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FROST PROTECTION FOR NORTH COAST VINEYARDS

Frost protection during the spring months after vine growth begins is an important consideration for vineyardists in California's north coastal grape-growing districts. Not all vineyards in this area, however, are subject to great enough frost hazards to warrant the use of frost protection systems.

The purpose of this publication is to describe methods and principles of frost protection and to compare installation and operation costs of the two principal frost protection methods used in Napa, Mendocino, and Sonoma Counties. These are the overhead sprinkler systems and the wind machine-heater combinations.

A frost protection system should be used only if it is economically sound. Economic considerations should include a long-term evaluation of probable crop losses from spring frosts compared to costs of providing and operating frost protection equipment.

DO YOU NEED FROST PROTECTION

Some measure of expected frost frequency and severity is helpful when deciding whether to buy a frost protection system. Every vineyard has a slightly different history of frost occurrence, and past records are the best information as to whether your area should be protected. Low-lying areas near river bottoms, or areas where brush, dense growth, or highway fills block natural air drainage are colder than vineyards along the hillsides.

The National Weather Service maintains key temperature stations during the frost season and has summarized the data from some of these stations in the north coast area. The Napa key station temperature summary is included as an example and guide.

Napa Key Station Low Temperatures

Observed During Fruit Frost Period, 1937 to 1974*

Lowest observed temperature: 25°F

Most consecutive nights at or less than:	
32°F	10 nights
30°F	6 nights
28°F	2 nights

Longest one night duration at or less than:	
32°F	9 hours
30°F	7½ hours
28°F	4¾ hours

Number of nights at or below:

	Yearly Average	Range
32°F	9	1–20 nights
30°F	4	0–16 nights
28°F	1	0–7 nights
26°F	(one night in 38 years)	

Number of hours at or below:

	Yearly Average	Range
32°F	27	<1–78 hours
30°F	12	0–40 hours
28°F	3	0–10 hours
26°F	(2 hours in 1944 only)	

*Compiled by Wesley L. Tuft, Agricultural Meteorologist, National Weather Service.

PRINCIPLES OF FROST PROTECTION METHODS

Sprinkler-Applied Water--Continuous Use

Protection by continuous sprinkler-applied water is based on the heat released when water freezes to ice. This method depends on the fact that a mixture of water and ice stays at the freezing point (32° F) until all water has changed to ice, or vice versa. By constantly rewetting the surfaces of the grapevine's leaves, shoots, and clusters, it is possible to maintain a film of water on the ice coating formed on the grapevine parts. This ice and water mixture maintains a protective temperature of 32° F on the tender vine surfaces.

It is essential to provide enough precipitation to keep water available for freezing on wet crop surfaces. If water is not available to constantly maintain the ice and water mixture, crop temperatures may drop to the damage point. On the other hand, excessive precipitation rates cause heavy ice buildup around vine parts and may waterlog the soil.

Wind Machines and Heaters

During the day the sun warms the earth's surface--soil, vines, etc.--which in turn warms the air in contact with it. A layer of warm air builds up over the vineyard as the air at ground level warms and rises.

At night the process reverses. The earth's surface loses heat through outward radiation to the clear, cold sky. The air in contact with the earth's surface is cooled and, since cold air is heavier than warm air, it tends to remain at ground level or flow to low areas. This nighttime condition is called inversion.

Frosts that develop under these conditions are called radiation frosts. They are characterized by cold air at the ground surface that builds up to varying heights, with warmer air above. Both wind machines and heaters work better when the warm air or ceiling is near the ground, a condition called strong inversion.

Wind machines depend on having warm air above the vineyard. They derive their effectiveness from mixing the warmer air with the cold air in the vineyard. The difference between the air temperature at 5 feet and 40 or 50 feet above the ground is a common way to measure or describe an inversion. By rule of thumb, one-fourth of the temperature inversion can be converted to a temperature rise by using a wind machine at 10 hp per acre.

