

Frost/Freeze Protection By Sprinkler Irrigation

By

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INTRODUCTION

Frost/freezing damage can cause severe crop losses for many fruits, vegetables and nursery crops. The most severe damage usually occurs when a freeze or frost takes place after buds and blossoms have begun to open. A severe freeze can also damage fruit which is already set, damage foliage, and can even kill limbs or entire plants. The degree of injury inflicted by low temperatures depends on a number of factors, including:

1. the type of plant and variety.
2. the stage of development of the crop. Most crops will not be damaged if a freeze occurs while they are dormant but can be severely damaged once buds and blossoms begin to open.
3. the amount of leaf cover over the blossoms and fruit. Leaf cover can provide some protection particularly against frost damage.
4. the severity and duration of the freeze. The colder the temperature and the longer the freeze period, the more severe the damage will be.
5. wind speed. A four mile per hour wind will prevent frost from forming as long as the temperature remains above 32°F.

Various means have been used by producers to minimize the effects of freezing temperatures. Some of the more common methods are orchard heaters, wind machines, and overhead sprinkler irrigation.

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Orchard Heaters:

Orchard heaters have been used for centuries to protect orchards. Most heaters are designed to burn oil and can be placed as freestanding units or supplied by a pipeline network throughout the orchard. Propane, liquid petroleum and natural gas have also been used as fuels. The initial cost is generally lower than for other systems, but the cost of the fuel makes this system the most expensive in terms of operating cost.

Wind Machines:

Wind machines can be effective during a radiation frost. Their purpose is to circulate warmer air

down to orchard level. A single wind machine can protect up to 10 acres. A typical wind machine is a large fan about 16 feet in diameter mounted on a 30 foot steel tower. The fan is typically powered by an industrial engine delivering 85 to 100 horsepower. Helicopters have been used as wind machines. They hover in one spot until the temperature increases, then they move to the next area. Repeated visits to the same area are usually necessary during a typical frost.

Sprinkler Irrigation:

Overhead irrigation is probably the most commonly used means of frost/freeze protection in the southeastern United States. Heat lost from the plant part to its environment is replaced by heat released as the applied water changes to ice. As long as water is supplied at an adequate rate the temperature of the plant will remain at or near 32° F. Advantages of overhead irrigation include lower operating cost, convenient to operate and multiple uses including drought prevention, heat suppression, fertilizer application and possible limb breakage from heavy ice loads.

Undertree sprinkler systems have also been used successfully for freeze protection especially in citrus groves in Florida. This system utilizes the sensible heat of the water to raise air and foliage temperatures. This system does not provide the same degree of protection as overhead irrigation because less heat is liberated than by the latent heat of fusion released when ice is formed on the tree surfaces. A major advantage of the undertree system is that limbs are not broken under heavy ice loadings. This can be a serious problem when using overhead irrigation on mature trees during an extended freeze.

This paper is intended to present the principles and methodology of frost/freeze protection using overhead sprinkler irrigation systems.

PRINCIPLES OF FROST PROTECTION BY IRRIGATION

Advective Freeze vs. Radiation Frost:

The term frost and freeze are often used interchangeably; however they are two separate conditions. An advective or windborn freeze occurs when a cold air mass moves into an area bringing freezing temperatures. Wind speeds are usually above five miles per hour and clouds may be present. Due to the high wind velocities cold protection is very limited during an advective freeze.

A radiation frost occurs on clear nights with calm winds. Air temperatures near the ground surface drop below freezing and there is normally warmer air higher in the atmosphere. This phenomenon is known as an inversion. Radiation frosts are usually shorter in duration than an advective freeze. Frost protection by irrigation is most effective during radiation frost conditions.

Irrigation for Frost/Freeze Protection:

In using overhead irrigation for frost/freeze protection the heat lost from the plant part to its environment is replaced by the heat released when water changes to ice. Specifically, as one pound of water freezes, 144 BTU's of heat energy are liberated. This is called the latent heat of fusion of water. As long as liquid water is freezing on the plant at all times, the surface temperature will remain at or near 32° F. Adequate water must be applied to compensate for heat losses by radiation, convection and evaporation.

