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Microsprayer Frost Protection in Vineyards

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I. OVERVIEW OF VINEYARD FROST PROTECTION

Low temperature damage is a significant problem in many grape-growing regions. Cold injury to grapevines may result from the winter minimum temperature; spring temperatures below -0.6°C (31°F), which may damage developing buds; or fall temperatures below -0.6°C (31°F), which may injure maturing canes and berries. This section will focus on factors influencing the incidence and severity of spring frost damage in California vineyards.

Efforts to minimize damage from spring freeze events can be divided into passive and active methods. Passive methods involve site selection, variety selection, and cultural practices, while active methods involve modification of the vineyard climate. The effectiveness of frost protection methods is dependant on the characteristics of the freezing event.

Types of Freeze Events

The types of freezing events encountered in California vineyards are radiation and advection freezes. These types of freezing events differ greatly in their frequency of occurrence and the meteorological conditions associated with them. Widespread cooling occurs as a result of the advection (horizontal movement of an air mass over land) of cold air into a region or from loss of heat due to radiation. An advection freeze occurs when cooling by advection predominates, and a radiation freeze occurs when radiational heat loss is the predominant form of cooling.

Radiation freezes occur mostly on clear, calm nights after cold air has moved into the region. The primary mechanism is loss of heat into space during the night. The rate of heat loss by radiation into space is partially determined by the amount of moisture present in the atmosphere. If the air is dry (low dew point) heat loss will be greater than when the air is moist. During radiation freezes, layers of cold air are formed with the coldest air usually found near the radiating surface. Normally, temperature decreases as height in the atmosphere increases. Thus, this meteorological condition is known as a temperature inversion (warm air layers over cool air layers).

An advection freeze occurs when a large mass of Arctic air invades and covers the region resulting in low day and night temperatures. Conditions can be clear or cloudy with strong winds which continue into the night. Due to the wind there is considerable mixing of the lower layers of the atmosphere.

Almost all spring freeze events in California vineyards are radiation freezes. Fortunately, a wide range of frost protection methods can be employed against radiation freezes. Advection freezes are relatively rare and normally occur only during the dormant season. The December 1990 freeze is an example of an advection freeze. There is little that can be done to protect vine-

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yards from damage during a severe advection freeze. Therefore, the remainder of the article will deal with the protection methods for radiation freezes.

Passive Protection Methods

Passive protection methods are used to avoid or minimize spring freeze damage. Site selection, variety selection, and cultural practices comprise passive protection methods. These methods can provide several degrees of protection, but generally do not offer as much protection as active methods. However, 0.6-1.2°C (1-2°F) of protection can often mean the difference between having a crop and crop loss. Also, passive protection methods do not cause significant increases in establishment costs for most vineyards.

Passive protection methods can be divided into those which are done prior to vineyard establishment and those which are done after vineyard establishment. Preplanting practices are site and variety selection while postplanting frost protection efforts involve cultural practices such as soil management, row middle management and pruning.

Site and variety selection are of great importance in reducing spring frost damage in vineyards. Site characteristics which influence air temperature are slope, exposure to the sun or aspect, and elevation. Sloping ground and elevation are important because they provide good air drainage. Cold air is more dense than warm air and flows downhill in a similar manner as water. Vines growing in low areas where cold air accumulates are more likely to be damaged by frost. In addition, sites which have impediments to cold air drainage – such as raised road beds, buildings or vegetation (forests, overgrown fence rows, etc.) – should be avoided. Sides of hills facing toward the sun (SE or SW slope) will be warmer than hillsides facing away from the sun. In the spring, warm temperatures can result in early bud development. Planting on a north slope instead of a south slope may delay bud burst and reduce the possibility of frost damage.

Another site characteristic which is important in certain vineyard districts outside California is distance from large bodies of water. Large bodies of water, such as the Great Lakes, substantially moderate the climate of land areas on the leeward side of these bodies of water. The modifying effect is sometimes one of cooling the air while at other times it is one of warming the air, depending on the season and the prevailing weather conditions. In early spring warm air moving over the lakes is cooled, which can delay bud burst beyond the period of time when frost damage is most likely. Later, after bud development has begun, cold air masses moving into the area are warmed by the lakes and late spring freeze damage is avoided. The beneficial effects of large bodies of water are greatest for sites which are as close to the leeward side of the body of water as possible. As distance increases, temperature modification due to large bodies of water decreases.

