used to increase acreage protected by Cold Air Drains®, by directing the flow of cold air. Placement and density of Cold Air Drains® is highly site specific, and the lower temperature limit of protection varies with site design.

OPERATION GUIDELINES

Cold Air Drains® should be turned on around 36°F and left on until the sun rises and frost danger has passed, generally 30 to 60 minutes after sunrise.

MANUFACTURERS

Shur Farms Frost Protection, (877) 842-9688, www.shurfarms.com



HEATERS

APPLICABILITY

Heaters also work best with temperature inversions, because if there is no inversion hot air will rise too high and a warm air circulation pattern will not form. Heaters are not commonly used as a sole source for frost protection because they require large amounts of fuel, are labor-intensive to light, and each heater generally covers only a small portion of an acre. They can be used in combination with wind machines to provide additional degrees of protection for colder frosts. Heaters alone can provide frost protection down to approximately 27°F, while heaters combined with wind machines can provide protection down to approximately 26°F.

OPERATION

Heaters must be turned on before the critical temperature is reached. Because it takes time to light multiple heaters, lighting must start early enough to allow all heaters to be lit before the critical temperature is reached. Impacts to air quality and proper methods for transport and storage of fuel should also be considered with the use of heaters.

MANUFACTURERS

AgHeat, Inc., (541) 490-1928, www.agheat.com

WEATHER STATIONS

The most effective weather station will provide the right data, from the right places, and will deliver the data in a useful format. Many weather stations can be equipped with multiple monitoring nodes or soil probes, so measurements can be taken simultaneously at various locations in the vineyard.

THE RIGHT DATA

Parameters useful for frost protection (especially for water frost protection systems) include temperature, humidity, dew point, and wind speed. Additional features that can be useful for irrigation include evapotranspiration and soil moisture information. Data sheets for tracking weather station data, in conjunction with frost protection and irrigation, have been included as Attachment B, Attachment C, and Attachment D.

THE RIGHT PLACES

When considering where to monitor weather on the vineyard, think about each block that is operated independently; meaning each block where water can be turned on separately from other areas, or each block that is served by an individual wind machine or Cold Air Drain[®]. If there are differences in climate between these areas, then individual monitoring nodes or sensors on a weather station can provide information that will allow you to turn on frost protection at different times in each block, which can result in energy and water savings.

Temperature sensors can also be placed strategically in order to get an idea of when a temperature inversion is forming. This can be achieved by placing sensors on a vertical pole, one at approximately 5 feet above ground, and one at approximately 30 feet above ground. Information regarding when an inversion is forming and the strength of that inversion can be useful in managing wind machines and Cold Air Drains[®], the effectiveness of which depends on the presence of a temperature inversion.

INFORMATION DELIVERED IN A USEFUL WAY

This is largely a personal preference. Some weather stations deliver information wirelessly to a hand-held device, or to a computer. Data can be posted online for the grower's retrieval, or can be kept local on the grower's computer.

Most weather stations also have software available for long-term tracking of weather data. Maintaining a good record of on-site weather data will, over time, help in refining operation of the frost protection system. Some weather equipment systems can be programmed to automatically call a phone number when a critical temperature is reached. Other systems use flashing lights that change color and flashing pattern depending on the temperature. Some weather equipment systems can be equipped to automatically turn on individual blocks of a frost/irrigation system when at a critical temperature. When selecting a system, note that many systems charge a monthly or annual fee for data reporting.

MANUFACTURERS

AdCon, (530) 753-1358, www.adcon.at

Davis Weather Stations, (800) 678-3669, www.davisnet.com

Hobo, (800) 564-4377, www.onsetcomp.com

Crossbow, (800) 926-9832, www.xbow.com

Ranch Systems, (415) 884-2770, www.ranchsystems.com

Sensaphone, (610) 558-2700, www.sensaphone.com

Spectrum Technologies, (800) 248-8873, www.specmeters.com

FLOW METERS

If water is being used as part of a frost protection system, flow metering is another important management tool. Propeller or magnetic flow meters should be installed in locations where they can be used to document how much water was applied to a particular area for frost protection. If blocks are being differentially treated for frost protection due to differences in microclimate, timing of bud break, or some other reason, multiple flow meters can be installed to gather more precise and useful data about how much water is being applied to each block. Metering flow can also help in identifying problems within systems, as when the metered amount of water applied is inconsistent with the amount expected based on duration of system operation.

MANUFACTURERS

Mace Water Monitoring Solutions, (888) 440-4215, www.macemeters.com

McCrometer, (951) 652-6811, www.mccrometer.com

Senninger Irrigation, Inc., (407) 877-5655, www.senninger.com

Rain Bird, (800) 724-6247, www.rainbird.com

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ATTACHMENT A: DETERMINING DEW POINT AND WHEN TO TURN ON SPRINKLERS

Relative Humidity (percent)	Temperature (°F)					
	32	36	40	44	48	52
100	32	36	40	44	48	52
90	29	33	37	41	45	49
80	27	30	34	38	42	46
70	23	27	31	35	39	43
60	20	23	27	31	35	39
50	16	19	23	27	30	34
40	10	14	18	21	25	28
30	4	8	11	15	18	22
20	-4	-1	2	6	9	12
10	-18	-15	-12	-9	-6	-3

Table 1: Select the relative humidity from the left column and the temperature from the top row in order to find the dew point in the center of the table. Adapted from the UC Davis Biometry Program's Frost Protection Quick Answers.

