



A Guide on  
How-To-Avoid-  
Frost-Damage  
on Crops &  
Orchards

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## Introduction

Anti-frost protection constitutes an integral part of deciduous plants growing in extensive regions in the world. This brochure is intended to give us a first basis for coping with this issue.

The idea is to explain, by means of professional articles, the principle and the basic terms of the phenomenon and the possible solutions. The professional literature and data banks include numerous articles that deal with the subject. The ones included here are only a small part of them. We shall continue to publish more articles that will widen our knowledge of the subject.

In many of the areas where deciduous crops are planted there exists a possibility of night-frost.

Here we are relating to Spring-frosts, (these crops being resistant to Winter-frosts), in the Spring when the crop begins to bud and flowering commences, there exists the possibility of wind-free, clear night skies where the temperature can fall below zero.

As we will understand later, it is possible to protect these crops by way of irrigation, as we irrigate, the water distributed by the sprinklers warms the surrounding atmosphere owing to its higher temperature and in addition some of this water freezes, thus releasing

energy in the immediate vicinity. In some cases a layer of ice will cover some of the leaves, branches and young flowers, as long as we continue to irrigate these ice layers, their temperature will never fall below zero.

It is possible to position the sprinklers either above or below the trees, we will adopt the first instance when the tree body is still relatively small, (when on trellises or when its radius is 2-3 meters).

The minimum volume of planned irrigation will be some 3 cubic meters per hour. (In areas where the temperature falls to -3, -4), this quantity of water will assure an energy release suited to protect the tree, in the event that temperatures are liable to fall below these levels, larger quantities of irrigation need to be planned.

Many factors will influence the protection of the tree, as we can understand from the articles in the booklet. The timing of the initiation and curtailing of the irrigation has a direct influence on the relative air humidity, the light wind conditions and more. It is therefore difficult to assure 100% success when using these methods, we are obliged to stress that these products and methods are tools designed to assist the farmer and need to be studied and adjusted to suit each different individual.

## The “Netafim” Solutions

A number of products in our range of products can help growers to cope with frost conditions. In order to learn their properties and advantages, we exhibit a given plot of land of 10 hectares planted at identical spacings. Each of our products has been used on this same plot. Also exhibited are the components of the various solutions so as to compare between their respective costs.

Because of the difference in prices and costs of the components in each country, we shall be able to decide which system is suitable to each grower according to the data, depending upon the limiting factor: quantity of water, cost of the system, price of energy, etc.

### Control of Anti-Frost Protection System

Netafim range of products includes an appliance which helps to activate the water system at the required time (see page 23).

- DC operated
- Analog sensor
- Up to 30 m length cable connection
- Operates DC solenoid or relay to pump



*By Valérie Gallia, Irrigazette,  
March/April, 2001*

## What can be done against springtime frost? (France)

**Springtime frost, along with hail, is one of the weather disasters that causes the greatest damage in fruit trees.**

Protection is indispensable in certain geographical sectors to insure regular harvest in terms of quantity and quality.

In frost prone areas, overtree sprinkler irrigation is the most efficient and economical way to combat frost.

*By Lawrence R. Parsons, The  
Citrus Industry, December, 1984*

## Cold protection (US)

**The Christmas 1983 freeze was a windy or advective freeze and was the worst freeze in Florida this century.**

The amount of Florida oranges lost in the freeze was greater than the entire orange crop expected to be produced in California this season.

*By Larry R. Parsons, Ph.D. Univer-  
sity of Florida*

## Freeze damage (US)

**The December, 1990 freeze was the worst freeze to hit California in more than five decades.**

Fruit damage was extensive and total tree damage may continue to appear for up to 2 years after the freeze.

*By Maxwell Norton, U.C. Cooperative Extension*

## Stonefruit frost protection (US)

**Figs are only hardy down to 0°F (-18°C) and grapes to +10°F (-12°C).**

This was evidenced by the fact that after the 1990-91 winter freeze, there was damage to fruitwood in the prunus species - including peaches, almonds, plums and apricots.

*By Tim Tesconi, New York Times, April 11, 2001*

## California frost damage in millions (US)

**The most damaging killer-frost season in 30 years has caused millions of dollars in losses for blurry-eyed North Coast grape growers who have worked through the night over the past week to save their crops.**

The cold weather continues, and growers Tuesday were preparing for another night of firing up wind machines and irrigation systems to keep frost from frying vulnerable buds. Depending on the area, frost damage in the North Coast counties ranges from 15 to 100 percent, with some vineyards escaping any damage. So far.

"This isn't over yet. It looks like we'll have another night of fighting frost," longtime Sonoma County grape grower Henry Bisordi said Tuesday.

He said the frost season can continue through mid-May in Sonoma County vineyards.

Agricultural officials have not put a dollar loss on the frost damage. But considering that wine grapes from Sonoma, Napa, Lake and Mendocino counties were worth \$836 million last year, even a 10 percent loss in production would cost growers more than \$80 million.

The vineyards are damaged by spring frosts because this is the season called bud break, when the vines send out tender young shoots that will produce this fall's grape crop. Frost damages the shoots, causing them to look like they've been burned with a torch. Once the shoots are damaged, grape production is severely reduced or wiped out completely.

He estimated 15 to 20 percent of the vineyards in the Sebastopol-Forestville area suffered some frost damage.

The cold snap has kept farmers up all night making sure frost systems are working. Spraying water on the vines when temperatures dip below freezing is the most common method of frost protection. The water freezes and encapsulates the green bud in ice, maintaining a constant 32-degree temperature and keeping the delicate tissue out of danger.

## Heat Transfer

Heat may be transferred from one material to another or from one place to another by three processes:

- **Conduction**

When a metal rod is warmed, the process of heat transfer is conduction. The molecules at the warm end of the rod are moving with high energy and colliding with nearby cooler molecules, giving them more energy. These, in turn, hit even slower molecules causing them to move faster and passing on energy. Heat is thus transferred down the rod.

- **Advection**

Transfer of heat by the movement of heated liquid or gas.

- **Radiation**

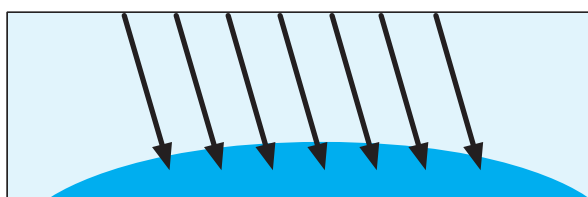
Movement of heat energy from one object to another without being physically connected. This is how we receive the sun's energy, and it is by radiant heat transfer that crops lose heat at night.

## Energy Exchange

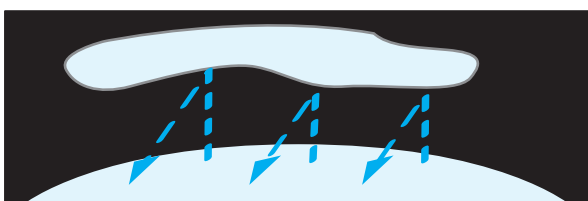
During the day, the sun's radiant energy warms the soil and other solid objects, such as crops. When these objects become warmer than the air, they pass heat to the air by conduction. This air becomes less dense, rises, and is replaced by cooler air from above. The advective mixing of these currents of warmer and cooler air is the method by which thousands of feet of the lower atmosphere are warmed.

The soil and crops may also radiate heat energy into space.

Water vapor, some of which can be seen as clouds and CO<sub>2</sub>, which is invisible, may absorb or reflect some of this energy, trapping it as heat near the earth's surface. This last phenomenon is known as the greenhouse effect.



During the day, sun's energy passes through most atmospheric gases and water vapor.



Energy radiated from soil surface is absorbed or reflected by water vapor and CO<sub>2</sub>.

At night, the situation reverses. There is no incoming heat to warm the soil and crops. They continue to lose heat through radiation and conduction until they are cooler than the surrounding air. The air then passes heat to the soil and crop, and the lower atmosphere cools. If no cloud cover is present to block the outgoing radiation, the soil, crop, and air temperatures will continue to decrease significantly. The greenhouse effect of cloud cover can limit this temperature decrease at night.

## Inversion

On a clear night, the heat from solid objects will continue to radiate out to space. Temperatures will drop significantly at the surface. The temperature in the lower tens to hundreds of feet of atmosphere inverts, that is, the temperature increases with altitude to the top of the air layer. The term inversion comes from atmospheric conditions being inverse to the normal daytime condition where air temperature decreases with height. The warm air in an inversion is important for some frost protection methods which depend on this source of heat.



Temperature zonation during an inversion. Temperature increases with height to the top of the inversion and then decreases. Frost protection techniques use the warmer air above the crop as a heat source.

Many factors are involved that affect the minimum temperatures which occur. Growers in mountainous, hilly, or rolling terrain are familiar with frost pockets or cold spots. These are formed by cold air drainage, i.e., cold, dense air flows by gravity to the lowest areas of a field where it collects. This causes temperatures to differ in relatively small areas, called micro-climates.

Soil moisture and compaction can have a significant effect on minimum temperature. A moist, compact soil will store more heat during the day than a loose, dry soil. Thus, it will have more heat to transfer to the crop at night. Cultivation should never be carried out prior to frost or freeze, because it loosens and dries the soil.

Ground cover also has an effect. Vegetation reflects more solar radiation during the day. It also transpires to cool its temperature. This reduces the heat that it stores and that which is stored in the soil below it. Moving a vegetative cover to heights shorter than two inches can reduce this effect. However, the frost and freeze protection disadvantages of ground cover management must be weighed against the benefits such as erosion control, dust reduction minimizing soil compaction, etc.

## Frost vs. Freeze

Although the terms frost and freeze are often interchanged, they describe two distinct phenomena.

An **advective**, or windborne, **freeze** occurs when a cold air mass moves into an area bringing freezing temperatures. Wind speeds are usually above 8 km

(5 mph) and clouds may be present. The thickness of the cold air layer ranges from 150m (500 feet) to more than 1500m (5000 feet) above the surface. Attempts to protect crops by modifying the environment are very limited under these conditions.

A **radiation frost** occurs when a clear sky and calm winds (less than 8 km (5 mph) allow an inversion to develop, and temperatures near the surface drop below freezing. The thickness of the inversion layer varies from 9-60m (30-200 feet)

There are two types of frost. A hoar frost, or **white frost**, results when atmospheric moisture freezes in small crystals on solid surfaces. During a **black frost**, few or no ice crystals form because the air in the lower atmosphere is too dry. The formation of ice crystals depends on the dew point, or frost point, which is the temperature to which air must be.