Variety selection can influence the incidence and severity of spring frost damage. Differences in frost susceptibility among varieties are often related to bud phenology. In general, as bud development proceeds in the spring, the critical temperature (temperature at which buds will endure for 30 minutes or less without injury) increases or becomes warmer. Therefore, varieties which have early bud burst and development are usually more susceptible to spring frost damage than varieties with late bud burst and development. For example, bud burst of Chardonnay vines is often two weeks earlier than bud burst of Cabernet Sauvignon vines when grown in adjacent blocks. Planting Chardonnay in frost prone sites without some active method of frost protection is inviting disaster. On the other hand, Cabernet Sauvignon might be planted on this site and grown successfully.

Varietal differences in frost tolerance may also be related to factors other than bud phenology. Johnson and Howell (1981) detected small but consistent differences

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in cold resistance of buds from three varieties at the same stage of development.

After the vineyard has been established, other passive protection methods can be used to reduce the chance of frost damage. Some examples are soil management, row middle management, and pruning.

Soil and row management can influence the minimum temperature in vineyards. The minimum temperature is affected by soil texture and soil water content. In general, peat and sandy soils do not store or conduct heat as well as loam or clay soils. Also, darker colored soils may absorb more solar radiation and store more heat than lighter colored soils. Consequently, if all other factors are the same, sandy soil would pose a greater hazard of frost damage than clay or loam soil. However, soil texture effects are probably not too important during most freeze events. Other factors usually have a greater impact than soil texture.

Soil conductivity and heat storage are also affected by the soil texture and soil-water content. This is due to the unique properties of water which allow it to store considerable heat. In addition, moist soil will conduct heat better than dry soil. Frost hazard is lower for moist soil as compared to dry soil. Growers with furrow irrigation can provide some protection for their vines by applying water before predicted freeze events. There would be no benefit from this action if the soil is already moist. Flooding the vineyard berm to berm is better than using furrows and the irrigation does not have to be deep, only the top foot of soil needs to be moist.

Row middle management can have an important impact on the susceptibility of vines to spring freeze damage. Until recently, recommendations for row middle management to avoid frost damage were to have moist, firm, bare soil in the row middles. The basis for these recommendations was that the conditions described favored absorption of solar radiation and subsequent transfer of the absorbed heat to vines during a freeze. These recommendations are still valid and should be followed in most situations. However, recent research results and grower observations indicate that in some situations the current recommendations need to be reexamined. Donaldson et al. (1993) found that vines where early season vegetation between rows was killed by spraying with herbicide had slightly warmer minimum temperatures than vines where row middle vegetation was controlled by mowing or discing. This occurred on most nights during the spring freeze season and was not influenced by vineyard canopy development. Also, some growers have observed that the presence of a cover crop (mowed close to the soil surface) has not caused increased risk of frost damage. Furthermore, the risk of frost damage with higher cover crops needs to be re-evaluated in different viticultural districts due to the positive benefits that have been documented from cover crop use.

Pruning practices can be effective in reducing frost hazard, particularly on sites which are frost prone. The most obvious pruning practice to avoid frost damage is delayed pruning or late pruning. This is an effective strategy for small acreages, varieties with early bud burst, or as mentioned above, sites which frequently have frost. Delayed pruning is not the answer when the grower has a large acreage which must be pruned, unless mechanical pruning is used. Another practice which can be implemented is long-cane pruning. Buds on a cane begin to develop at the apex of the cane. This can be used to provide protection for buds at the base of the canes which are retained for fruiting during standard pruning. Vines are pruned to retain long canes and then, after the frost period has passed, canes are cut back to the proper length. Long cane pruning is effective for frost protection, but would not be cost effective for most vineyards in California due to the trellis systems used and additional labor requirements.