Orchard heaters provide heat by direct radiation and by convection. Hot-stack heaters, like the return-stack type, give out 25 to 30 percent radiant heat. Radiant heat travels on a line of sight from the heater to the vine or any other surface in the vineyard.

Wind machines and heaters working together provide more frost protection than either used alone. The increased efficiency results from mixing the hot air and gases generated by the heaters directly with the air in the vineyard. The heater and wind-machine combination is especially effective on nights when there is a small inversion -- little warm air above the vineyard for the wind machine to pull down and no ceiling to stop the upward progress of the warm air generated by the heaters.

VINEYARD SIZE AND SHAPE

In the north coast counties, vineyard sites on valley floors are often rectangular in shape, resulting in regular vine spacing on relatively flat terrain. But vineyards may vary considerably in size and shape when they border streams or natural drainage channels or are flanked by roads. Because of the wide range in form, there is virtually no such thing as a "typical vineyard" from the standpoint of designing a frost-protection system with either sprinklers or wind machines and heaters.

We decided, therefore, to compare the costs of frost protection systems on a 40-acre square vineyard. Because the grower does much of the labor except for pruning and harvesting, 40 acres are considered an economic unit for grape production in this geographic area. In our other published studies, we use this unit size as the basis for evaluating the cost of establishing a vineyard and producing wine grapes in the north coast area. We recognize that the design data may not be typical for many vineyard situations, but the comparisons are nonetheless valid.

DESCRIPTION OF THE SYSTEMS AND THEIR OPERATION

When to Use Frost Protection--Measuring Temperature

Temperatures should be monitored in the colder areas found in low spots or where cold air flow is blocked by brush and trees. At least three or four temperature sensors should be located in each block to be protected, or one for every 10 acres of vineyard.

The standard orchard minimum thermometer accurately measures low temperatures when mounted in a shelter made with two pieces of 1- x 8-inch wood, 18 inches long, fastened in an L shape to form a top and back. Mount the shelter 5 feet high on a stake, facing north and away from heaters. Paint with white enamel so it can be seen more easily at night. Always shelter thermometers or temperature sensing devices because they will not accurately read air temperature if exposed to the sky.

Other available temperature monitoring devices include electrical thermistor equipment. This equipment is accurate and can be equipped to read from remote locations, even via telephone.

Any temperature device should be checked for accuracy before each frost season. Place thermometers in a 10 gallon bucket or insulated jug of water and melting ice that is stirred frequently. The water-ice mixture will be 32° F. Errors of each temperature measuring device can be noted or corrected.

Permanent Sprinklers

The sprinkler system described here is a permanent, underground system with risers fixed to stakes supporting the vines. (See table 2 for a description of essential parts.) The sprinkler heads are placed on these risers, which are spaced in a 32- x 48-foot rectangular pattern. This conveniently corresponds to a vine and row spacing of 8 x 12 feet with a sprinkler at every fourth vine in every fourth row. Wider spacings are not recommended because uniformity of water application is not sufficient for complete protection. In fact, a 30- x 40-foot spacing is sometimes recommended when compatible with row and vine spacing.

The system uses asbestos-cement pipe for the main and submain lines. Rigid plastic (polyvinyl chloride -- P.V.C.) lateral lines and risers distribute the water to the system's individual laterals. All the pipelines are buried about 18 inches below the soil surface so they will not interfere with normal cultural practices.

While underground sprinkler systems can be installed after the vineyard is established, there are distinct advantages to installing them at planting time. The vineyard block size can be coordinated with the design of the main, submain and lateral lines. Vine and sprinkler spacing can be coordinated. The trenching can be done with less restriction and without damaging the vines' root systems.

Our figures are based on contract rates for commercial installation including trenching, laying, and backfilling. Many growers do this work with vineyard labor under the training and advice of the designer and materials supplier. This may result in substantial savings.

- Water Application Rate

  A precipitation rate of 0.11 to 0.13 acre-inches per hour has been established as the amount needed under most frost conditions in north coast vineyards. Vineyards have been protected at this rate when temperatures dropped to as low as 25° F.