### Radiation frost

- Calm winds less than 8 km (5 mph)
- Clear skies
- Cold air mass 9-60m (30-200 feet) deep
- Inversion develops
- Two typed: white and black
- Cold air drainage occurs
- Successful frost protection likely

### Advection freeze

- Winds above 8 km (5 mph)
- Clouds may exist
- Cold air mass 150-1500 m (500 to 5,000 ft) deep
- Protection success limited

## Microclimate Monitoring



Although minimum temperatures may vary across a forecast zone because of microclimates, relative conditions for an area should be quite similar during each frost/freeze occurrence. It is very advantageous to record weather conditions for each occurrence in selected parts of the farm. One can observe and record actual and forecast temperature, cloud cover and wind speed.

In cloudy, breezy weather, the observed lows are likely to be very close to forecast values, but under **clear, calm conditions, frost may need to be anticipated even when no frost is forecast.**

The use of past observations can become an essential ingredient to predicting future conditions and modifying the zone forecast for a farm. The information collected will also allow the grower to place protection equipment in those areas where it will most likely be needed.

During a radiation frost, careful records of past occurrences can help make the critical decision of whether or not to begin protection measures. This is especially critical in areas where overhead irrigation is used. Microclimate information gathered before the establishment of a crop can help the grower select site, type, and amount of protection equipment.

## Air temperature

Minimum recording thermometers are not expensive and are a wise investment for any grower concerned with frost/freeze protection. The placement and number of thermometers depends on the area and the grower's interest.

Some growers place one thermometer in the coldest spot and organize their protection plans around the worst possible case. This is one approach, except that much of the area will receive more protection than it needs, perhaps costing the grower unnecessary time and fuel. If the protection system allows variable rates of protection, then many thermometers are needed.

## Crop temperature

Knowing the temperature of the crop you are trying to protect is a critical piece of information in protection decisions. It is often the practice to use air temperature as the "decision maker."

This can be misleading because the atmospheric conditions which create frosts also cause crop temperatures to be different from air temperatures (usually colder), but not always by the same amount.

The difficulty in the past has been how to accurately and economically measure the crop temperature. This has encouraged growers to use the air temperature, but add a "safety factor" of several degrees. This often causes systems to be started before they actually need to be, resulting in excess water and energy use. There are also situations where, by being able to confidently wait to start, the need to protect is avoided completely.

Thermocouples are temperature-measuring devices small enough to be inserted into buds, blossoms or small fruit. They are inexpensive and easy to make.

Digital thermometers that read thermocouples are now available. These meters and the thermocouples can be used in different ways.

A grower could move through the crop measuring the temperature in various locations by inserting one thermocouple, taking a reading, removing it and going to the next location.

A grower could also place thermocouples fitted with connectors in numerous locations and then visit each with the meter to read them. Another method would



be to bring the wires from the thermocouples to a central location and have a switch that enables the meter to read multiple sensors. Any of these ways will give a very accurate picture of what's happening throughout the crop area that is to be protected.

The economic feasibility of the latter two methods should be assessed, however, due to the cost of the connectors and the additional wire required.

A grower can customize a plan that suits his needs and budget. This relatively small investment can increase frost protection decision making skills significantly and will certainly add confidence in deciding when to begin protection.

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## Methods of Frost/Freeze Protection

All frost/freezing protection methods are based on preventing or replacing radiant heat loss. The proper choice of protection equipment for a particular site depends on many factors. The advantages, relative costs, and operating principles of the predominant methods are discussed below. See table after summary.

### Site Selection

The best method of frost/freezing protection is good site selection. Microclimate monitoring may be used to evaluate a site before planting. Visualizing the flow of cold air and its possible buildup in low spots or behind cold air dams, such as fences, hedges, wooded areas, is the most effective, quick method of site selection. If a site has good cold air drainage, then it is likely a good production site as far as frost/freezing damage is concerned.

### Heaters

Heating for protection has been relied upon for centuries. The increased cost of fuel has provided incentive to look at other methods; however, there are several advantages to using heaters that alternatives do not provide. Most heaters are designed to burn oil and can be placed as free-standing units or connected by a pipeline network throughout the crop area. The advantage of connected heaters is the ability to control the rate of burning and shut all heaters down from a central pumping station simply by adjusting the pump pressure. A pipeline system can also be designed to use natural gas. Propane, liquid petroleum, and natural gas systems have been used for citrus.

Heaters provide protection by three mechanisms. The hot gases emitted from the top of the stack initiate advective mixing in the crop area, tapping the important warm air source above in the inversion. About 75% of a heater's energy is released in this form.

The remaining 25% of the total energy is released by radiation from the hot metal stack. This heat is not affected by wind and will reach any solid object not

blocked by another solid object. Heaters may thus provide some protection under windborne freezing conditions. A relatively insignificant amount of heat is also conducted from the heater to the soil.

Heaters provide the option of delaying protection measures if the temperature unexpectedly levels off or drops more slowly than predicted.

The initial installation costs are lower than those of other systems, although the expensive fuels required increase the operating costs. There is no added risk to the crop if the burn rate is inadequate; whatever heat is provided will be beneficial.

Growers have also tried burning old rubber tires for frost protection. Some heat is added to the crop area by these fires, but there has been a misconception that the smoke acts like a cloud.

Smoke does not provide the greenhouse effect of water vapor, because the smoke particles are too small to block longwave radiation loss. In fact, smoke not only has no effect on outgoing radiation; it actually impedes warming in the morning, because smoke particles are the right size to block the incoming short-wave solar energy.

Legal regulation of fires must also be considered before burning tires or other materials for frost protection.

### Irrigation

Irrigation is another method of frost/freezing protection. Heat lost from the crop is replaced by heat released as the applied water changes to ice. Specifically, as 1 gram of water freezes, 80 calories of heat energy are released. As long as ice is being formed, this latent heat of fusion will provide heat.

Irrigation for frost protection, often called sprinkler irrigation, is done with sprinklers mounted above or below the crop canopy. Under-canopy, usually under-tree, sprinkling with micro-sprinkler nozzles has been successful in California and Florida.

Although there is some risk involved, the advantages of irrigation are significant. Operational costs are lower, because water is much cheaper than oil or gas. Irrigation systems are convenient to operate, because they are controlled at a central pump house. In addition, there are multiple uses for the same system, e.g., drought prevention, evaporative cooling, fertilizer application, and possibly pest control.

There are some disadvantages. The first and most important is that if the irrigation rate is not adequate, the damage incurred will be more severe than if no protection had been provided.

Inadequate irrigation rate means that too little water is being applied to freeze at a rate which will provide enough heat to protect the crop. The situation is made complex by another property of water, evaporative cooling or the latent heat of evaporation.

As 1 gram of water evaporates, 600 calories of heat energy are absorbed from the surrounding environment. When compared to the 80 calories released by the warmer air down to crop level. They are not effective in an advective freeze. A single wind machine can protect approximately 10 acres, if the area is

relatively flat and round. A typical wind machine is a large fan about 16 ft. in diameter mounted on a 30-ft steel tower. The fan is powered by an industrial engine delivering 85 to 100 Hp. Since wind machines are effective only under radiation frost conditions, a grower choosing this method should be confident that it is under such circumstances he will most often need protection.

Wind machines use only 5% to 10% of the energy per hour required by heaters. The original installation cost is quite similar to that for a pipeline heater system, making wind machines an attractive alternative to heaters for frost protection. However, they will not provide protection under windy conditions. Wind machines are sometimes used in conjunction with heaters. This combination is more energy efficient than heaters alone and reduces the risks of depending solely on wind machines. When these two methods are combined, the required number of heaters per acre is reduced by about half.

Helicopters have also been used as wind machines. They hover in one spot until the temperature has been increased enough and then they move to the next area. Repeated visits to the same location are usually required.

## Chemicals

The objective of having an inexpensive material that could be stored easily until needed, easily applied and provide frost protection has existed since the mid 1950s. Numerous materials have been examined. These fall into several categories but, in general, they have been materials that allegedly either: 1) changed the freezing point of the plant tissue, 2) reduced the ice nucleating bacteria on the crop and thereby inhibited ice/frost formation, 3) affected growth, i.e. delayed dehardening, or 4) worked by some “undetermined mode of action.” To this author’s knowledge, no commercially available material has successfully withstood the scrutiny of a scientific test. There are, however, several products that are advertised as frost-protection materials. Growers should be very careful about accepting the promotional claims of these materials.

Research continues, and some materials have shown some positive effects. Growth regulator applications which delay bloom seem to hold the most promise at this time.

## Fog

Man-made fog has been tried as a frost-protection method. The principle is to duplicate the greenhouse effect. If a “cloud” could be produced blanketing the crop area, it would decrease the radiative cooling and stop the plant from dropping to the critical temperature. So far, there has been some experimental success but a practical system has not been developed. The difficulty lies in producing droplets large enough to block the outgoing longwave radiation and keeping them in the atmosphere without losing them to evaporation.

## Summary

The proper method of frost/freezing protection must be chosen by each grower for the particular site considered. Once the decision has been made, several general suggestions apply to all systems.

If frost/freezing protection is to be practiced successfully, it must be handled with the same care and attention as spraying, fertilizing, pruning, and other cultural practices. Success depends on proper equipment used correctly, sound judgment, attention to detail and commitment.

Don’t delegate protection of the crop to someone with no direct interest in the result. Complete preparation and testing of the system should be accomplished well before the frost season begins.

Likewise, don’t shut down the system before the threat of frost has definitely passed. Double check the system shortly before an expected frost. Problems that are handled easily during the warm daylight can become monumental and even disastrous during a cold, frosty night when every second counts.



	Advantages	Disadvantages	Comments
Site Selection	Choose location with good cold air drainage		Best method of frost protection; visualize air flow and/or monitor minimum temperatures
Heaters	Installation costs lower than irrigation; allows delay; no risk if rate not adequate	Fuel oil expensive	Free-standing or pipeline
Irrigation	Operational costs lower than heaters; can be used for conventional irrigation	Installation costs relatively high; risk damage to crop if rate inadequate; limbs may break; waterlog risk, no protection in wind >8 km (5 mph)	Plant part protected by heat of fusion; irrigation must continue until melting begins; backup power source essential
Wind machines	Installation cost similar to heaters	No protection in wind >8 km (5 mph) or advective freeze	Mixes warm air near top of inversion down to crop height
Fog	Blocks outgoing heat and slows cooling	Has potential but is not currently practical	Uses greenhouse affect to trap heat and limit cooling



## Irrigation as a tool for frost and freeze protection of agricultural crops

For years farmers and researchers have understood the value of applying water to crops during periods when the temperature drops below 0°C (32°F). The temperature of 0°C is the freezing point of water and is the temperature at which crops start to become damaged due to the formation of ice crystals in their tissue cells.

The point that this starts to occur is considered the crops critical temperature. The critical temperature usually is slightly lower than the freezing point of water and depends on the duration at the temperature.