Active Protection Methods

Active frost protection methods involve modification of the vineyard climate. The climate of the vineyard may be altered by 1) utilization of atmospheric heat (wind machines, helicopters); 2) addition of heat (heaters, sprinklers); and 3) a combination of using atmospheric heat and addition of heat (wind machine/heater combinations). Atmospheric heat can be used for frost protection if a temperature inversion exists. Wind machines or helicopters are used to mix the warm air aloft with the layer of cold air next to the ground. Depending on the strength of the inversion (difference in temperature between the 1.5m [5 ft] and 18.3m [60 ft] level) and other characteristics of the freeze event, protection down to approximately -1.7°C (29°F) can be attained in this manner. Use of heaters in combination with wind machines allows for protection down to approximately -3.3°C (26°F).

The addition of heat to a vineyard may be accomplished by using heaters or by the freezing of water applied by sprinklers. Twenty to forty heaters per acre are required depending on whether heaters are being used alone or in combination with wind machines. The lower number of heaters per acre is generally suitable when heaters are combined with wind machines for frost protection. Use of heaters alone can provide up to 2.5°C (5°F) of protection. However, the use of heaters can be problematic. The cost of fuel and labor to operate heaters can be high; there is a danger of hazardous materials clean-up if fuel is spilled; and, depending on the type of fuel used, air pollution may be a concern. Local and county regulations should be consulted before heaters are purchased. For these reasons, heaters are primarily used only in combination with wind machines and only on sites without adequate water for sprinkler frost protection. In addition, if the site rarely has temperatures below -1.7°C (29°F) the use of wind machines alone is justified.

Use of sprinklers can protect vines when temperatures fall to -3.9°C (25°F) if conditions are ideal. Water from the sprinklers supplies heat to the vine-water-atmosphere system. The heat is released as water cools to 0°C (32°F) and then freezes to ice. The most important factor in this situation is the heat of fusion (released as water freezes to ice). A gallon of water releases 300kcal (1200 BTU) of heat as it freezes. Water is also evaporating in the vine-water-atmosphere system. The evaporation of water causes a loss of 2300kcal (9000 BTU) per gallon. Therefore, to maintain a positive heat balance, significantly more water must freeze than evaporates. This amount has been determined to be a factor of 7.5 units of water or more for every unit of water that evaporates. This, along with a buffer for the humidity of the air and wind speed (factors which can increase the evaporation rate) is the basis for the sprinkler application rate used in the design of systems. The recommended application rate is 6.9 to 8.2 millimeters (0.11 to 0.13 inches) per hour or a pumping capacity of 470 liters per minute per hectare (50 gallons per minute per acre).

Design of the sprinkler frost protection system is critical. A qualified expert should be consulted to design your system. It may also be appropriate to check references provided by the engineer or specialist that you are considering.

All active methods of frost protection must begin before the critical temperature is reached. This is particularly important for sprinkler frost protection. When sprinklers are first started an initial temperature drop often occurs due to evaporation. This temperature drop can injure vines if the sprinklers are started too late.

Low dew point can further exacerbate this problem. To avoid damage under these conditions, sprinklers should be started at 1.1°C (34°F) if the dew point is -4.4°C (24°F) or above; 1.7°C (35°F) if the dew point is -6.7 to -5.0°C (20-23°F); or 2.2°C (36°F) if the dew point is -9.4 to -7.2°C (15-19°F). This recommendation should only be followed when a frost is predicted. Sprinklers may be turned off when the air temperature has risen to 1.1°C (34°F).

Vine Recovery from Frost Damage

If protective measures fail and the critical temperature is reached, injury will occur. The grower faced with this situation must manage his vineyard to maximize yield for the current season and vegetative growth so that yield is unaffected in the following season. Freeze injury usually does not result in complete crop loss. The grapevine node has three growing points or buds (the primary, secondary, and tertiary buds). Primary buds usually develop first and have the greatest crop potential. Due to their early development, primary buds are also more susceptible to frost damage than are secondary and tertiary buds. Certain varieties, such as Thompson Seedless or Concord bear almost their entire crop from primary buds. Other varieties will bear a partial crop from secondary, tertiary, and latent buds. For some wine grape varieties, the amount of crop from growing points other than the primary bud can be significant.