  All sprinklers are operated simultaneously, so pumping capacity of at least 50 gallons of water per minute (gpm) per acre is needed during the system's entire operating time to obtain the established precipitation rate. In addition, sprinklers must rotate in one minute or less to rewet vines frequently enough for protection. Sprinklers must also be properly spaced to uniformly cover the entire vineyard.

- Sprinkler Starting Temperatures

When sprinklers are first started a temperature drop often occurs, but lasts only until they have made several revolutions and the plants are well wetted. The temperature drop is due to evaporation of some of the water into the drier air. If sprinklers are started too late, this temperature drop can damage the crop. Fortunately, during most California spring frosts humidities are high, so little evaporation occurs and the temperature drop is small. Most growers start when temperatures drop to 33° F or 34° F.

On rare occasions, cold dry air masses do move into the state. During these times, sprinklers must be started sooner so the initial temperature drop does not go below temperatures damaging to the vine. Most frost forecasts mention the dewpoint temperature of the air. This temperature remains relatively constant during the day and is an indirect measure of humidity. The chart below can be used as a guide for starting overhead sprinklers in grapes to avoid damage from an initial temperature drop. The dewpoint temperature given at the 7:00 p.m. or later frost forecast can be used. Start sprinklers a degree or two sooner if the temperature is dropping fast and it takes more than 5 or 10 minutes before sprinklers are running at full pressure. This table only applies when a frost is predicted.

Dewpoint Temperature	Starting Temperature for Sprinklers
24°F & above	34°F
20° – 23°F	35°F
15° – 19° F	36°F

- Stopping Sprinklers

After sunrise only, if there is no wind, it is safe to end sprinkling when the air temperature outside the treated area has climbed to 32° F. If it is windy, wait until the air temperature has risen to 34° F. However, it is not necessary to wait until all ice has melted.