For example, in citrus the critical temperature at four hours is -2°C (28°F). This means that a **citrus**



**tree can stand a temperature of -2°C (28°F) for four hours before sustaining damage.** After four hours the damage is proportional to the time that the temperature remains below the critical temperature. Temperatures below -2°C (28°F) for a short period of time (one or two hours) will cause only minimal damage.

Temperatures over -2°C (28°F) can be tolerated for extended periods of time with only minor damage (partial leaf burn, partial defoliation, etc., but no wood damage). Other factors such as stage of growth (if the plant is in early stages of growth or mature), fruit set (whether the crop is still on the plant or not), dormancy (whether the plant is actively growing or is dormant), plant water content (whether the plant is under water stress or not) and overall plant health will influence the critical temperature for a specific crop.

### Water for freeze protection

There are three ways that water can transfer heat for freeze protection. The first way is through **radiation**. Water pumped from wells will be introduced into the field at a much higher temperature than the surrounding air temperature (in Florida the temperature for water coming from a well is a standard 22°C (72°F), except for those wells found in conjunction with geo-

thermal warm spots). As the water cools, it transfers energy to the surrounding air, warming it, thus keeping the temperature around the plants above the critical temperature.

The second way is through **conduction**. This method is similar to the previous method except instead of radiating its energy to the atmosphere, the energy is transferred to the plant itself. The water is sprayed on the cooler plant which creates a temperature gradient between the water and the plant. The energy from the higher temperature water will move to the lower temperature plant. The increase of energy in the plant increases the temperature of the plant, keeping it above its' critical temperature.

The third and most efficient way is through **latent heat**. Latent heat is the heat that is either absorbed or given off during a change of phase of a material. An example of this is the phase change of water as it goes from a liquid to a solid. During this phase change, 80 cal per gram of water are given off with no change in the temperature of the water (this is due to the decrease in potential energy as the molecules lock into position in the crystal structure of the solid. Miller, 1977).

As the water is sprayed onto the plant it freezes, changing phase from a liquid to a solid, liberating the 80 cal per gram of water to keep the plant temperature above its' critical temperature.

Several methods of applying water to crops have been investigated, each using one more ways of transferring heat energy to maintain temperatures at or above the plants critical temperature.

Most of these methods use irrigation systems to distribute the water to the crop, whereas some methods use specialized equipment.

### Sprinkler irrigation

The most popular and effective type of irrigation used in freeze protection is the **fixed sprinkler system**. It relies on the two concepts of latent heat and, to a lesser degree, heat conduction. Water is sprayed directly onto the crop. Conduction of heat energy is from the water (at a higher temperature) to the plant surface (at a lower temperature). Latent heat (80 cal per gram of water) is produced as the water freezes to the plant, changing phase from a liquid to a solid. As water is continually applied to the plant there is a continuous release of latent heat maintaining the temperature of the plant above its critical temperature. Costs for these systems are minimal as the irrigation system is already in place. The main cost is the energy required to pump the water to the sprinklers.

One method of sprinkler irrigation used for freeze protection is the overhead fixed sprinkler system. This method is used in most low growing, high value crops such as strawberries. Water is continuously applied to the entire plant maintaining temperatures as described above.

Temperatures in experiments conducted by Dr. George Hochmuth, applying 6.4 mm/h (0.1 inch/h) of water, showed that this method, during atmospheric

temperatures of  $-10^{\circ}\text{C}$  ( $14^{\circ}\text{F}$ ), maintained temperatures at or above freezing,  $0^{\circ}\text{C}$  ( $32^{\circ}\text{F}$ ) (Hochmuth, et. al., 1993). He also reported that only 6% of the flowers and 15% of the mature fruit in this test had been frozen. This means that 94% of the future crop, and 75% of the present crop, had been saved as well as the plants themselves. The potential of plant limb breakage is very minimal due to the low growing characteristics of these crops.



## Micro-emitter irrigation

Another method of sprinkler irrigation for freeze protection is the use of micro-emitter irrigation. This method is used in orchards or high value tall crops. This method is preferred over sprinkler irrigation due to heavy ice build-up on upper branches causes large amounts of limb breakage. Micro-emitter irrigation is the low volume application of water close to the soil surface through a small microsprinkler, in a spray pattern from zero to 360 degrees.

For freeze protection 90 degree patterns have been found to be the most efficient (Rieger et. al., 1986). The micro-emitter is positioned so that the water is sprayed directly to the trunk of the tree. As with the overhead sprinklers, as the water strikes the trunk of the tree, it freezes into ice and releases latent heat. In experiments conducted by Rieger, temperatures were maintained at  $-1^{\circ}\text{C}$  ( $29^{\circ}\text{F}$ ) and above on the trees where micro-emitters were used and ice was formed when air temperatures reached as low as  $-6^{\circ}\text{C}$  ( $21^{\circ}\text{F}$ ). Application rates ranged from 84 liters (22 gallons) per hour to 38 liters (10 gallons) per hour per emitter for this experiment.

Other experiments conducted by Dr. Larry Parsons give similar results. Using an application rate from 20 to 100 liters (5.2-26.4 gallons) per hour per emitter, trees were protected up to two meters above the soil surface (Parsons et. al, 1991).

In orchard conditions the purpose of freeze protection is directed at protecting as much of the tree as possible. If the trunk and root system are saved the

tree will regrow relatively quickly bypassing the three to five year stage of establishment that a replant must go through before it starts producing a harvestable crop.



## Flooding

Flooding is a method of freeze protection involving surface irrigation. Flooding involves the movement of large amounts of water onto the surface of the field through a series of ditches and furrows to cover as much of the field surface as possible. This method is based on the radiation of heat energy from the water to the surrounding air. This costs involved in this method are similar to that of the sprinkler method as ditches and furrows are already in place for surface irrigation and the only input is the energy required to move the water onto the field.

The major drawbacks to this method is the large amount of water needed, the reduction of the quality of this water during use and the lack of tolerance by the crop to being inundated by water for long periods of time. The volume of water needed is large because the field must be covered as much as possible to achieve maximum radiation. In averaging this over the ditches furrows and growing surfaces

Plants usually can tolerate standing water for short periods of time, but the periods of time required for protection during freezes usually far exceeds this tolerance. The time of inundation is much longer than the actual period of freezing temperatures due to the time it takes to totally inundate the field prior to freezing temperatures and remove the water after the freeze. The reduction in water quality can be high depending on the recent applications of herbicides, fertilizers, fungicides, etc. These three factors have led to the reduced use of flooding for freeze protection in most crops.

The use of water, distributed through irrigation systems can mean the difference between complete loss of crop or orchard due to freezing temperatures, or sustaining only minor damage. When designing an irrigation system, one must take into consideration all the uses of the system. If a system that has not been designed for freeze protection is used to protect plants from low temperatures, it will on a whole cause more damage than had it not been used due to poor coverage or intermittent coverage.

<sup>1</sup> N.N.

## The Role of Water in Frost Protection

Water is a remarkable substance that plays a key role in many aspects of life on earth. The physical properties of the substance known variously as H<sub>2</sub>O, water, ice, vapor, etc., enable it to be used as a tool in environmental modification schemes, and in particular, make it very useful in frost protection. In order to explain and understand this role, it will be helpful to review these physical properties.

### Energy

Energy can be stored in many forms. Heat is a form of energy particularly interesting to this discussion, for heat can obviously be used to combat cold or low temperatures which may damage crops. Heat can be added to, stored by, or released by water, depending on circumstance. To the extent we can predict and control these processes, we may be able to use water to achieve heat-related aims.

### Heat Storage

When heat is added to a substance, it may be stored in two ways. Some of the heat is stored as potential energy, which is related to the structure and average distance between the molecules of the substance. For example, as heat is added to a solid, the potential energy increases, the distance between the molecules increases, and the substance (generally) expands.

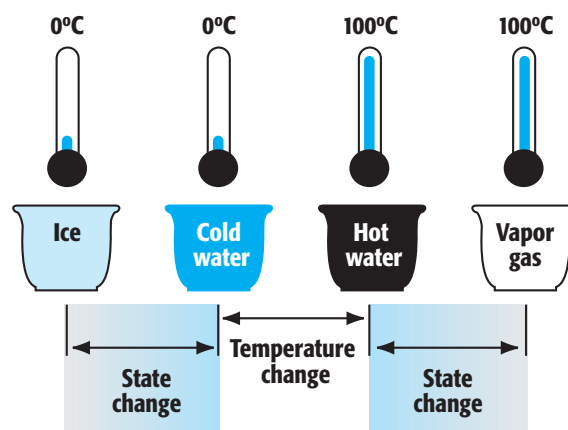
The same is generally true of a liquid. The situation for a gas is complicated because gas naturally expands to fill the available volume. The remainder of the heat added to the substance will be stored as kinetic energy (kinetic ~ dynamic ~ in motion), which is related to the velocity of the molecules of the substance. It is this kinetic energy that is sensed as temperature. For this reason, the heat stored as kinetic energy is sometimes called "sensible heat." When heat is added to either a solid or liquid, the temperature generally rises, indicating the increase in molecular speed and the increase in kinetic energy.

To discuss these physical characteristics further, it is necessary to introduce the notion of "changes of state." The "state" of a substance refers to whether it is solid, liquid, or gas. A change of state occurs whenever a solid changes to a liquid (or vice versa), or a liquid changes to a gas (or vice versa). Temperature changes while ice stays ice or while water stays water do not constitute changes of state.

### Changes of-State

**NO CHANGES OF STATE** - As long as ice stays ice, the prime observable effect of adding heat to the ice will be an increase in its temperature. Some portion of the added heat will be stored as potential energy, affecting molecular distances and hence the density of the ice. But the main feature of the ice we would see change is its temperature. Similarly with water. When heat is added to water, as long as it stays water, the

primary observable effect is its increase in temperature. As heat is extracted from water, its temperature will fall. The relationship between the amount of heat added or released and the temperature change is 8.3 BTU/3.7 lit.(1 US gallon) per °C/°F temperature change. To increase the temperature of one 3.7 lit.(1 US gallon) of water 4°C (10°F), 83 BTU must be added to the water; when the temperature falls 4°C (10°F), 83 BTU/3.7 lit.(1 US gallon) will be released (assuming the water remains water-no change of state is involved).



When water changes state (to ice or vapor) it does not change temperature. Water temperature changes without a state change.

**CHANGES OF STATE - ice/water** - At a temperature of 0°C (32°F), the substance known as H<sub>2</sub>O can exist as either ice or water, depending on the amount of heat in the form of potential energy that exists within the substance.

The nature of water is that when heat is added to ice at 0°C (32°F), it will influence the potential, but not the kinetic energy of the substance. When a certain quantity of heat has been added, the ice will melt to water, and that water will still be at 0°C (32°F).

