Frost Protection for North Coast Vineyards

The authors are
Amand N. Kasimatis, Extension Viticulturist, Davis;
Bruce E. Bearden, Farm Advisor, Mendocino County;
Robert L. Sisson, County Director and Farm Advisor, Sonoma County;
and Keith Bowers, Farm Advisor, Napa County.

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

This publication describes methods and principles of frost protection and compares installation and operation costs of the two principal frost protection methods used in Napa, Mendocino, and Sonoma counties: overhead sprinkler systems and wind machine-heater combinations.

A frost protection system should be used only if it is economically sound; that is, if the probable crop losses due to spring frosts over the long term outweigh the costs of providing and operating frost protection equipment.

Cooperative Extension
Division of Agricultural Sciences
UNIVERSITY OF CALIFORNIA

Leaflet 2743

Do you need frost protection?

To make the right decision about whether to buy a frost protection system, you must have some measure of expected frost frequency and severity. Every vineyard has a slightly different history of frost occurrence, and past records provide 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 on hillsides or sloping ground.

The National Weather Service maintains key temperature stations during the frost season and has summarized the data from some of the stations in the north coast area (see table 1). The summary of the temperatures recorded at the Napa key station is included as an example and guide.

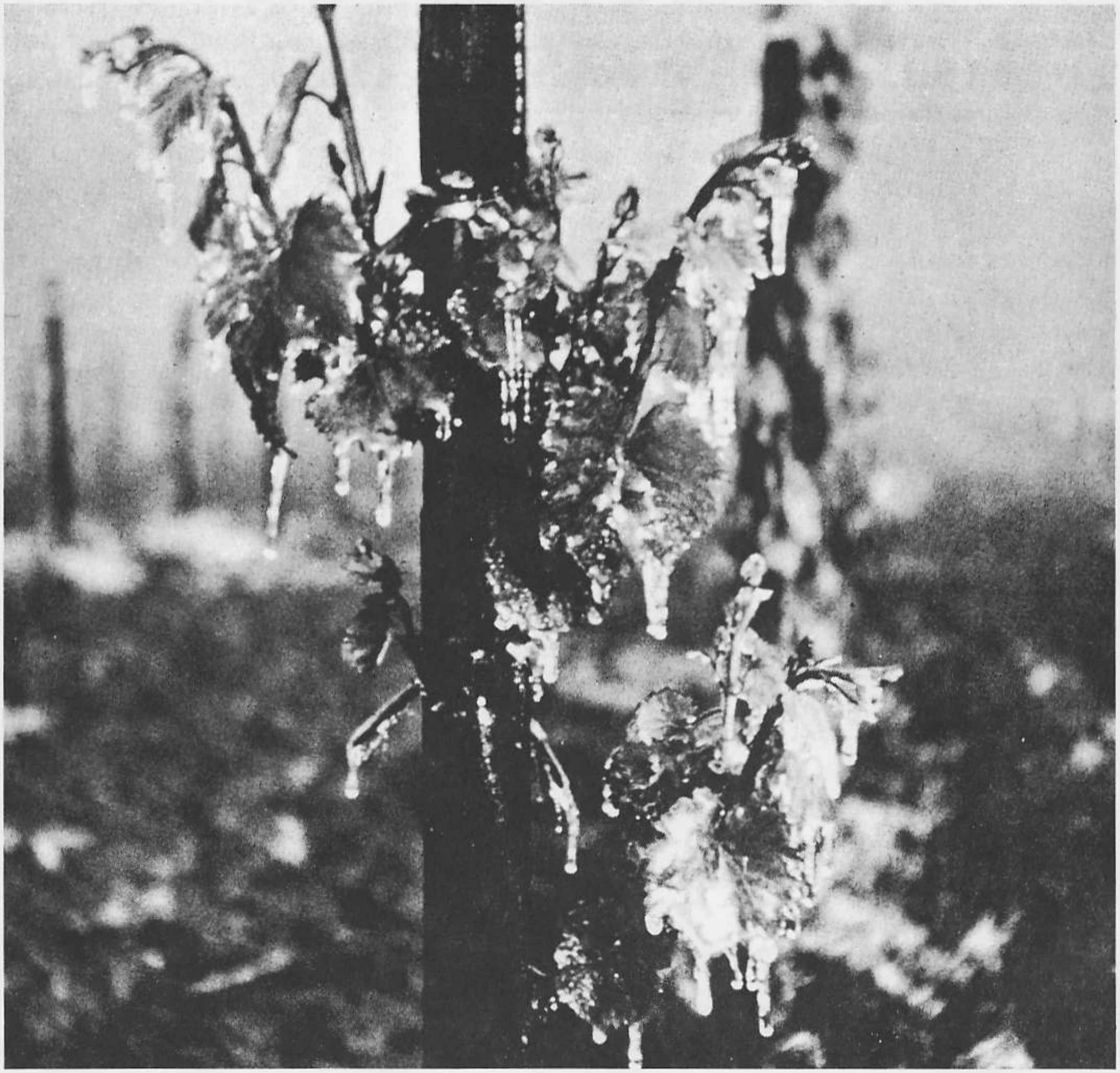

Fig. 1. Shoot breakage has not been experienced with sprinkling during spring frosts. This photo, taken just after sunrise, shows the extent of ice buildup on the shoots after sprinkling during the severe frost conditions in April 1964.

TABLE 1. Low Temperatures Observed During Fruit Frost Period (Mid-March to Mid-May)—1937 to 1981—at the Napa Key Station

	32°	30°	28°	26°F
Most consecutive nights at or below	10	6	2	1*
Yearly average number of nights at or below	7	3	1	.02*
Range in number of nights per year at or below	1–20	0–16	0–7	0–1*
Yearly average number of hours at or below	27	12	3	—†
Range of number of hours per year at or below	<1–78	0–40	0–10	0–2†
Longest single duration—in hours—at or below	9	7½	4¾	2

SOURCE: Compiled by Harold L. Coffer, Agricultural Meteorologist, National Weather Service.

*One night in 44 years at or below 26° F (lowest observed temperature: 25° F).

†Two hours in 1944 only.

Principles of frost protection methods

Sprinkler-applied water—continuous use. Continually applied sprinkler water protects grapevines by releasing heat as the water freezes to ice. A mixture of water and ice stays at the freezing point (32° F) until all the 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 (see fig. 1). The ice and water mixture maintains a protective temperature of 32° F on 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, temperatures may drop low enough to cause damage. 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, because cold air is heavier than warm air, it tends to remain at ground level or flow to lower areas. This nighttime condition is called *inversion*.