Proebsting and Brummund (1978) evaluated the response of Concord grapevines to spring freezing injury. All shoots were lost on frozen vines (complete primary bud kill), while control vines (protected by sprinklers) displayed no shoot injury. Freeze injury delayed bloom which appeared to be beneficial since conditions were generally unfavorable during the normal bloom period. As a result, vines which were injured had more berries/cluster than non-injured vines. Frost damage reduced yields significantly, and the reduction was due to a reduction in the number of clusters per vine. Berries from injured vines were less mature than berries from non-injured vines.

Removal of injured shoots was investigated by Kasimatis and Kissler (1974) to find a method of increasing the yield of vines exposed to frost. Treatments consisted of removal of all primary shoots, removal of frost-damaged shoots only, and control. None of the shoot removal treatments significantly improved yield. Shoot removal had little effect on fruit maturation. For most situations, it appears that removal of frozen shoots would not be beneficial.

Growers should also evaluate their cultural practices following a spring freeze event which injures vines. If crop loss is severe, pest and disease control measures may be reduced somewhat without influencing the crop potential for the following season. Other cultural practices, such as cultivation, irrigation, etc., should be done in a normal manner to allow for good vegetative growth.

Summary

Frost protection is an important element of commercial viticulture. Nearly all vineyard regions of the world are subject to spring frost damage. Avoidance of frost damage can be achieved through use of passive or active methods. Passive methods, such as site selection, variety selection, and cultural practices are less costly than active methods but may only provide a few degrees of protection. On the other hand, active methods (wind machines, heaters, wind machine/heater combinations or sprinklers) are more expensive but can provide 2.8-3.3°C (5-6°F) of protection under ideal conditions. A combination of passive and active methods will likely produce the most effective frost protection program.

II. EVALUATION OF MICROSPRAYERS FOR FROST PROTECTION

Reduction in water use or increased water use efficiency are important concerns for wine grape growers. However, conservation of water must not reduce productivity, wine quality, or increase production costs. The application of water directly to the crop, eliminating unnecessary watering between the crop rows is known as targeted frost protection. Targeted systems have been used in tree fruit and citrus orchards to provide frost protection while reducing the amount of water used. Potential benefits of a targeted system, such as microsprayers or microsprinklers, for frost protection in vineyards include reduced water use; reduced need for reservoir capacity; lower equipment costs for installation (smaller pumps and pipe); and less energy use.

A. EQUIPMENT DEVELOPMENT AND SELECTION

Targeted frost protection for orchards was pioneered in part by the New Zealand Agricultural Engineering Institute (1986). Tests were carried out in Central Otago, New Zealand to evaluate the effectiveness of targeted frost protection on peach and nectarine trees.

The microsprinklers used in the New Zealand study were installed 5 m (16 ft) apart, producing a wetted diameter of 3.5 m (11.5 ft) and an application rate of 4 mm/hr. The wetted pattern from these microsprinklers is circular. In order to best use targeted frost protection on a vineyard, the Center for Irrigation Technology (CIT) determined an emission device would have to produce a wetted strip. This eliminated microsprinklers because of their inherent circular pattern. The search was begun for a microsprayer (fixed pattern) that produced a rectangular pattern.

A preliminary investigation suggested the microsprayer needed to protect vines should produce a pattern approximately 1 m by 3.7 m (3.3 ft by 12 ft). This is based partially on the typical vine spacing of approximately 2 m (7 ft). Thus a microsprayer could be placed on every other vine to provide a continuous wetted strip 1 m (3.3 ft) by the length of the vine row.

Since typical vine row spacing is around 3.7 m (12 ft), frost protection would be provided on 25 to 30 percent of the vineyard area. This has the net effect of reducing the total water requirement for the frost protection system by the same rate. Thus, if this approach provides the same level of frost protection, water application rates per hectare can be reduced from 470 l/min (50 gpm), to 150 l/min (16 gpm). This holds the potential for significant water and energy savings.