If this same quantity of heat is then removed from the water at 0°C (32°F), it will freeze again and revert to ice, still at 0°C (32°F). The quantity of heat involved in this change of state is called the "heat of fusion" (sometimes called the latent heat of fusion), and for water has the value 1,200 BTUs per 3.7 lit.(1 US gallon). This amount of heat must be absorbed to melt ice at 0°C (32°F) to water at 0°C (32°F), and this amount of heat will be given up as water at 0°C (32°F) freezes to ice at 0°C (32°F).

As water boils, at 100°C (212°F) at sea level, it changes to steam. But water can change to vapor through evaporation at any temperature. Even though the water involved in any frost protection scheme will be no where near the boiling point, evaporation of the water to vapor may occur.

**CHANGES OF STATE - water/vapor** - Evaporation of water to vapor at the same temperature of the original water requires the addition of heat in the amount of 9,000 BTU/3.7 lit.(1 US gallon). Condensation of the vapor to water (as on a cold drink glass) without temperature change releases 9,000 BTU/3.7 lit.(1 US gallon). The 9,000 BTU/3.7 lit.(1 US gallon) of heat involved in this state change is called the "heat of vaporization" (sometimes called the latent heat of vaporization).

## The Role of Water in Frost Protection

BTU= (British Thermal Unit)

The amount of heat needed to raise the temperature of one pound (0.4 kg) of water by 1°F (0.5°C)

<sup>1</sup> Director, Center for Irrigation Technology. California State University, Fresno, California

**CHANGES OF STATE - ice/vapor** - Although we don't usually think about it, H<sub>2</sub>O can change state from solid to gas (and back) directly, without going through a liquid phase. The heat required to evaporate ice at 0°C (32°F) to vapor at 0°C (32°F) is 10,200 BTU/3.7

lit.(1 US gallon). As vapor at 0°C (32°F) condenses to ice, also at 0°C (32°F), heat in the amount of-10,200 BTU/3.7 lit.(1 US gallon) is released.

## Other physical properties

Water has other properties of specific significance to frost protection schemes. Specifically worthy of men-

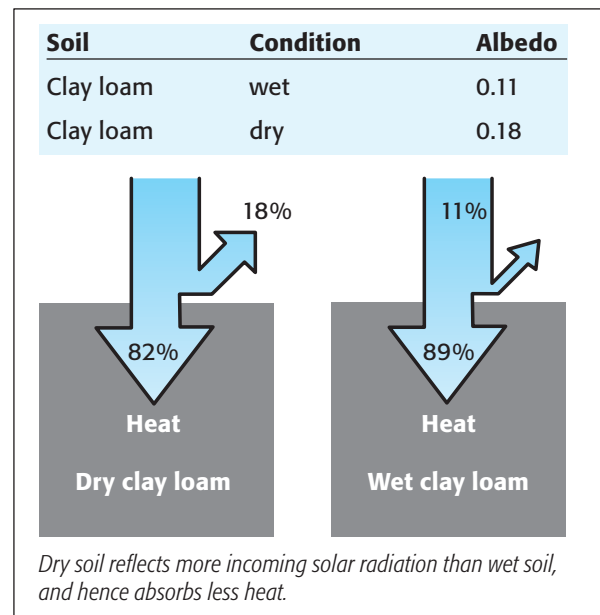
tion here is the fact that water can affect the way in which the soil interacts with light and heat.

### Albedo

"Albedo" is a fraction representing the portion of incoming radiation that is reflected by the soil. The higher the albedo, the higher is the portion of the incoming radiation that is reflected and not absorbed by the soil. (The albedo of a white car would be higher than that of a black car, which absorbs heat more readily.) Wet soils typically have lower albedos than dry soils. For example, Hanks and Ashcroft (1980) report albedos for wet and dry clay loam soil in the following table.

Soil	Condition	Albedo
Clay loam	wet	0.11
Clay loam	dry	0.18

Wet soil absorbs more and reflects less of the incoming energy it receives than dry soil. This allows wet soil to absorb more heat during the day which might be released beneficially at night when frost damage is potentially the greatest. Secondly, the presence of water in the soil increases its "heat capacity," or ability to hold and store heat. Soil with a volumetric moisture content of 0.2 (20% water by volume) can hold twice as much heat per unit volume as can dry soil. So a wet soil is able to absorb more of the energy it receives, and can store more of that energy than can a dry soil.



## Frost protection schemes

**OVERCROP SPRINKLING** - With this method, water is applied above the crop by sprinklers. Water supplies heat to the crop-water-air system, which is released as the water cools to 0°C (32°F), and then freezes to ice. The major factor here is the heat of fusion released as the water freezes. If, for example, the temperature of the water supply is 17°C (62°F), a 3.7 lit.(1 US gallon) of water will supply 17-0°C (62-32°F) x 8.3 BTU/°F = 249 BTU of heat as it cools from 17-0°C (62-32°F). In freezing, however, this same 3.7 lit.(1 US gallon) of water releases 1,200 BTU of heat. Water will also take heat away from the system as it evaporates. Evaporating water will take away 9,000 BTU per 3.7 lit.(1 US gallon). The evaporation rate will depend on the humidity of the air (greater evaporation with lower humidity) and the wind speed (greater evaporation with higher wind speed).

al. (1990), the physics of heat transfer during under-tree springing are not fully understood. However, it seems that the same mechanisms mentioned in regard to overcrop sprinkling are also involved here. Heat will be released by cooling and freezing water, and will be absorbed by water evaporating. Barfield et al. (1990) suggest that in addition, heat may be transferred to the crop as vapor and mist diffuse through the crop canopy and condense or freeze there, releasing heat.

In order to maintain a positive heat contribution to the system, much more water must freeze than evaporates. At least 7.5 times as much water must freeze as is evaporated (9,000 BTU/3.7 lit.(1 US gallon) evaporated § 1,200 BTU/3.7 lit.(1 US gallon) frozen = 7.5) if the net benefit is to be positive. For every 3.7 lit.(1 US gallon) that evaporates, 7.5 x 3.7 lit.(1 US gallon) or more must freeze to have a net heat gain.

**FOGGING** - Barfield et al. (1990) suggest that the production of fog (10 - 20 micron drop size) by special fog generators may provide frost protection because (1) the fog inhibits the radiating heat loss from the orchard, and (2) the fog transfers heat to the crop as it condenses and freezes, in a manner similar to under-tree sprinkling systems. It should be noted that drops small enough to qualify as fog are not produced by sprinklers normally used for undertree sprinkling.

**FLOODING** - Wetting the soil in anticipation of frost conditions may provide benefit in some circumstances. As noted before, wetting the soil reduces soil albedo, increasing the soil's ability to absorb energy. Wetting also increases the soil's heat capacity, so the soil can store more heat. If conditions are such that additional absorbed and stored heat is released during frost danger periods, some benefit will accrue.

**UNDERTREE SPRINKLING** - According to Barfield et

**SPRINKLING FOR COOLING TO DELAY BLOOM** - The efficacy of this procedure has been questioned

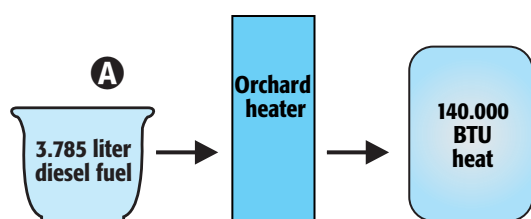
for a variety of reasons, but to the extent that it is effective, it relies on evaporative cooling. As water is vaporized, it draws heat from the air, cooling the environment. The cooling either prolongs the crop's dormant

period, or delays its accumulation of heat units. Hopefully, this will delay the development of buds until after the danger of frost has past.

## Comparison Fuel - Water

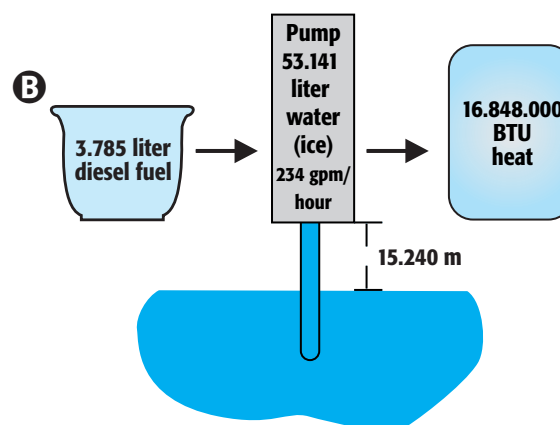
That water can play a very significant role in frost protection can be demonstrated by an example comparison. Suppose you have 3.7 lit.(1 US gallon) of diesel fuel. This can be burned in an orchard heater

system to produce heat and protect the crop. The energy content of this 3.7 lit.(1 US gallon) of diesel fuel is about 140,000 BTU, so if the fuel is burned, it will release 140,000 BTUs of heat into the orchard.



**A** A 3.7 lit.(1 US gallon) of diesel fuel can be burned in an orchard heater, producing 140,000 BTU of heat.

As an alternative, the 3.7 lit.(1 US gallon) of diesel fuel can be used to power a pump providing water to the orchard via a sprinkler system. 3.7 lit.(1 US gallon) of diesel fuel is sufficient to pump water at a rate of 234 Gallons for one hour\*. Pumping at that rate and time produces 234 Gallons x 60 min/hr x 1 hour = 14,040 3.7 lit.(1 US gallon)s of water. As this amount of water freezes, it releases 14,040 3.7 lit.(1 US gallon)s x 1,200 B'lwU/3.7 lit.(1 US gallon) = 16,848,000 BTU of heat into the orchard.



**B** As this water freezes, it releases 16,848,000 BTU of heat.

- Frost protection with water may be many times more energy-efficient than using orchard heaters. In the example above actually 120 times more efficient.
- In summary then, the role of water in frost protection is to use its physical properties to add heat to the crop in such a way as to protect it.

## Frost Protection by Sprinkling

Protecting crops against damaging late spring frosts has always been a problem for horticulturists in New Zealand, and particularly so for the orchardists in the Central Otago area where frost protection has been required ever since commercial operations began in the 1930's.

Prior to about 1974 virtually all frost protection was carried out using oil-fired orchard heaters, although a few growers were using overhead sprinkler systems. Sprinkler methods had also been under investigation since the mid-1960's by the DSIR Plant Diseases Division at their research orchard at Earnsclough.

The results of this work demonstrated that overhead sprinkler systems could cope with most of the frost conditions experienced in Central Otago and established the basic design parameters relating to application rates and rotation times. The foresight of those involved in this work became evident in 1973, which saw the beginning of a sequence of continuous oil price rises and shortages of oil.

It soon became apparent that oil-fired orchard heating systems would no longer be economic and growers were able to turn to overhead sprinkler systems with the knowledge that this method had been proved successful under New Zealand conditions.

By 1976 a considerable number of growers had installed sprinkler systems in Central Otago. There was concern, however, that the performance of some of the installed systems was not up to the standard expected. At this time the Institute was approached by both the M.A.F. Advisory Services Division and the DSIR Plant Diseases Division to see if it could assist in resolving some of these problems.