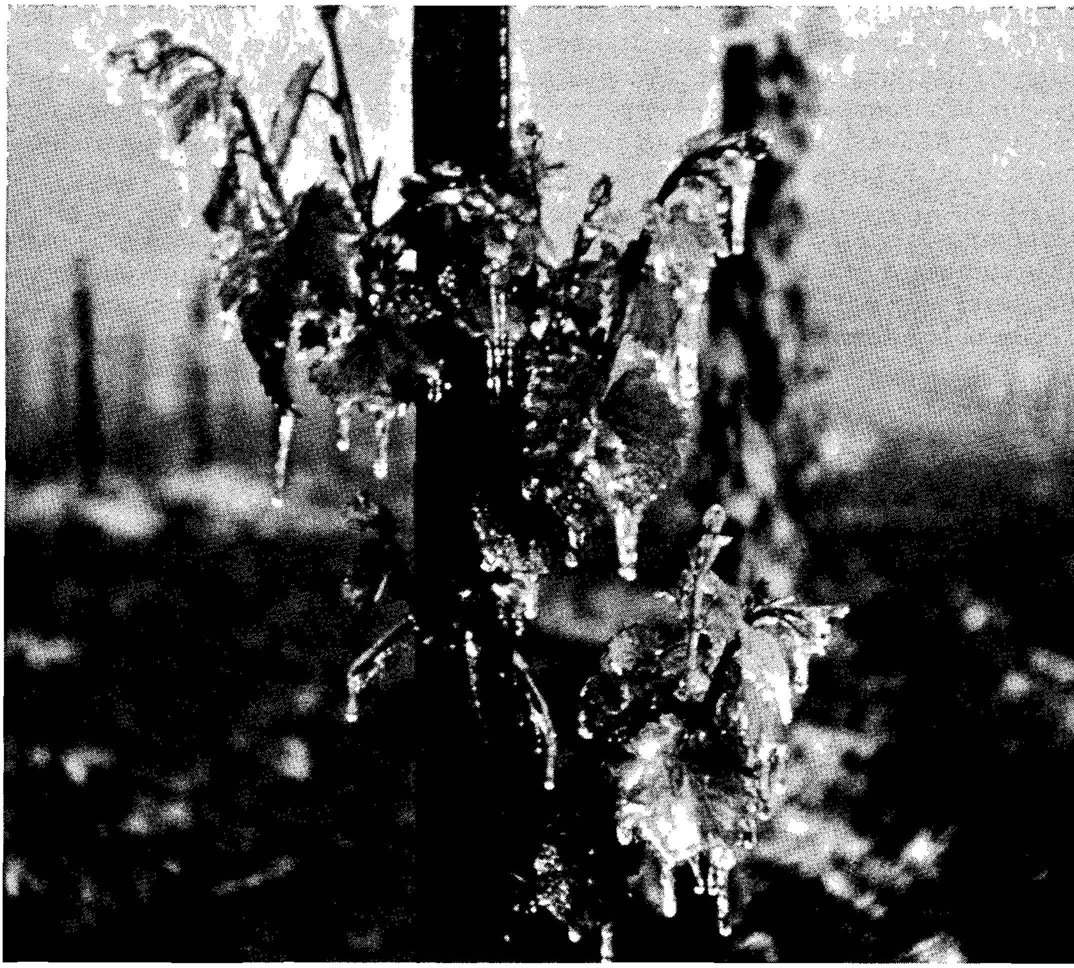

Figure 1. Shoot breakage has not been experienced with sprinkling during spring frosts. This photo, taken just after sunrise, shows the extent of ice buildup on the shoots after sprinkling during the severe frost conditions in April 1964.

- Reservoirs

Sources of water for irrigation also can provide water for frost protection. Most vineyards in the north coast counties are not irrigated, although an increasing number are being brought under irrigation as water resources are developed. Adequate supplies of underground water for irrigation exist only in certain geographic areas. In other areas, water is available from rivers (for those with water rights), from water supplies impounded by dams, or from nearby creeks; but availability is usually restricted to the early part of the growing season. When diverted to reservoir storage, water from these sources can provide frost protection in the spring, even though the supply may not be adequate for seasonal irrigation. Because of the diversity of sources and the wide cost range in obtaining this water and conveying it to the vineyard reservoir site, this study does not consider the investment in facilities needed to deliver water to the reservoir.

Reservoir capacity. A water requirement of at least 2,000 gpm (50 gpm per acre x 40 acres) is needed to simultaneously protect 40 acres of vines. With a smaller continuous water supply, 400 gpm for example, the construction of a reservoir is a necessity. The reservoir and well pump should have capacity to protect for at least 10 hours--all night during a severe frost or for a succession of frost nights.

The reservoir capacity needed depends on the amount of well (or river) water available during a frost. For example, a well pump with a 400 gpm capacity needs a reservoir with a 2.9 acre-foot* capacity, while a 1,000 gpm well pump needs only a 1.8 acre-foot reservoir to have sufficient water for a 10-hour frost.

A grower can expect to operate a sprinkler system an estimated 42 hours during the frost period. This is based on field experience and on studies of the numbers of cold nights (32° F or lower) reported by the National Weather Service in its annual reports for Napa, Sonoma, and Mendocino County stations. The hour usage may be greater for sprinklers than for wind machines.

Therefore, if water is obtained from an impoundment with no well or river water available during the frost period, the reservoir must hold enough water for the estimated 42 hours of frost. Many growers prefer an impoundment that holds enough water for 60 hours. An impoundment reservoir that holds 22 acre-feet has enough capacity to protect 40 acres for 60 hours.

Reservoir area. About 1/2 to 2/3 acre of land space is required for a 12-foot-deep reservoir holding 3 acre-feet. Generally, 8 to 12 feet is an optimum depth for this size reservoir, since the sloped sides would require more land space if it were deeper. A 20-acre-foot reservoir, 16 to 20 feet deep, with 2-to-1 side slopes requires a little over 2 acres of space. An 8-foot-deep, 20-acre-foot reservoir requires over 3 acres of land.