Frosts that develop under such 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 a temperature inversion. By rule of thumb, a temperature rise of one-fourth the temperature inversion can be achieved 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 rise of the warm air generated by the heaters.

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. A simple shelter can be made with two pieces of 1- × 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 it 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. Such equipment is accurate and can be equipped to be read from remote locations, even by 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.

Frost-protection systems and their operation

In the north coast counties, vineyard sites on valley floors are often rectangular, 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 no "typical vineyard" on which to base the design of 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, and to make general evaluations and descriptions of systems on 40-acre plots. Because the grower does much of the labor, except for pruning and harvesting, 40 acres are considered an economic unit for grape production in the north coast area. We recognize that the design data may not be typical for many vineyard situations, but the comparisons of data are applicable to most other types of vineyards.

Permanent sprinklers. The sprinkler system described here is a permanent, underground system with risers fixed to stakes supporting the vines. (See table 3 for a description of essential parts.) The sprinkler heads are placed on the risers, which are spaced in a 32- × 48-foot rectangular pattern. The pattern conveniently corresponds to a vine and row spacing of 8 × 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- × 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 laterals. All the pipelines are buried 18 inches or more below the soil surface so they will not interfere with normal cultural practices.

Although 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; and 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 the work with vineyard labor under the training and advice of the designer and materials supplier, which 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 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. If sprinklers are started too late, the 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 such times, sprinklers must be started sooner so the initial temperature drop does not reach temperatures damaging to the vines. Most frost forecasts mention the dewpoint temperature of the air. Dewpoint 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 to 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 and above	34 ° F
20 °–23 ° F	35 ° F
15 °–19 ° F	36 ° F

Stopping sprinklers. Only after sunrise, if there is no wind and the air temperature outside the treated area has climbed to 32 ° F, is it safe to end sprinkling. If it is windy, wait until the air temperature has risen to 34 ° F. It is not necessary to wait until all ice has melted.