During the early part of this study it became apparent that the biggest problem was the lack of appreciation by growers, designers and contractors of the importance of uniformity of water distribution. Although most systems were applying the required average application rate, sprinkler spacings were, in some cases, so great that the resulting distribution pattern would not provide adequate protection over the whole area. Our initial approach was therefore to demonstrate the **importance of uniformity** and to provide advisory staff with performance data for the various combinations of sprinklers and spacings then in use.

As frost events usually occur under near-calm conditions it was felt that the sprinkler performance data collected under still-air conditions could reasonably be used to predict system performance. A programme of sprinkler testing was undertaken using the various types of sprinkler, nozzle sizes and operating pressures in common use in the Central Otago area.

The performance of these sprinklers at various spacings was then estimated by using a computer overlapping technique to calculate, from the still-air distribution patterns, the probable overlapped distribution pattern.

Since this initial work in 1976 the horticultural industry has undergone considerable expansion both in terms of the areas being developed and the type of crops grown. In many cases the installation of frost protection systems has been considered an essential part of this development and this has resulted in continued requests for performance data for different sprinklers and in particular, different spacings.

As a consequence of these requests a considerable amount of estimated performance data for a range of sprinklers, nozzle sizes, pressures and spacings has been collected. The major function of this report is to summarise this information so that it becomes more readily available to designers of frost protection systems.

## Overhead Sprinkling

The particular factor that makes it possible to protect crops from frost damage by sprinkling with water is the large amount of heat which is released when water changes from a liquid to a solid.

When a cubic meter of water is cooled by **one degree Celsius, 1.2 kWh of energy is released.** This amount of energy is released for every degree of cooling that takes place until the temperature reaches zero.

At this point a very much larger amount of energy is released as the water undergoes a change of state from a liquid to a solid. In fact about **93 kWh of energy is released when one cubic meter of water changes from a liquid at 0°C to ice at the same temperature.**

It should be noted that as far as frost protection is concerned the initial temperature of the water is of little consequence, as a relatively very small amount of energy is made available from the cooling of the water in comparison with that made available from the change from liquid water to ice. **The objective of a sprinkler frost protection system is therefore to maintain a film of water over the particular organs of the plant to be protected.** Even if a layer of ice forms, the temperature of the ice and the plant tissue inside it will not fall appreciably below zero as long as the surface of the ice is kept wet.

The factors involved in maintaining a film of water over the whole plant structure are complex.

• **The amount of water applied must be such as to provide sufficient heat release to prevent the temperature from falling below the critical level.**

At the same time the plant is only capable of “holding” a certain amount of water and this will vary, depending on the type of plant, the particular stage of growth and the way in which the water is applied.

• **Ideally the water would be supplied continuously and at a rate just exceeding that required to release enough heat energy to keep crop temperature above the critical value.**

This concept has been adopted on an experimental

basis by using small spray nozzles mounted above each tree. In the field situation, however, this is not very practical because of the large amount of pipework required. Instead, conventional impact-drive sprinklers are used. Because of the intermittent nature of the application made by these sprinklers two factors are very important:

- **The application rate**
- **The sprinkler rotation time**

If insufficient water is applied or the time interval between applications is too long, all the water applied in one application (rotation) will freeze and the temperature may drop below the critical value before the next application is made.

At first sight it may appear that the rotation time is self-compensatory in that the slower the rotation rate the more water is applied per revolution. This overlooks the question of how much water can be “held” on the foliage and branches of the tree.

Once the tree or plant is “full” any further application of water will just run off and be wasted. The balance between rotation rate and application rate is therefore very important. Research in both New Zealand and overseas indicates that rotation times in the range of 30-60 seconds provide adequate performance, with the upper limit being considered an absolute maximum. (Hewett, 1971; Wolfe, 1969).

Although it would be desirable to be able to vary the application rate to match the prevailing conditions, this is impractical with conventional sprinkler systems which must, therefore, be designed to cope with the most severe conditions likely to be encountered. Table 1 lists suitable average application rates which may be used for design purposes. Hewett (1971) suggests that for Central Otago conditions an average rate of 3.8 mm/hr should be adequate, while for less frost-susceptible areas, say from Canterbury northwards, this figure could be reduced to 3.0 mm/hr.

Suggested average application rates for overhead sprinkler frost protection systems.(After Hewett, 1971).

Deciduous fruit trees (°C)					
Application rate mm/hr	2.5	3.0	3.8	4.6	6.4
Min. temp. screened thermometer	-2.2	-3.3	-4.2	-4.7	-5.8
Approx.min. temp. exposed thermometer	-3.3 to -3.9	-4.4 to -5.0	-5.3 to -5.9	-5.7 to -5.8	-6.9 to -7.8

Low growing crops (°C)					
Application rate mm/hr	2.5	3.0	3.6	4.6	
Min. temp. screened thermometer	-2.2	-3.3	-5.0	6.7	
Approx.min. temp. exposed thermometer	-3.3 to -3.9	-4.4 to -5.0	-6.1 to -6.7	-7.8 to -8.3	

*Note: A screened thermometer is one that is arranged so that it is not exposed directly to the sky. For a description of temperature measurement in orchards and for further details regarding the above Table, readers are referred to Hewett, 1971.*

It must be emphasised however that these application rates will provide protection **only if the application is uniform**. It is not always possible to achieve high levels of uniformity with the relatively low application rates required, especially when sprinkler and lateral spacings are constrained by tree spacings.

In addition there is no easy way of assessing the reduction in frost protection performance due to a given reduction in uniformity. This problem has led the Institute to adopt the concept of the minimum application rate necessary to provide adequate protection as a performance parameter. The use of this parameter has been made possible by the use of the computer overlapping programme, which enables the percentage of the area receiving less than or equal to any given application rate to be determined very easily.

Sprinkler systems can therefore be assessed on the basis of the percentage of the area not likely to receive adequate protection, a more meaningful parameter than some sort of uniformity coefficient.

The only problem in developing this approach was in deciding on suitable values for the minimum application rate as most of the available research results are expressed as average application rates.

By assuming that a statistical normal distribution adequately describes the population of intensities produced under a sprinkler system, Hart and Reynolds (1965) showed how the application rate equalled or exceeded over any given percentage of the sprinkled area, could be calculated for a given average application rate and a given value of Christiansen's Uniformity Coefficient.

This technique was used to determine the probable minimum application rates occurring under systems having the average application rates contained in the previous recommendations. In doing this it was assumed that the frost protection systems used for the research trials applied the water uniformly (Christiansen's uniformity coefficient of 80%) and were attempting to obtain almost complete protection (over at least 90% of the sprinkled area).

Using this technique it was found that for an average application rate of 3.8 mm/hr and a uniformity coefficient of 80%, at least 90% of the area would receive an application rate of 2.5 mm/hr or more. Similarly, but for an average application rate of 3.0 mm/hr it was found that 90% of the area would receive 2.0 mm/hr or more.

The calculations suggested that where an average application rate of 3.8 mm/hr had been recommended a minimum rate of 2.5 mm/hr is required to achieve adequate protection and where an average of 3.0 mm/hr had been recommended a minimum rate of 2.0 mm/hr is required.

These two values have been adopted as minimum design rates and the performance data includes the percentage of the sprinkled area receiving application rates less than or equal to these two values, that is, **the percentage of the area likely to receive inadequate protection**. It is suggested that this parameter is one of the more important factors to be used in deciding on the adequacy of a particular layout.

## The Cold War is still alive!

"Cold has caused more tree deaths than all other calamities in the industry combined," Faryna says from his Florida home. The Christmas 1983 and January 1985 freezes alone eliminated more than a fourth of the state's total citrus acreage. And an unfair portion of the losses occurred in Lake, Orange and other Florida northern citrus belt counties.

## Elevating microsprinklers for cold protection

It's only partly because he battles freezes annually for himself and numerous customers that we asked Faryna to share his cold protection techniques. It also helps that the 50-year-old grower has been in the caretaking business since high school. Another major reason we called on him is the fact that he devised the technique of elevating microsprinklers to give trees better protection from the cold.

The third-generation grower elevated a few micro-sprinklers with good results in the 1983 freeze and elevated many sprinkler jets in 1985. Bolstered by his earlier successes, he elevated the sprinkler heads on all trees he cared for in the 1989 freeze. Trees defoliated and there was some hand pruning, but the trees didn't die.

"Without the elevated jets, this citrus would not be here today because we were able to bring it through

1989 with temperatures in the teens," Faryna says. His innovative but proven technique is now used by most northern tier growers.

He says his decision to elevate microsprinklers when no one else had suggested it was "just self survival." He figured that by elevating the sprinklers so the trunk and scaffold would be bathed with water, "in theory, it couldn't freeze."

## Have a plan

The first thing is, you need to have a plan and you need to implement it in late summer or early fall," Faryna says. No plan will fit all growers; it must be tailored to individual groves.

Faryna urges growers to think about scenarios in which they would use water for cold protection, as well as situations in which they wouldn't.

This planning process helps growers make better decisions when a freeze arrives. "We've had some growers use water improperly and cause some problems," he says. "When things start happening, sometimes you don't think as clearly when the pressure's on."

As part of your planning, seriously consider elevating your microsprinkler jets if your grove is located in an area prone to severe cold (see 'Jet Placement' later).

Case Study

1

The Cold War is still alive!

Case Study

1

## Reliable pumps and water sources

Make sure your pumps are working well in advance of freeze season. Have your diesel engine serviced, and have a good auxiliary fuel system on it. "Spend a few minutes looking at belts, hoses and fuel filters," Faryna says. Replace worn ones and old ones.

"Try to avoid filling the fuel tank the day you're going to run because that stirs the sediment in the tanks, and that can clog the filters," Faryna cautions.

"It's important to have enough fuel capacity to run at least two nights," he adds. In the 1989 freeze, he had to run pumps for 48 straight hours.

If you pump out of lakes, make sure the suction line is covered by enough water to work properly and that the straining screen is in good shape. Look closely at the filtration system to ensure clean water is coming out.

Check your microsprinklers. "Have the jets properly clean so they're all working."

Most growers in the northern tier have gone to diesel pumps to ensure they can pump water throughout an entire freeze night or two. Many who relied on electricity in the 1980s lost their trees when electric companies shut off electricity, eliminating the tree-saving flow of water.

Faryna urges any of his caretaking customers who still use electric pumps to switch to diesel. "If the forecast is for a critical event (like temperatures in the teens or low 20s), that's easy, turn it on," Jackson says. "No matter what the conditions are, water helps in a critical freeze."

If you rely on electric pumps, have back-up generators in working condition.

## A good forecast

"Have a reliable forecast - one you have confidence in," Faryna suggests. "And try to understand what the forecast means for you."