If the irrigation rate is not adequate, the damage may be more severe than if no protection had been provided. If wind velocities are high and/or if relative humidities are low water may evaporate from the plant surfaces. If this occurs evaporative cooling will actually lower the temperature of the plant. As one pound of water evaporates 1080 BTU's of heat energy are absorbed from the surrounding environment. When compared to the 144 BTU's released by freezing it becomes apparent that 7 ½ times more water must be freezing than evaporating in

order to have a net heating effect. For this reason frost/freeze protection by irrigation is not usually recommended if wind velocities exceed five miles per hour. If the relative humidity is low, the sprinkler system should be started at a higher than usual temperature to compensate for the evaporative cooling that will occur as the first water strikes the plants.

Typically, sprinkler systems should be started when the air temperature in the orchard reaches 34° F. It should operate continuously until the air temperature increases to above 32° F. and the ice on the plants has begun to melt.

Crops and Critical Temperatures:

The ultimate goal of frost/freeze protection is to prevent plant parts (particularly the flowers and fruit) from being damaged by temperatures that drop below the critical level. This critical temperature varies from crop to crop and also depends on the stage of flower and fruit development. [Table 1](#) gives the critical temperatures of several tree fruits at various stages of development. The dates that crops reach these stages depends on the geographic location and local climate.

Table 1: insert here

DESIGN OF OVERHEAD IRRIGATION FOR FROST/FREEZE PROTECTION

Precipitation Rates and Sprinkler Spacing:

The desired precipitation rate for adequate cold protection will depend on the crop to be protected. For low growing crops such as strawberries, the precipitation rate should be between 0.12 and 0.15 inches per hour; medium sized plants such as blueberries and grapes need 0.14 to 0.16 inches per hour; and large trees such as apples and peaches need 0.16 to 0.18 inches per hour. As a general rule precipitation rates should not exceed 0.2 inches per hour. At these high rates run-off becomes excessive and excessive ice build-up on trees causes increased damage from broken limbs. Table 2 indicates the degree of protection afforded by various precipitation rates at several wind velocities.

Table 2. Precipitation Rates* for frost protection.

Minimum Temperature °F	Wind Speed (mph)		
	0-1	2-4	5-8
27	0.10	0.10	0.10
26	0.10	0.10	0.14
24	0.10	0.16	0.3
22	0.12	0.24	0.5
20	0.16	0.3	0.6
18	0.20	0.4	0.7
15	0.26	0.5	0.9

* Rates are inches per hour.

Source: Gerber, J. F. and J. D. Martsolf. 1965. Protecting citrus from cold damage. Univ. Fla. Arg. Ext. Cir. 287.

The precipitation rate applied by a sprinkler irrigation system will depend on the sprinkler discharge and the spacing between sprinklers. Generally, the desired sprinkler spacing will be determined first and then a sprinkler will be selected with an appropriate discharge rate and wetted diameter.

Sprinklers are typically spaced in the range of 40x40 feet to 80x80 feet. The precise spacing will often depend on the spacing of the crop to be watered. For tree crops, it is desirable to have a row of sprinklers in every other tree row in order to provide adequate coverage over the whole tree. Also, the outside row of sprinklers should be located at the edge of the field to provide adequate coverage for the outside row of trees.

In order to provide uniform coverage, sprinkler spacing should be from 50 to 60 percent of the wetted diameter of the sprinkler. Under no circumstances should the spacing exceed 70 percent of the effective sprinkler diameter. Typically, every other row of sprinklers is staggered to provide a triangular pattern; however sprinklers may also be spaced in a square or rectangular pattern.

Once the spacing is determined, the desired sprinkler nozzle capacity may be determined using the equation for calculating precipitation rates:

$$R = \frac{96.3 \times Q}{S \times L}$$

Where: R = application rate (in./hr.)

Q = output of one sprinkler (gal. /min.)

S = spacing between sprinklers (ft.)

L = spacing between rows of sprinklers (ft.)

Table 3 gives precipitation rates for selected nozzle capacities and sprinkler spacing.

Table 3. Precipitation Rates for Selected Nozzle Capacity and Sprinkler Spacings.