A hydraulic review suggested a targeted flow rate of around 11.5 l/hr (3 gph). Initial laboratory testing at these flow rates and a pressure of 207 kPa (30 psi) produced a droplet spectrum with a high incidence of fine drops. Since the destination of these drops cannot be predicted in light winds, it was determined that conventional product design would not work under field conditions. An alternative product design was sought.

The ideal product would produce large droplet sizes, while operating at extremely low flow rates. A new product that met this criteria was identified. It was the Pulsator™ microsprayer, which is manufactured by NIBCO Irrigation Systems. As given in its name, this product delivers water in pulses. The design has a small accumulator which delivers water in short bursts or pulses. This allows for a microsprayer to deliver water at an instantaneous rate of 21 l/h (5.5 gph) or so. The net delivery rate, though, is around 11.5 l/h (3 gph) due to the pulsing feature. The advantages of this technique are its larger average droplet size and increased wetted radius at comparable flow rates of conventional microsprayers.

Technicians with CIT worked with product engineers at NIBCO to evaluate and recommend changes in the wetted pattern. Computer modeling using CIT's Sprinkler Placement and Coverage Evaluation (SPACE) program was utilized to select the design which proved most advantageous. A prototype was recommended for field testing.

B. FIELD STUDY

The purpose of this trial was to investigate the use of microsprayers for frost protection in a commercial vineyard.

The objectives were as follows:

1) To determine if an alternative method of frost protection (targeted microsprayer system) in vineyards was feasible, and;

2) To determine if this method was less water consumptive than current practices.

Materials and Methods

The experimental site was a Chardonnay vineyard located near Los Alamos, California. Plots were established during early March 1993 and data were collected from March 11, 1993 through May 20, 1993 and March 14, 1994 through May 23, 1994.

The microsprayer (Pulsator™) being evaluated uses a pulsing action that produces larger diameter droplet sizes while maintaining lower application rates as compared to those found with conventional microsprayer design. This microsprayer produces a narrow band of water (approximately 0.6 m [24 in] wide) directed over the cordon of the vine. Microsprayers were installed in every vine row and mounted 0.56 m (22 in) above the cordon on every other stake, approximately 3.6 m (10.5 ft) apart. A two-hectare (5 ac) block of microsprayers was compared to an adjacent sprinkler block. The sprinkler block included a typical design and installation for commercial coastal vineyards. Sprinkler spacing was 15.6 m by 12.8 m (50.0 ft by 42.0 ft), using a conventional impact type head and a 2.78 mm (7/64 in) nozzle. The water source for both systems was an above-ground reservoir filled by pumping groundwater. Water was passed through a perforated tube filter for the sprinklers and a sand-media filter for the microsprayer system. Water use was measured by a Rockwell sealed register meter.

Data collected for the microsprayer and sprinkler blocks were bud temperature, air temperature, and relative humidity. Air temperature was also recorded at 0.46 m (18 in) from the cordon and the middle of the vine row (at cordon height). Environmental conditions monitored outside the vineyard were air temperature, wind speed and direction, and relative humidity. Environmental data were collected with Omnidata data loggers using a series of thermocouples for bud temperatures (attached at bud locations) and Physchem RH sensors for air temperature and relative humidity. A data logger and associated sensors were located within the microsprayer and sprinkler blocks and outside the vineyard.

Results and Discussion

Data collected during selected spring freezing events in 1993 and 1994 are presented in Table 1 and Figures 1-4. Due to the low number of spring freezing events in 1993 and 1994, data collection was limited at the selected vineyard sites. During the spring freezing events which were observed, microsprayers provided a level of frost protection which was similar to that provided by sprinklers. Also, the use of microsprayers resulted in a savings in water use of approximately 80 percent during selected freezing events.

The data presented are preliminary and further research is needed before general recommendations on microsprayer use for frost protection can be given.

Table 1. Selected characteristics of frost protection events in 1993 and 1994. Cat Canyon Vineyard. Los Alamos, California.