By tracking weather information in areas north of the citrus belt, he can see if a freeze is as bad as predicted before it gets to him. If it's not, he can probably figure it won't be as bad in Umatilla, either.

Once you have a reliable forecast, you need to consider what that forecast will mean in your grove. Proximity to a lake may make your grove warmer than the forecast temperature; being in a low pocket may make it colder.

## Selecting a Jet

"We select our jets up here primarily for cold protection," Faryna says. "For cold protection, a random droplet jet seems to work best. The random droplet will strike the crotch of the tree and bathe it and protect it.

We try for a minimum of 56 lit. (15 gallons) per hour per tree, but understand that some systems don't have that capacity."

In the summertime, Faryna says, the random droplet jet provides "OK" irrigation coverage, not as good as some other styles. Jets with moving parts or spinner types are prone to stick and freeze. But they tend to provide better irrigation coverage. Remember that cold protection is the top priority in Umatilla.

## Jet placement

Microsprinkler jet placement is critical for cold protection. Place the jet "under the tree as close as practical on the northwest side," Faryna says. Since most killer freezes blow in from the northwest, the water from the microsprinkler will be blown into the tree, providing protection.

Tree root density may keep you from getting the jet right up against the tree, but get it within a foot. This placement also keeps it out of the way of herbicide booms.

Now for the idea that has made Faryna somewhat famous, at least locally - elevate the microsprinkler jet 55-75 cm (24-30 inches) above the ground on half-inch PVC pipe. From this height, the water will bathe the trunk and scaffold limbs.

"You need to wrap the poly tube around the PVC stake several times to prevent ice loading from pulling the jet down," Faryna says. He laughs: "That's called learn the hard way."

The caretaker says the elevated water supply makes it easy to protect a one-year-old tree. Although the protection is diminished in trees that are 10-15 years old, there's still some protection. So he uses elevated microsprinklers in all trees, regardless of age. "We don't skirt our trees, and feel that the lower skirts help contain the heat from the cold protection process."

Some might conclude that if elevating the microsprinkler 30 inches is good, elevating it more would be even better. Faryna thinks they'd be wrong. "Don't be greedy," he says. "You're going to get ice loading that's going to cause a lot of damage. You can't protect the whole tree - you need to protect the trunk and scaffold limbs."

Faryna adds that while elevated microsprinkler jets with random droplets work well in the northern citrus belt, "this is not for everyone." Growers in southern areas of the citrus belt where freezes seldom occur might prefer to use non-elevated spoke jets which provide better irrigation coverage.

"We use tree wraps on our young trees as an additional level of protection with the elevated jets," Faryna says. If your pump or water source fails, "the wrap could give you something to work with" by holding in some of the tree's heat.

## To water or not?

Don't waste your time calling Faryna the afternoon before a freeze to ask him if you should run water. He makes that decision for scores of growers who trust him with their total grove care, but not for anyone else. "Water can be good and it can be bad," he says. "It can cause damage under the wrong conditions."



**“You have to be prepared to accept the responsibility” whether to run water, Faryna declares. “It’s very unfair to ask someone else to make the decisions for you and then judge after the fact. You have to play your hand the best you can. I don’t think anyone can say, ‘You need to run tonight.’”**

There is one situation where the call is easy, according to Jackson. He says it’s easy to decide to use water on a night when temperatures are forecast to be in the teens. “If the forecast is for a critical event (like temperatures in the teens or low 20s), that’s easy, turn it on,” Jackson says. “No matter what the conditions are, water helps in a critical freeze.”

It’s trickier planning for a night when the forecast is for a low of 27 degrees, though. “The marginal forecast with dry air, low dewpoints and wind, in that situation you’re going to cause damage (by applying water),” Faryna says. The damage in this situation would be caused by evaporative cooling, which can make the tree colder than it would have been if no water had been used. “With air temperature of 27, water could take you to 24 degrees.”

## When to start?

You’ve decided to run water. When do you turn it on? “Start early,” is Faryna’s advice. Then if you have a dead battery or a pump problem, you can fix it and still get going. But if the temperature has dipped to 32 degrees at the microsprinkler jet, it’s probably already frozen and you’ll never get it running.

Faryna points out that a grower with one or two blocks can wait longer to start running water than a caretaker with scores of pumps. The grower might get his pumps going in minutes; it’ll take Faryna’s five-man crew three or four hours to crank 85 pumps irrigating thousands of acres.

He won’t say exactly when to start because “no two situations are alike.” He will say that if you’ve decided to run water, you’d probably better start before the temperature dips below 2°C (34°F) at the microsprinkler jet. And if you have lots of pumps to crank like he does, you’ll have to start some when the temperature is higher.

Jackson says if he decided to use water, “I’d turn them on at 2-3°C (36-38°F)” if that temperature is reached in the afternoon or early evening. He adds that most growers who use water turn it on before sunset, while some turn water on when the temperature hits 2.0-2.5°C (36-37°F).

Faryna also urges growers not to start running water hours before it’s necessary, because that’s wasteful of water.

“Be mindful of the water resource,” he says.

## When to stop

“You don’t have to wait until all the ice is melted” the day after a freeze to shut off water, Faryna says.

“You can shut off safely a lot of times before the ice is melted” - often at 35 or 37 degrees.

Jackson says research has indicated water can be shut off safely after a freeze when the wet bulb temperature has reached 34 degrees. The wet bulb temperature is the temperature air cools to when water is added, and is measured with a sling psychrometer.

If you don’t have a sling psychrometer and don’t know what the wet bulb temperature is in your grove, you’re like most growers. Never fear: Jackson said FAWN will provide wet bulb temperatures on its Inter-



net site starting this winter. Jackson said a wet bulb reading close to your grove will usually suffice since humidity varies little over broad areas.

## After freeze season

When the freeze season ends, Faryna removes tree wraps because he fears they could contribute to phytophthora development.

He also fears that leaving the microsprinkler jets elevated, where they keep the tree trunk wet much of the year, could contribute to phytophthora. He smiles and says, “I advise caution to all of us growers who are doing that.”

Faryna and some other growers leave the microsprinkler jets elevated year-round because it’s expensive to put them up and take them down. Jackson estimated it costs \$40 per acre in labor costs to elevate and then lower the jets. He thinks about half of Lake County’s growers who elevate jets take them down in the spring.

## Citrus in north central Florida after the 1980s freezes

Case Study 2

A survey of north central Florida citrus growers who suffered drastic losses in the 1980s freezes reveals how some of those growers have coped.

The survey of 30 growers in Lake, Marion, Orange, Pasco, Seminole and Volusia counties was conducted in the 1998-99 season. Twenty-nine of the 30 growers were male, with the greatest percentage in the 60-69-year-old age category. Former University of Florida graduate student Joan Carter conducted the survey as part of her work on a master's degree in geography. She wrote an article about the survey's results with UF extension horticulturist Jim Fergusson.

Following are some excerpts from the article:

- Most growers surveyed lost from 75 to 100 percent of their groves during the freezes of the 1980s. When these seasoned growers replanted after the 1985 freeze, they reduction strategies to minimize future freeze damage. Microsprinkler irrigation for freeze protection was the most commonly cited strategy, with one grower using both three microsprinklers per tree and grove heaters.
- Tree density per acre for all citrus increased from 82 trees per acre in 1975-76 to 128 trees per acre during the 1995-96 season ... Respondents mentioned higher tree densities as a strategy to improve both freeze protection and early returns but acknowledged that this was at the cost of increased irrigation rates and other per acre production costs. Several growers reported planting trees, especially on Flying Dragon rootstock at densities of 250 to 359 trees per acre. One grower who had doubled his tree density over plantings lost during the 1980s said he would increase tree density even more while another had reservations because pickers objected to harvesting fruit within the closely planted rows.
- Rootstock and scion selection was another element of risk management for growers replanting groves after the freezes of the 1980s... Many growers in this survey planted trees on trifoliate orange, Flying Dragon, Cleopatra mandarin and Swingle citrumelo rootstocks... Growers selected scion cultivars based on the following strategies: 1) early, high maintenance fresh fruit brings high prices and avoids freezes 2) mid and late season cultivars are lower maintenance, bring lower prices, but can be sold under most conditions, barring a major freeze.
- Growers indicated they used multiple sources for information about citrus production. Other growers and newspaper/magazines were the most commonly cited source, followed by agrochemical representatives, extension agents, grower organizations and electronic and Internet sources. Large growers use the Internet for email, and computers for weather information, recordkeeping and production automation. Fewer

small growers used computers. Computers were also used more by younger than by older growers.

When growers were asked about their sources of influence when they made plans for substantial changes to their operations, they indicated they read research results and studies, observed what others did and conferred with family or partners. To a lesser degree they consulted with agricultural agents and other professionals.



- More than half of the respondents reported they use agricultural diversification strategies, including other horticultural crops like watermelons and other fruit crops, producing honey, raising livestock and pursuing organic certification. Citrus income tended to be a complementary source of income for about two-thirds of all growers surveyed. Only one-third relied on citrus for at least 75 percent of their household income.
- All but one of the 30 growers were producing citrus before the freezes of the 1980s. Their decision to replant groves appeared to be related to their perception that they could effectively adjust their production practices to freeze risks and their acceptance of the risks as they saw them. Perhaps the greatest single factor here was intensification: increasing inputs to generate greater and earlier returns, including microsprinkler irrigation and greater tree densities.
- The relationship between growers and the marketing chain has also changed, with fewer packinghouses in this region and the utilization by some growers of direct marketing and other innovative sales arrangements. From 1978 to 1997 the number of packinghouses statewide decreased by 15 percent from 152 to 128.

<sup>1</sup> CITRUS INDUSTRY • November/December 2000

# Overtree Sprinkling Provides Orchard Frost Protection

Overhead or overtree (OT) sprinkling provides the highest level of frost protection of any available single field system, and it does so at a very reasonable cost. However, there are several disadvantages to OT sprinkling, and the risk is high if the system fails in the middle of a frost event. It is the only frost protection method that does not rely on the strength of the temperature inversion to contain or supply its heat, and it is the only system that can provide protection in windy frost conditions with proper design.

The entire block or orchard should be sprinkled at the same time when OT sprinkling is used for cold temperature protection. OT frost protection is not used with most stone fruit trees, since they may not be able to support the ice loads, and there may be some limb breakage. OT systems are never used with wind machines for frost protection. A trellis must be designed to withstand ice loadings if OT sprinkling for frost protection is anticipated.

Water requirements are quite high in this system. Generally, adequate levels of OT protection require that 31-36 l/acre (1.0-1.2 cm/h) 70 to 80 gallons/acre (0.15 to 0.18 inches) of water on a total protected area basis be available for the duration of the heating period. Dependable water supplies capable of sustaining 60 to 80 hours of frost protection per week at these rates are often required.