Wind Machines and Heaters

The orchard heaters used in this study are the return-stack type. They radiate heat to vines efficiently and, when properly operated, meet the requirements of most smog control districts. Twenty to 25 heaters per acre, considered a reasonable number for the north coast grape-growing area, give up to 4° F to 5° F protection when used with a wind machine. The heaters are evenly distributed through the vineyard except along the edges, where a greater concentration is needed. Heaters should not be placed within 100 feet of the wind machine. A wall of strongly rising hot air from heaters too close to the machine will divert its air blast upward out of the vineyard.

The costs of tower-mounted and ground-level wind machines have been compared, based on delivery of between 8 and 10 fan-hp per acre. Two dual, tower-mounted wind machines give more economical coverage than four single-engine tower mounts on a 40-acre square vineyard. The dual machine has two engines and fans on a single tower.

*An acre-foot of water (the amount of water covering an acre one foot deep) equals 325,851 gallons.

Four movable or ground-level wind machines are compared with two dual tower-mounted machines. Each movable machine is assumed to be on a platform or mount just high enough for the air blast to clear the tops of the vines. Each one of the movable machines in the example covers 10 acres.

Wind machines are operated an estimated 30 hours per season during frost years. Heater use in conjunction with wind machines is figured on the basis of all heaters burning the equivalent of 15 hours, although only a portion may be lighted at any one time. As temperatures fall on a cold night, wind machines are turned on and the temperatures are carefully watched at thermometer stations. If temperatures remain relatively stable at 32° F or above, heaters are not lighted; if temperatures decline below 32° F, heat is added to the protection system.