Season	Number of frost protection events[z]	Frost protection events below 0°C (32°F)		Water Use[y] l/min/hectare (gal/min/acre)
1993	4	April 28 May 12 May 13 May 14	Sprinkler	495 (53)
			Microsprayer	103 (11)
1994	2	April 11 April 28	Sprinkler	495 (53)
			Microsprayer	103 (11)

[z] During the 1987-1992 period, this vineyard location experienced more than seven spring freeze events per season.

[y] Data collected on last frost protection event of each season only.

Figure 1. Frost Event of April 28, 1993, Cat Canyon Vineyards, Los Alamos, California

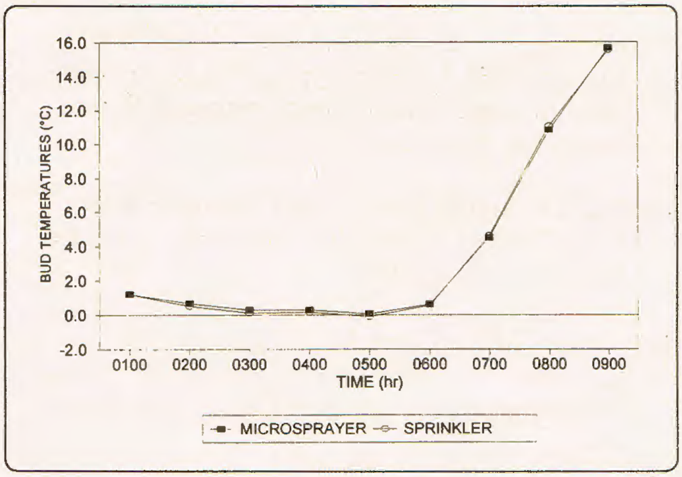


Figure 2. Frost Event of May 14, 1993, Cat Canyon Vineyards, Los Alamos, California

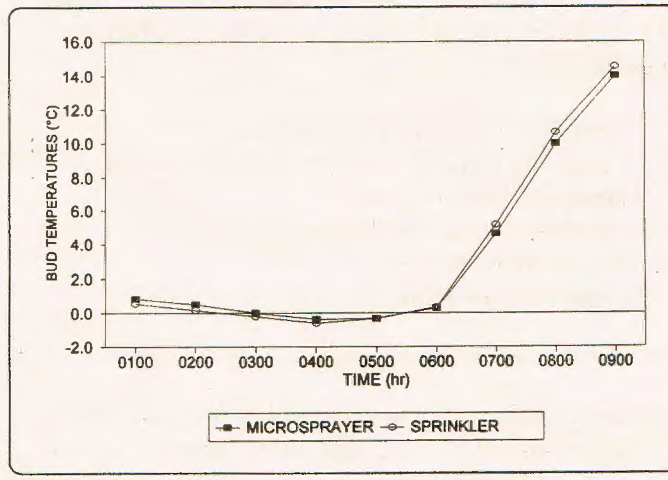


Figure 3. Frost Event of April 11, 1994, Cat Canyon Vineyards, Los Alamos, California