Temperature to turn on sprinklers	Dew Point Temperature (°F)																		
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	
40.7																			
40.3																			
39.9																			
39.5																			
39.1																			
38.7																			
38.2																			
37.8																			
37.3																			
36.8																			
36.3																			
35.7																			
35.2																			
34.6																			
34																			
33.3																			
32.7																			
32																			

Table 2: Select the current dew point temperature from the top row in order to find the air temperature in the middle of the table at which sprinklers should be turned on and off in order to avoid a temperature dip below 32°F. Adapted from the UC Davis Biometry Program's Frost Protection Quick Answers.

Example: If the air temperature is 40°F, and the relative humidity is 50%, the dew point is 23°F (from Table 1). At a dew point of 23°F, sprinklers should be turned on at 37.3°F (from Table 2).

ATTACHMENT B: FROST PROTECTION TRACKING SHEET – OVERHEAD IMPACT SPRINKLERS & MICROSPRAYERS

Block: _____ Sensor Location: _____ Acreage: _____
 Sprinkler Type: _____ Sprinkler Rate/Acre: _____ Pumping Rate: _____

Date	Time	Temperature (°F)	Relative Humidity (%)	Dew Point (°F) ¹	Wind Speed (mph)	Total Hours	Total Water Used (Gal, AF)	Notes (crop damage, presence of liquid phase throughout ² , etc.)
Start								
Stop								
Start								
Stop								
Start								
Stop								
Start								
Stop								
Start								
Stop								
Start								
Stop								
Start								
Stop								
Start								
Stop								
Start								
Stop								

¹ When choosing a weather station, note that some weather stations are equipped to calculate dew point.

² Refers to the presence of liquid water on the vines throughout frost event. If water from sprinklers is completely frozen, with no liquid water present of the surface of the ice, then the crop is not being protected.

ATTACHMENT C: FROST PROTECTION TRACKING SHEET – TOWER AND TOWERLESS WIND MACHINES

Block:		Sensor Location:			Acreage:		
Date	Time	Temperature at 5' (°F)	Temperature at 30' (°F)	Total Hours	Fuel or Energy Used	Notes (crop damage, etc.)	
Start							
Stop							
Start							
Stop							
Start							
Stop							
Start							
Stop							
Start							
Stop							
Start							
Stop							
Start							
Stop							
Start							
Stop							

ATTACHMENT D: IRRIGATION TRACKING SHEET

Block: _____ Sensor Location: _____ Acreage: _____

Emitter Nominal Flow Rate: _____ Vine Spacing: _____ Number of Emitters per Vine: _____

Before/ After Irrigation Event	Date	Soil Water Observations Equipment Used & Units:			Ambient Air			Plant Properties			Water Applied		
		12-inch or other () depth Target:	24-inch or other () depth Target:	36-inch or other () depth Target:	Temp (°F)	Wind Speed (mph)	Relative Humidity (%)	Leaf Water Potential ⁴ (bars)	Stomatal Conductance ⁵ (mmol/m ² /s)	Evapo- transpiration ⁶ (Eto x Kc)	Irrigation System Runtime (hours)	Irrigation Water Applied ⁷ (gallons)	Irrigation Water Applied ⁸ (inches)
Before													
After													
Before													
After													
Before													
After													
Before													
After													

³ See soil probe manufacturer's recommendation for target

⁴ Leaf water potential can be measured using a pressure chamber

⁵ Stomatal Conductance can be measured using a leaf porometer

⁶ ET₀ can be obtained from www.cimis.water.ca.gov; K_c (crop coefficient) for winegrapes = (Average Width of Shaded Area Between 2 Vines)/(Row Width) x 0.017

⁷ Irrigation water applied can be obtained using a flow meter or by multiplying # vines per acre x # emitters per vine x nominal flow rate of emitters x time system was run. Comparing flow meter results to the multiplication method can provide information on whether the irrigation system is functioning as expected.

⁸ Inches of water applied = [gallons of water applied per vine (# emitters per vine x flow rate of emitters in gph x time in hours) x 231 cubic inches per gallon]/[area of ground per vine (row spacing in inches x vine spacing in inches)]

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Where water is used for frost protection, it may be subject to regulation by the State Water Resources Control Board, the Department of Fish and Game, and/or the National Marine Fisheries Service. Additional regulations may also apply with regard to placement of wind machines within migratory bird nesting areas. Local air quality regulations should also be consulted for fuel-burning frost protection systems.