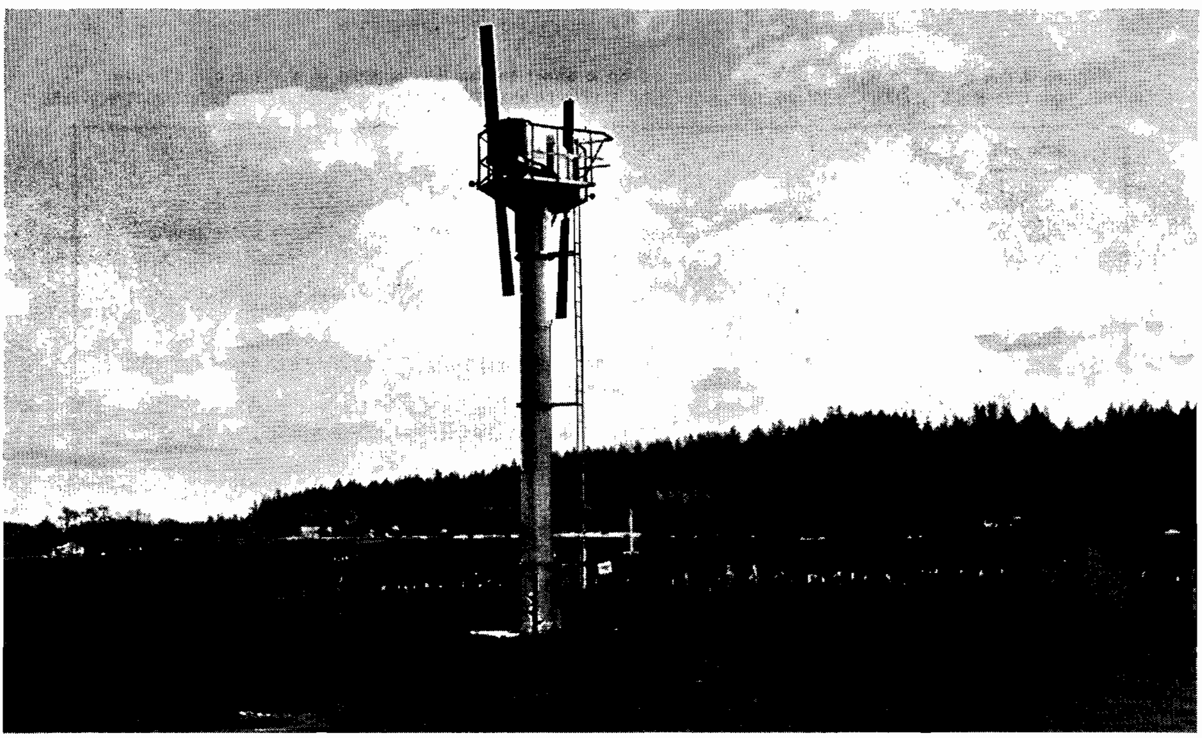

Figure 2. A permanently installed, tower-mounted, dual-engine wind machine is shown in a vineyard. Note the second machine in the center background.

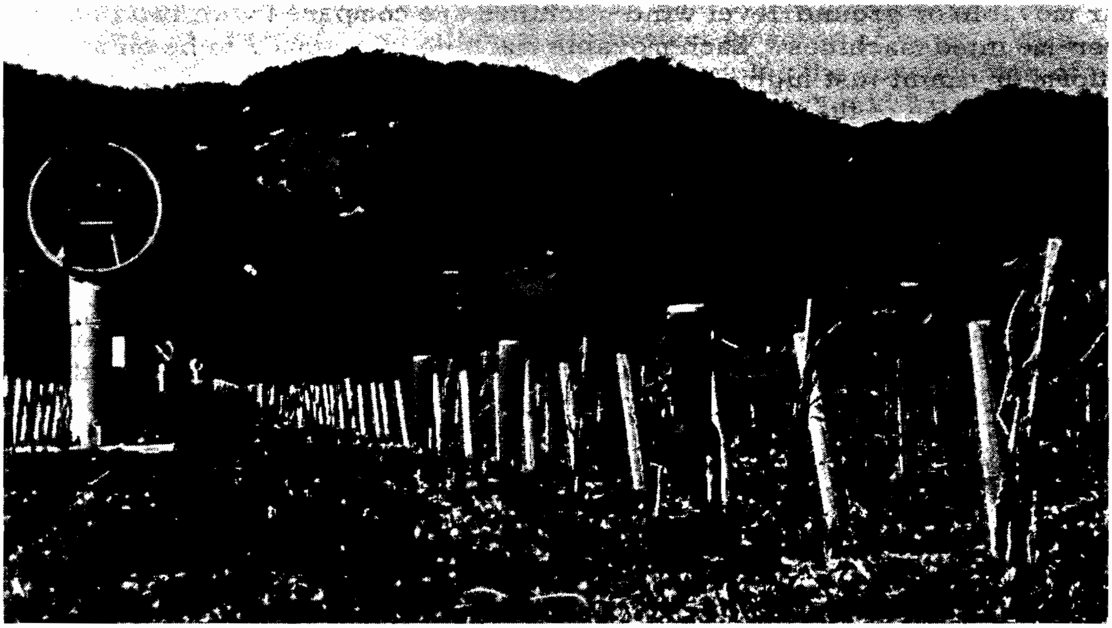

Figure 3. A movable wind machine, mounted on a short tower, is located in a vineyard avenue.

- Smoke Nuisance

Every grower who uses heaters should do more than simply abide by the regulations of the Air Pollution Control District. In the interest of maintaining good relations with urban neighbors, growers should do everything possible to hold smoke nuisance at the absolute minimum.

Smokiness depends on:

burning rates--excessive burning rates produce more smoke.

soot accumulation--frequency of cleaning depends on the type of heater and rate of burning.

air leakage--leakage increases soot accumulations and smoke and makes it hard to accurately control burning rates.

wind--stack-type heaters are more smoky in a breeze than during calm weather.

Regulate return-stack and other hot-stack types of heaters one minute after lighting. Burning rates should be controlled by opening the draft regulator a maximum of 1 to 1½ holes. Check heaters regularly during the night and adjust to control burning rates or to conserve fuel if the temperatures can be maintained.

If more heat is needed in the early morning, it is better to light more heaters than to open regulators too far. If the oil is low in the bowls and there is some residue, opening the regulators usually produces excess smoke.