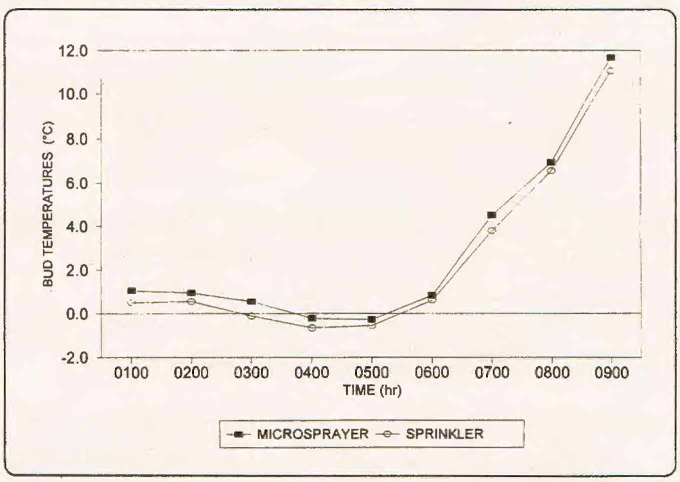
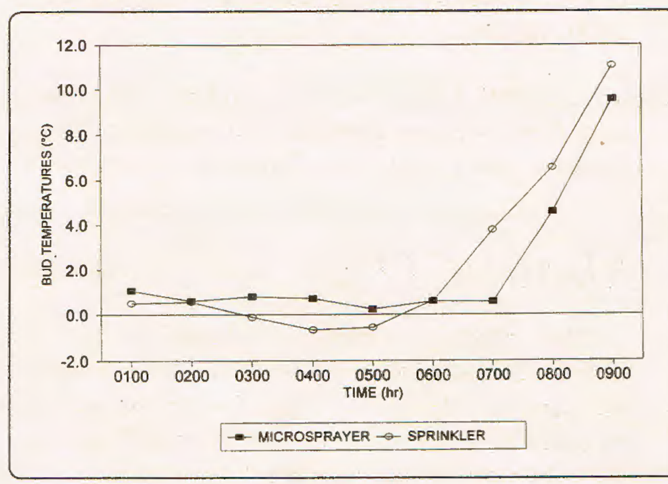


Figure 4. Frost Event of April 28, 1994, Cat Canyon Vineyards, Los Alamos, California



Continuing studies will include a series of tests under controlled freezing conditions in a cold chamber.

III. SUMMARY

Sprinklers have been used successfully for many years as an active frost protection method in vineyards. With increasing population and environmental pressures, along with unfavorable climatic conditions, water supplies for frost protection are becoming more costly to use. Previous studies have evaluated the use of microsprayers and/or microsprinklers for frost protection in other crops, such as trees (Davies, et al., 1988; Evans, 1991; Parsons, 1991; Rieger and Myers, 1990; von Bernuth and Baird, 1989).

The purpose of this study was to determine if microsprayer technology could be improved upon and proven for use as a frost protection alternative in vineyards. As a result, researchers and a microsprayer manufacturer cooperated to develop a targeted microsprayer technology that was used as an active spring frost protection method in a commercial vineyard. The targeted microsprayers were designed specifically for vineyard applications and were evaluated under laboratory and field conditions.

Targeted microsprayers were compared to conventional sprinklers in a commercial vineyard during the springs of 1993 and 1994. Data collected and presented here indicate that targeted microsprayers provided frost protection similarly to conventional sprinklers, but with 80 percent less water used.

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About VERC...

The mission of the Viticulture and Enology Research Center (VERC) is to develop and apply new and emerging technologies related to viticulture, enology, food processing, and related disciplines in cooperation with appropriate industries, governmental agencies, and other units of California State University, Fresno.

Research efforts of the center are conducted with the goals of creating new jobs in the state of California, enhancing the environment, and improving our quality of life.

For more information on programs or services, contact VERC at the following address:

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http://www.atinet.org/cati/verc

About CATI...

The **California Agricultural Technology Institute** (CATI) is a non-profit, educational institution committed to improving the profitability of California agriculture.

Based at California State University, Fresno, CATI operates under a permanent research mandate from the California State Legislature. Funding support is bolstered by a variety of public and private institutions that acknowledge CATI's leadership in applied research and information dissemination to the agricultural community.

CATI oversees operations of four centers which serve as bases for research and development activities. They include the **Center for Agricultural Business** (CAB), which offers resources and expertise in the areas of production agriculture and agribusiness; the **Center for Irrigation Technology** (CIT), which works with growers, irrigation equipment manufacturers and government agencies to improve irrigation equipment and water use efficiency in both agricultural and urban areas; the **Viticulture and Enology Research Center** (VERC), which conducts research in the areas of product development, grape variety testing, pest and disease control, and dried fruit technology; and the **Center for Food Science and Nutrition Research** (CFSNR), which conducts research and seeks to strengthen partnerships between private industry and public agencies in the areas of food science and nutrition research.

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