OT systems typically start earlier and run longer than undertree frost protection systems. The table presents suggested starting temperatures for OT sprinkling for frost protection. Because of the need to have a continuously wet, dripping canopy, it is generally recommended that individual sprinkler heads rotate at least once every 60 to 90 seconds. Precautions should be taken so that ice does not build up on the actuator springs or in the bearings and stop sprinkler head rotation.

### Suggested starting temperature

The following are suggested starting temperatures for overtree sprinkling for frost protection based on wet bulb temperatures to reduce the potential for bud damage from "evaporative dip".

Wet bulb temperatures		Starting temperature	
°F	°C	°F	°C
≥ 26	≥ -3.3	34	1.1
24 to 25	-4.4 to -3.9	35	1.6
22 to 23	-5.6 to -5.0	36	2.2
20 to 21	-6.7 to -6.1	37	2.8
17 to 19	-8.3 to -7.2	38	3.3
15 to 16	-9.4 to -8.9	39	3.9

Under mild to moderate frost protection conditions, cycling of OT frost systems is possible if the following conditions are met:

- Adequate computerized controls are available to monitor bud temperatures and to cycle water applications

- There is still adequate water and the hydraulic capacity to operate the entire system at one time over extended periods (if the bud temperatures approach critical levels)

- The buds and tree maintain unfrozen (free, dripping) water at all times.

This is a high risk option! It is recommended that OT systems for frost protection not be cycled.

Bloom delay is OT evaporative cooling in the spring. It is intended to delay bloom, which ostensibly keeps the buds "hardy" until after the danger of frost has passed. It has been found to delay bloom of apples, peaches, pears, and other crops. However, it has not been successful as a frost control measure on deciduous trees, because of water uptake by the buds which causes them to lose their ability to supercool. This results in critical bud temperatures that are almost the same as those in non-delayed trees. In other words, although bloom is delayed, there is no delay in critical bud temperatures and, thus, no frost benefit.

The most important variable influencing frost damage to blossoms is the development state. In general, the more developed a flower, the more sensitive to damage it will be.

It may be possible to delay bloom and thus reduce the chance of frost damage. Sprinkler irrigation of orchards after the rest period is completed and any time the temperature is over 45°F has experimentally been shown to cool buds enough to delay bloom up to two weeks.

Bud Development Stage	10%		90%	
	°C	°F	°C	°F
<b>PEACHES</b>				
First swelling	-8	18	-17	1
Calyx green	-6	21	-15	5
Calyx red	-5	23	-13	9
First pink	-4	25	-9	15
First bloom	-3	26	-6	21
Full bloom	-3	27	-5	24
Post bloom	-2	28	-4	25
<b>CHERRIES</b>				
First swelling	-8	17	-15	5
Side green	-6	22	-13	9
Green tip	-4	25	-10	14
Tight cluster	-3	26	-8	17
Open cluster	-3	27	-6	21
First white	-3	27	-5	24
First bloom	-2	28	-4	25
Full bloom	-2	28	-4	25
Post bloom	-2	28	-4	25
<b>APRICOTS</b>				
Tip separates	-7	20	-18	0
First swelling	-9	15	-	-
Red calyx	-6	22	-13	9
First white	-5	24	-10	14
First bloom	-4	25	-7	19
Full bloom	-3	27	-6	22
In the shuck	-3	27	-5	24
Green fruit	-2	28	-4	25
<b>APPLES</b>				
Silver tip	-9	15	-19	2
Green tip	-8	18	-12	10
Half-inch green	-6	23	-9	15
Tight cluster	-3	27	-6	21
First pink	-2	28	-5	24
Full pink	-2	28	-4	25
First bloom	-2	28	-4	25
Full bloom	-2	28	-4	25
Post bloom	-2	28	-4	25

## Overtree Sprinkling

### Case Study

# 3

<sup>1</sup> FRUIT GROWER, March, 1995

## Experience with frost protection in California vineyards

Frost protection in North Coast vineyards has always been a problem in some of the more desirable growing areas. Growers need to consider several potential problems when considering the needs for frost protection. Fortunately, winter kill is seldom a problem in the North Coast. (We all hope that December 1990 was an exception). Low temperature problems generally occur in the spring. Temperatures of -0.5°C (31°F) sustained for a couple of hours, can kill all green growth and opening buds. Several degrees of damage can be experienced from just barely damaging young shoot tips through completely killing entire shoots, including clusters.

Once the damage is assessed, decisions must be made whether to remove the damaged shoots to encourage the pushing of the secondary and/or tertiary shoots or to do nothing and hope for the best. The degree of damage is also related to the amount of growth that has occurred before the frost. Young shoot tips and flower clusters are less cold hardy than more mature wood and leaves. Cold damage is generally believed to be caused by the formation of ice crystals in the liquid of the cells and, as it expands, the rupturing of cell walls occurs and dehydration causes death. Stored carbohydrates can slow this process and affect the degree of damage that will occur.

The practical side of frost protection for a grower has many ramifications:

- 1 Young vines planted the previous spring. Greenhouse bench grafts need protection during the winter and early spring. This is accomplished by mounding over with soil or filling the protective milk carton with soil, sand, or pine shavings. If shavings are used, be careful not to allow rot organisms to start during wet-springs. We lost a great number of unprotected vines during the unprecedented cold last winter. Remember, it is also several degrees colder at ground level especially with little or inadequate weed control.
- 2 Two and three year old vines that are being trained up the trellis are subject to greater damage if they have been "pushed" the previous season and did not really harden off.
- 3 Varieties vary in the time they push in the spring, i.e., Chardonnay push earlier than Cabernet Sauvignon. This could be a consideration in where to plant.
- 4 One frost in the spring can reduce cropload by as much as 50 percent therefore there is no such thing as "I cannot afford frost protection". It really means that you cannot not afford it if you need it.
- 5 Spring "T" budded or sidewhip grafted vines are particularly sensitive to winter kill problems because without a cropload they tend to continue to grow later and the wood does not mature as well. This is particularly true in deep soils and vigorous rootstocks such as St. George.
- 6 Cultural practices can affect ground temperature and its heat-absorbing ability and result in the following:

• Bare, firm, moist ground	warmest
• Shredded covercrop, moist ground	0.2°C (½°F) colder
• Low growing covercrop, moist ground	0.4-1.2°C (1-3°F) colder
• Dry, firm ground	0.8°C (2°F) colder
• Fresh, disked, fluffy ground	0.8°C (2°F) colder
• High cover crop	0.8-1.6°C (2-4°F) colder
• High cover crop with restricted air-drainage	2.0-2.8°C (5-7°F) colder

The necessity of frost protection is dependent upon many factors including topography, elevation, slopes, air drainage, variety, and obviously the generalized climate of the area. The North Coast, the Russian River Valley, Knight's Valley, Carneros, and Ukiah are all considered frost-prone areas. Elevations above 600 feet are generally frost free. In other words, the need for frost protection ranges from none to absolutely essential.

Frost protection techniques, other than cultural practices, include overhead sprinklers, wind machine/orchard heater combinations, or straight wind machines. Other techniques such as plastic tubes with hot air and cyclic sprinkling have not proven successful. Antibacterial sprays to kill nucleating bacteria are being researched now and might be useful in the future.

### • Overhead Sprinklers

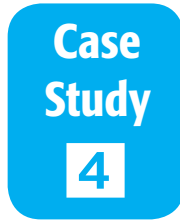
Water availability is the single largest problem with overhead sprinklers. With a water requirement of at least 189 lit.(50 gallons)/acre, reservoirs are frequently required for water storage thus increasing costs and utilizing land that might otherwise be planted.

Wells greater than 946-1135 lit.(250-300 gallons) are rare in the North Coast and are used for recharge only. Reservoir construction is also becoming more difficult due to the myriad of federal, state, county, and regional regulations limiting size, runoff area, construction techniques, and whatever else someone can think of to make it more difficult. Water Rights Laws are also being challenged on many fronts and we could well be in for some dramatic changes.

When determining total season water needs, always plan on the worst case scenario for your area. It is far better to have water left over at the end of the season than to run short on the last night or two.

The single most important aspect of an overhead sprinkler system for frost protection is the design. Correct engineering will ensure the proper application rate of 25 mm/acre (0.11 inch/acre) and a sprinkler rotation of at least 1 revolution per minute. Also the pump and engine must be compatible and we always recommend an internal combustion engine (diesel, propane, gas, etc.). Each has advantages and disadvantages but electric motors are never used due to the possibility of a power failure which is very likely on a frost morning. Power poles have a tendency to jump out in front of cars during frost periods. One small tip is to be sure and bury main line, submains, and laterals deep enough to avoid future problems when ripping or sub-soiling.

<sup>1</sup> Instructor, Santa Rosa Junior College Agriculture Department



A properly engineered and installed system does not insure that frost damage will be avoided. The system must be used properly for maximum frost protection. Many areas in the state have frost warnings on local radio stations and also a call-in-line (for growers only).

This will help the grower determine the possibility of a frost and where his ranch fits in compared to the key stations the forecaster is using. Dew point is also considered when frost is possible to help determine when (or if) to start the system. The lower the dew point, the warmer the pre-frost temperature needs to be when starting. This is because drier air creates greater initial evaporative cooling and results in a sudden drop of ambient air temperature.

Several charts are available and they recommend starting the system at 1°C (34°F) when the dew point is -3°C (26°F) and above. A dew point of -9°C (15-16°F) requires a 4°C (38-39°F) starting temperature.

In the field (coldest spots) temperature sensors are wired to an alarm and are set off at a predetermined temperature. This can be done over the telephone lines if needed for widely scattered locations. Vehicle-mounted sensors with in-the-cab readouts are also available to allow the grower to check actual temperatures in the field. The decision to begin protection varies each time depending on current conditions:

- potential fog moving in
- a breeze starting
- over-cast clouds moving in
- sheer luck

Once up and running, they must stay on until the air temperature rises above 0°C (32°F). Some growers believe in waiting until all of the ice has melted to be on the safe side. Experience is the only sure-fire way to determine the answer to all these variables and in some instances, even that has not been enough.

• **Wind Machine/Orchard Heater Combinations**

When adequate water is not available, the next alternative is the use of wind machine and orchard heater combinations. The effectiveness of these systems is dependent upon the spread in temperature between 4 feet and 40 feet above the vineyard floor.

A wind machine alone can generally raise the vineyard temperature about 25 percent of this difference. (In other words an 3°C (8°F) spread will give a 0.8°C (2°F) raise.)

The use of orchard heaters with 10-15 heaters per acre will frequently double this warming when burning at a full rate. Heaters can burn up to 1 gph of diesel and thus the labor of refueling daily and the cost of the fuel can be significant.