Return-stack heaters need little cleaning if properly operated -- probably not more than one cleaning every two or three seasons of use. Jumbo Cone® heaters, on the other hand, should be cleaned every 20 hours of normal burning, that is, every season of use. Lazy-flame heaters need to be cleaned after 8 to 10 hours of normal burning to stay within the legal limits of smoke output.

COSTS OF FROST PROTECTION

Costs per season of frost protection using the various methods are as follows:

	Per acre
Tower mounted wind machines and heaters	$ 230
Movable wind machines and heaters	220
Permanent sprinkler — electric motor	200
Permanent sprinkler — diesel motor	190

The total costs of operation are included--all cash costs; labor, whether hired or family; and depreciation and interest on the investment.

The entire cost of the sprinkler system is charged to frost protection even though the system also may be used for irrigation and summer cooling. The labor rate of $3.50 per hour includes social security, workmens compensation, and other fringe benefits.

All investments are based on costs of new equipment; individual growers may reduce some costs by purchasing used equipment.

Tables 1 and 2 detail the seasonal costs for permanent sprinklers and for a combination of wind machines and heaters.

TABLE 1. Cost of Vineyard Frost Protection Using a Combination of Tower Mounted Wind Machines and Heaters--Based on 40 Acre Vineyard

Investment per acre	Cost	Annual Overhead Depreciation	Annual Overhead Interest 8%
Wind machines (2 per 40 acres)--15 year life	$650	$43.00	$26.00
Heaters 20 @ $15--10 year life	300	30.00	12.00
Oil storage tank--10 year life	15	1.50	.60
Tank trailer--10 year life	10	1.00	.40
Thermometers, alarms, etc.--10 yr life	10	1.00	.40
Total	$985	$76.50	$39.40

Operating cost per acre - based on 30 hours per season	Per Acre
Gasoline for wind machine--30 hrs. @ 1 gal/hr. @ $0.37	$ 11.10
Fuel for heaters--15 hrs., 160 gal. @ $0.33	52.80
Labor for moving pots and filling--3 hrs. @ $3.50	10.50
Labor to light heaters and tend wind machines--3 hrs. @ $3.50	10.50
Truck--2 hrs. @ $3.50, pickup 1/2 hr. @ $3.00	8.50
Repairs and maintenance	10.00
Taxes	9.80
Miscellaneous	.90
Total cash cost	$114.10
Depreciation	76.50
Interest	39.40
	$230.00

The investment for movable wind machines would be $560 per acre, resulting in a saving of $10.20 per acre for depreciation, interest, and taxes compared to the tower-mounted machines.

TABLE 2. Cost of Vineyard Frost Protection With a Permanent Sprinkler System --Based on 40-Acre Vineyard

Investment per acre	Cost	Annual Overhead Depreciation	Annual Overhead Interest 8%
Reservoir - 30 year life	$ 400	$13.35	$16.00
Pipeline			
Mainline	170		
Laterals	430		
Installation	300		
Total pipeline - 20 year life	900	45.00	36.00
Pump installation - 50 gpm			
Pump with diesel engine	250		
Filters installed	60		
Intake pipe and valves	25		
Discharge manifold	25		
Alarm system	10		
Total pump - 15 year life	370	24.65	14.80
Total investment per acre	$1,670	$83.00	$66.80

Operating cost per acre - based on 42 hours per season	Per Acre
Diesel fuel 9.0 gal @ $0.33	$ 3.00
Water .5 acre feet @ $5	2.50
Repairs and maintenance	15.00
Taxes	15.70
Labor 1 hour	3.50
Miscellaneous	.50
Total cash	$ 40.20
Depreciation	83.00
Interest	66.80
	$190.00

Using a pump with an electric motor would increase the annual cost by $8-10 per acre due primarily to the utility service demand charge.

If the sprinkler system is also used for irrigation, part of the overhead cost might be charged to that operation. Charging half of the depreciation and interest to irrigation reduces the cost of frost protection to $115 per acre.

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