Sprinkler Spacing (ft.)	Gallons Per Minute/Sprinkler								
	2	3	4	5	6	8	10	12	15
30 x 30	.21	.32							
30 x 40	.16	.24	.32						
40 x 40		.18	.24	.30					
40 x 50		.14	.19	.24	.29				
40 x 70		.12	.16	.20	.24	.32			
50 x 50		.12	.15	.19	.23	.31			
50 x 60			.13	.16	.19	.26	.32		
60 x 60				.13	.16	.21	.27	.32	
60 x 70					.14	.18	.23	.28	.34

On orchard crops the sprinkler systems are typically permanent set with buried PVC pipe. On annual crops and perennial crops such as strawberries, a solid set aluminum pipe sprinkler system is often used. This allows the system to be moved during a land preparation or to other fields as desired.

Sprinklers:

Conventional impact sprinklers can be used for frost and freeze protection. Sprinklers should be constructed of brass or some other metal. Plastic sprinklers may become brittle and break during freezing temperatures.

Sprinklers should have a fairly rapid rotational speed - at least one revolution per minute. Some manufacturers have special frost protection sprinklers with little or no counterbalance arm so that they will rotate at a high speed. However, these sprinklers have a disadvantage in that their diameter of coverage is somewhat reduced.

Single nozzle sprinklers are normally used in order to achieve the low application rates desired.

Field Monitoring:

On nights when freezing temperatures are expected temperatures should be checked at least hourly. The thermometer(s) should be placed at the level of the plants in a low spot in the field exposed to the open sky. Accurate thermometers should be used and they should be checked prior to use by placing them in a container of well stirred ice water. If accurate they should read 32° F.

Typically, the sprinkler system should be started when the temperature reaches 34° F. If the relative humidity is low the system may need to be started at a slightly higher temperature.

If a source of power is available a thermostat may be wired to switch on a warning bell when the temperature drops to a predetermined setting (usually 36° to 38° F.).

Field Drainage:

Adequate field drainage is essential when using sprinkler systems for frost/freeze protection. During an extended freeze several inches of water may be applied to a field. This generally occurs during early spring when the soil is probably already saturated. Consequently, adequate surface and/or subsurface drainage should be provided.

Water Supply:

In designing a sprinkler system for frost/freeze protection everything must be sized so that the whole field can be watered at once. Once the system is started, water must be supplied continuously to the entire field until the freeze is over. This results in a much higher pumping requirement than is common for systems designed strictly for irrigation. Irrigation systems are usually designed with several zones that are operated separately. A system designed for frost/freeze protection requires that pumps, pipes, valves and other components must be larger. For this reason, these systems cost significantly more than those used strictly for irrigation. This pumping capacity required at various precipitation rates is given in Table 4.

Table 4. Pumping Capacity Required

Precipitation Rate (In./Hr.)	Pumping Capacity Required (GPM/Acre)
0.11	49.8
0.12	54.3
0.13	58.8
0.14	63.4
0.15	67.9
0.16	72.4
0.17	76.9
0.18	81.5
0.19	86.0
0.20	90.5

Because of the large pumping capacity required, frost/freeze protection systems commonly pump from a storage reservoir such as a pond or lake. A reservoir may be spring fed, fed by surface runoff or supplied by pumping should be sufficient to supply 10 days of frost protection for 14 hours per day. The actual requirement may be more or less depending on the crop, the geographic area and the maximum number of days freezing temperatures are expected once the crop reaches the critical stage.

Pumping units should be reliable and should be maintained in top working condition. Any

equipment failure during the middle of a freeze could cause catastrophic crop failure. Most growers prefer to use an internal combustion engine as a power source. This eliminates the possibility of an electric power failure shutting down the sprinkler system. In addition, many growers will have a back-up power unit in case one fails.

SUMMARY

Overhead sprinkler irrigation has proven to be one of the most effective means of protecting a variety of crops against frost/freeze damage. A properly designed system can protect crops to temperatures as low as 20° F.

In order to be effective in protecting crops, the sprinkler system must be properly designed. For this reason, it is always advisable to have the system designed by a competent irrigation designer. In addition, the system must be operated correctly to achieve the desired results. It is the grower's responsibility to see that he is properly informed to operate the system effectively. Timing is critical in protecting crops from frost/freeze damage, and it makes little sense to spend the money to install a sprinkler system and then not know how to operate it properly when a killing freeze occurs.

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