Reservoirs. Sources of water for irrigation also can provide water for frost protection. However, many 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 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 those sources can provide frost protection in the spring, even though the supply may not be adequate for seasonal irrigation. Whatever the source of water, it would be prudent to determine by laboratory analysis whether the chemical quality of the water is satisfactory for vineyard use. Because of the diversity of sources and the wide cost range in obtaining 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 × 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 the 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 period.

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

A grower can expect to operate a sprinkler system an estimated 42 hours during the frost period. That estimate 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 duration of usage may be somewhat 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 ½ to ⅔ acre of land is required for a 12-foot-deep reservoir holding 3 acre-feet. Generally, 8 to 12 feet is an optimum depth for this size of 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° to 5° F protection when used with

Fig. 2. This movable wind machine is situated in a vineyard avenue. Note two similar machines in the background, and the placement of return-stack heaters.

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 (see fig. 3).

Wind machines are operated an estimated 30 hours per season during average 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 stable at 32 °F or above, heaters are not lighted; if temperatures decline below 32 °F, heat is added to the protection system.

Smoke nuisance. Every grower who uses heaters should do more than simply abide by the regulations of the Air Pollution Control District. To maintain 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 difficult to accurately control burning rates.
- wind—stack-type heaters are more smoky in a breeze than during calm weather.