Controversy still exists about whether tall tower machines are better or worse than low profile machines. Most frequently total cost for the acreage is the deciding factor. With encroaching urbanization, growers must also be concerned about the noise pollution factor. Finally, and most importantly, the air pollution factor of the orchard heaters must be considered. **Be sure and check local ordinances!**

It should be clear that wind machine/orchard heater combinations are used in areas with little chance of severe frosts. The initial cost for this protection system is about equal to sprinklers (excluding water development) and operating costs are significantly higher.

Other possibilities will probably become available over time, but today we can summarize that overhead sprinklers perform the best over the widest range of temperatures when adequate water is available.

## Sprinkler application rates

Applying water directly to flower buds allows the heat released from freezing water to maintain a bud temperature near freezing, which is a few degrees above the critical damaging level. As long as the rate of water being applied and the rate of freezing are balanced, bud temperature will remain close to the freezing mark. Insufficient application can do more damage than no

protection at all, because evaporation may cause flower bud temperature to drop below air temperature.

One problem with overtree sprinkling is not knowing how much water to apply. Rates for different conditions have been determined using the sprinkler application rate model FROSTPRO (Perry, 1986) and are shown in the table below. Note that lower humidities will increase the application rate.

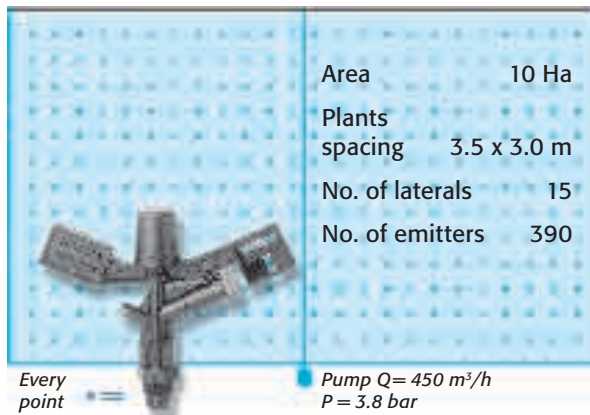
Sprinkler application rates from FROSTPRO, mm per hour				
Temperature (°C)	Wind speed (km)			
	1	2	3	6
-1	.05	.05	.09	.12
-2	.07	.10	.15	.16
-3	.10	.13	.20	.24
-4	.12	.17	.26	.32
-5	.14	.20	.31	.40
-6	.17	.24	.37	.47

Sprinkler application rates from FROSTPRO, inches per hour				
Temperature (°F)	Wind speed (mph)			
	1	2	5	10
30	.05	.05	.09	.12
28	.07	.10	.15	.16
26	.10	.13	.20	.24
24	.12	.17	.26	.32
22	.14	.20	.31	.40
20	.17	.24	.37	.47

Note: Results are based on the assumptions that the critical temperature of the bud is 28 F and the relative humidity is 75%

### Cyclone N-95

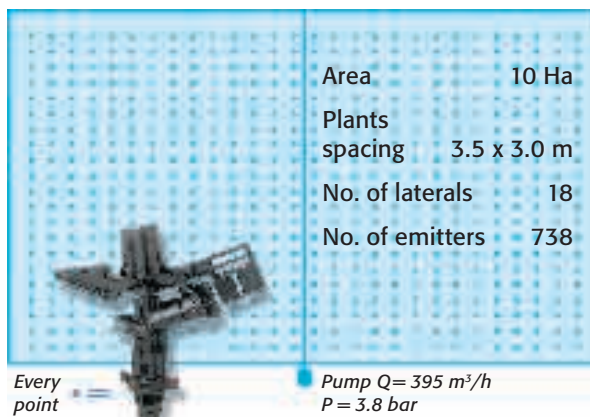
- A small number of sprinklers, very large water ducts.
- High pressure needed to operate them and as a result, high energy costs. If one sprinkler does not function because of a technical failure, a large area will not be protected.



Nozzle	3.5 + 2.2
Nominal emitter flow rate	1120 l/h
Distance between heads	16.0 m
Distance between laterals	17.5 m
Precipitation	4.08 mm/h
Discharge variation	11.06 %
Desing flow rate	450 m <sup>3</sup> /h
Desing pressure	4.6 bar
Horse power	106 HP
Conduction pipe 280/6	96 m
Conduction pipe 225/6	88 m
Conduction pipe 160/6	70 m
Conduction pipe 50/5	6000 m

### Cyclone N-85

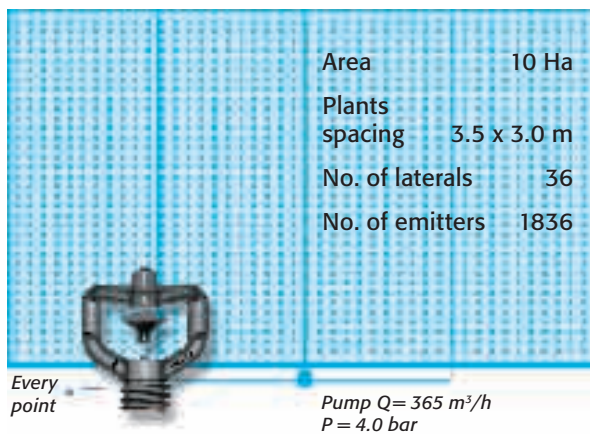
- A few sprinklers per area unit, large water ducts
- In this system, we need less energy than in the previous one because the sprinklers function regularly at a lower pressure and the influence of each sprayer on



Nozzle	2.45 + 1.5
Nominal emitter flow rate	530 l/h
Distance between heads	10.0 m
Distance between laterals	14.0 m
Precipitation	3.79 mm/h
Discharge variation	10.88 %
Desing flow rate	395 m <sup>3</sup> /h
Desing pressure	3.8 bar
Horse power	75 HP
Conduction pipe 225/6	145 m
Conduction pipe 160/6	107 m
Conduction pipe 50/5	7200 m

### Powernet 15°

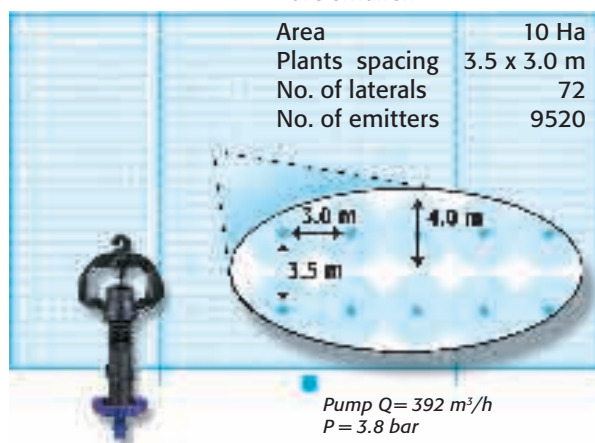
- These sprinklers are meant to supply a solution to those growers who do not want to use hammer-sprinklers to protect their crops, for fear of ice accumulation on the spring, which would stop the sprinkler's operation.
- Our hammer-sprinklers (95 and 85), used in anti-frost protection systems in hundreds of hectares around the world, function with no failures (the upper spring is covered so that no ice can accumulate upon it).
- Powernet sprinklers, which have no springs and function continuously, thus enhances the user's sense of security.



Nozzle	1.7
Nominal emitter flow rate	190 l/h
Distance between heads	8.0 m
Distance between laterals	7.0 m
Precipitation	3.55 mm/h
Discharge variation	7.52 %
Desing flow rate	365 m <sup>3</sup> /h
Desing pressure	4.0 bar
Horse power	73 HP
Conduction pipe 160/6	272 m
Conduction pipe 140/6	282 m
Conduction pipe 110/6	231 m
Conduction pipe 90/6	232 m
Conduction pipe 25/4	14400 m

## Supernet SR

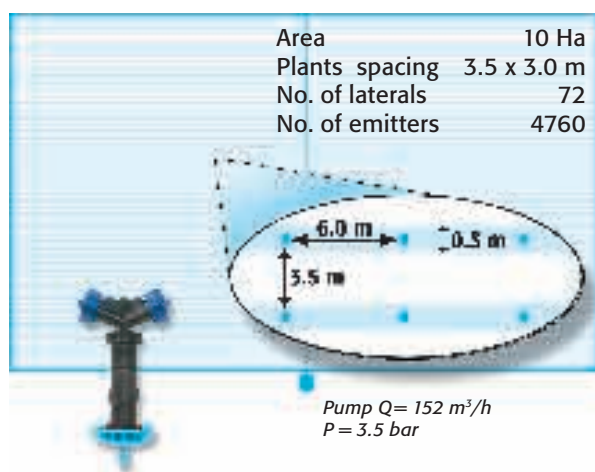
- A regulating mini-sprinkler is installed on each tree, ensures an optimal sprinkling rate on the protected area without wasting water on the areas between the trees. The longer is the distance between the plants, the greater will be the advantages of this system (in terms of water savings).
- A larger number of sprayers are indeed needed for the area, but the pipes' diameters are smaller.



Nozzle	0.7
Nominal flow rate	40 l/h
Distance between heads	3.0 m
Distance between laterals	3.5 m
Precipitation	4.41 mm/h
Discharge variation	0 %
Desing flow rate	392 m <sup>3</sup> /h
Desing pressure	3.8 bar
Horse power	74.5 HP
Conduction pipe 160/6	308 m
Conduction pipe 140/6	196 m
Conduction pipe 110/6	196 m
Conduction pipe 25/4	28800 m

## Stripnet

- This new regulating product gives anti-frost protection to vineyards and trellising cultures, irrigates narrow long strips and prevents irrigation of uncultivated areas.
- This system, though requiring a large amount of products per area unit, allows significant savings in water and energy.



Nozzle	0.5
Nominal flow rate	30 l/h
Distance between heads	6.0 m
Distance between laterals	3.5 m
Precipitation	10 mm/h
Discharge variation	0 %
Desing flow rate	152 m <sup>3</sup> /h
Desing pressure	3.5 bar
Horse power	26.6 HP
Conduction pipe 160/6	72 m
Conduction pipe 140/6	60 m
Conduction pipe 110/6	60 m
Conduction pipe 90/6	59 m
Conduction pipe 25/4	28800 m

## NET 0406 Controller

An analog temperature sensor connected to the unit, enables continuous reading of the temperature between -10o and 60o C. When the ambient temperature drops below the predefined set-point, the irrigation is started and will continue until the temperature raises above the second set-point.

Even if by mistake the relation is inversely defined, the controller will still execute the frost protection

The controller needs no external powering, it is operated by two 9 Volt alkaline batteries and it activates two wired 12V DC latching solenoid. Alternatively, a dry contact thermostat can be used.

The Controller can also activate a second output through which it signals to an external controller or to an alarming device that the frost protection process has started.

The Controller reports the currently measured temperature, the battery voltage, the current status, the number of activations by the sensor and informs about various kinds of malfunctions.





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