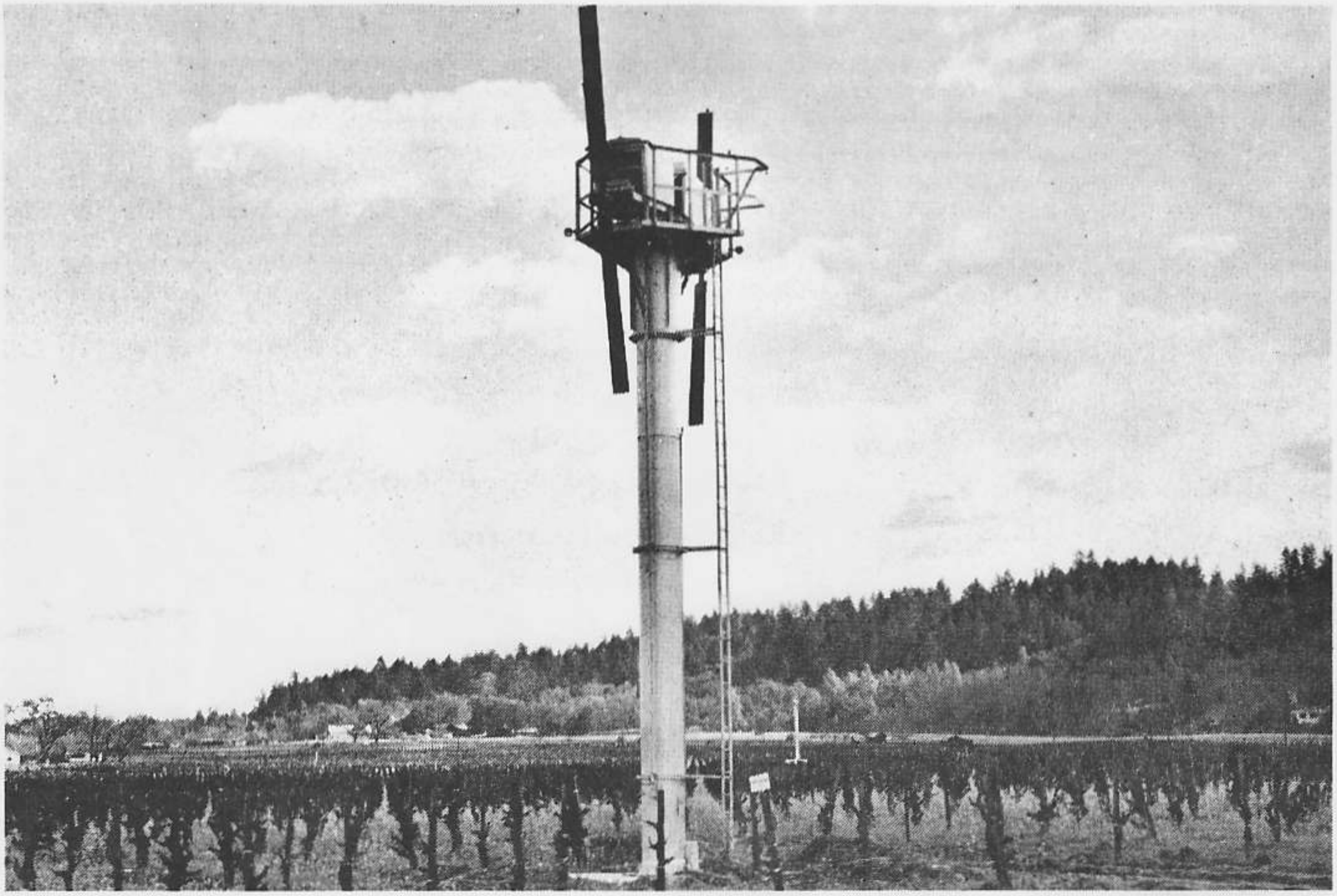

Fig. 3. Permanently installed, tower-mounted, dual-engine wind machine in a vineyard. Note second machine in the center background.

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 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

The total costs of frost-protection operation are included in tables 2 and 3: all cash costs, labor, whether hired or family, and depreciation and interest on the investment.

In table 3, 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 $7.35 and $8.60 for night work per hour includes social security, workmen's 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 2 and 3 detail the seasonal costs for permanent sprinklers and for a combination of wind machines and heaters.

TABLE 2. Per Acre Investment and Operating Costs for Vineyard Frost Protection Using a Combination of Tower-Mounted Wind Machines and Heaters—Based on 40-Acre Vineyard

		Annual overhead	
Investment cost per acre		**Depreciation**	**13% interest**
Dual-wind machines (2 per 40 acres) —15-yr life	$1,264	$ 84	$ 82
Return-stack heaters, 20 @ $25 —10-yr life	450	22	29
Oil storage tank—10-yr life	20	2	1
Tank trailer—10-yr life	21	2	1
Thermometers, alarms, etc.—10 yr life	15	2	1
Total	**$1,770**	**$112**	**$114**

Operating cost per acre, based on 30 hrs per season	**Per acre**
Gasoline for wind machine —30 hrs @ 1 gal/hr @ $1.20/gal	$ 36
Fuel for heaters—15 hrs, 160 gal @ $1.10/gal	176
Labor for moving heaters and filling—3 hrs @ $7.35/hr	22
Labor to light heaters and tend wind machines —3 hrs @ $8.60/hr	26
Truck—2 hrs @ $6.60, pickup ½ hr @ $7.90/hr	16
Repairs and maintenance	15
Taxes	18
Total cash cost	**$309**
Depreciation	$112
Interest	114
Total operating cost per acre	**$535**

The per-acre investment for four movable wind machines would be about the same as for two dual tower-mounted machines.

TABLE 3. Per-Acre Investment and Operating Costs for Vineyard Frost Protection with a Permanent Sprinkler System—Based on 40-Acre Vineyard

			Annual overhead	
Investment cost per acre			**Depreciation**	**13% interest**
Reservoir (15 acre feet)—30-year life		$ 375	$ 12	$ 24
Pipeline—20-year life				
Mainline	$300			
Laterals, risers, sprinkler heads	650			
Installation	460			
Subtotal		1,410	70	92
		$1,785		
Pump (50gpm/acre) with diesel engine		450		
Filters, installed		95		
Intake pipe and valves		65		
Discharge manifold		60		
Total pump—15-year life		670		
Alarm system		15	46	45
Total per acre		**$2,470**	**$128**	**$161**

Operating cost per acre, based on 42 hrs per season	**Per acre**
Diesel fuel—9.0 gal @ $1.10/gal	$ 10
Repairs and maintenance	20
Taxes (real and property)	25
Labor 1 hr	9
Miscellaneous	2
Total	**$ 66**
Depreciation	128
Interest	161
Total operating cost per acre	**$355**

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 $260 per acre.

To simplify information, trade names of products have been used. No endorsement of named products is intended, nor is criticism implied of similar products which are not mentioned.

COOPERATIVE EXTENSION
UNIVERSITY OF CALIFORNIA
Berkeley, California 94720

Issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, in cooperation with the United States Department of Agriculture, Jerome B. Siebert, Director, Cooperative Extension, University of California.

PRINTED AUGUST 1982

5m–8/82–MK/FB