Irrigation For Frost Protection Of Strawberries

Pam Fisher and Rebecca Shortt – Ontario Ministry of Agriculture Food and Rural Affairs

Summary

- Frost injury can cause significant damage to strawberry plants, especially open bloom, but also to unopened buds if it is cold enough.
- Strawberry fields are often colder at ground level than the weather forecast suggests.
- Irrigation for frost protection works because heat is released as water freezes.
- Irrigation rates must be adjusted to account for evaporative cooling due to winds and relative humidity. More water is required on windy nights.
- Failure to apply enough water can result in greater damage than no irrigation at all.
- When to start up the irrigation is critical. Two tools can determine the optimum time for starting frost protection: dew point, and wet bulb temperatures. Use the dew point and table 5 to determine the temperature at which to start irrigation. Alternatively measure the wet bulb temperature; irrigation should start before the wet bulb temperature reaches the critical temperature (table 1).
- Dew point is also useful in predicting the lowest expected temperature, and how quickly the temperature will drop.
- In general, the start temperature for frost protection is higher when the humidity is low; the start temperature for frost protection is lower when the humidity is high.
- Where row covers are used, irrigation can take place over the cover. Information on temperatures under the cover can be determined by using digital thermometers and thermocouples.

Introduction

There's nothing colder than a strawberry field on a frosty spring night. Strawberry plants bravely bloom in early spring, often before the last frost. The blooms are close to the ground, and the ground, covered with straw, doesn't provide much heat. That's why many strawberry growers pull a few all-nighters each spring to run the irrigation system and use a thermodynamic principle to protect their crop from frost injury.

This paper will describe types of frost, frost injury, and how irrigation can be used to protect strawberry plants from frost injury.

Symptoms of Frost Injury

Frost occurs when the temperature around the plant drops below 0°C (32°F). At this temperature, pure water forms ice crystals on surfaces which have fallen below the freezing point of water.

Plant sap is not pure water; therefore strawberries have a lower freezing point than 0°C (32°F). When the critical temperature (Table 1) is reached, crystals form and damage cell membranes allowing cell fluids to leak out.

Frost can kill flowers outright, or injure them enough to cause misshapen berries. When a flower is injured by cold, the pistils are killed first. If killed after pollination, then embryos do not develop. A seedy spot on the berry forms, with hollow seeds. Sometimes fruit cracks at the bottom. Leaves can also be injured by the frost, especially when they are growing vigorously and very tender. The edges or tips of leaves blacken, and then dry out.

Although this article comes from Canada, it is one of the best explanations of frost protection for strawberries we have found. Bear in mind however, that it is written with matted row production in mind, and there are a few statements that may not apply to strawberry production on plastic in our region.

Additional information on frost protection may be found at the Strawberry Growers Information Portal. And be sure to sign up for the Berry Info email alerts (see resource section), which let you know about alerts that have been posted at the Information Portal.

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Figure 1: Frost-injured strawberry bloom

Figure 2: Misshapen berries resulting from blooms which are partially damaged by frost

Figure 3: Frost injury on strawberry leaves

Frost usually damages the biggest and earliest bloom. This represents the best and most lucrative part of the berry crop, because prices are highest at the beginning of the season. Further, the first flowers to open produce the largest fruit. If 5 percent to 7 percent of the flowers are lost, and these flowers are mostly king bloom, the total crop will be reduced by 10 to 15 percent.

Critical Temperatures for Frost Injury

Bloom and flower parts are most susceptible to freezing temperatures.

Table 1. Critical temperatures of strawberries based on stage of development (Perry and Poling, 1985)

Stage of Development	Approximate Critical Temp. °C (˚F)
Tight bud	-5.5 (22˚F)
"Popcorn"	-2.2 (26˚F)
Open blossom	-1.1 (30˚F)
Fruit	-2.2 (28˚F)

These temperatures are tissue temperatures, and a degree or two lower than the critical air temperature in the plant canopy. There are many variables that affect the actual critical temperature for a given plant and the amount of injury.

- Duration of cold
- Growing conditions prior to the cold event
- Cultivars: (because of plant habit, or avoidance, rather than genetic differences)
- Stage of development
- Super cooling (in the absence of ice nucleation points, plant sap can cool below the freezing point without forming ice crystals)
- Soil type and condition (moist dark soil holds more heat than dry light soil)

Understanding Heat Transfer

Cold conditions occur when heat is lost. Cold can not be added, only heat can be removed.

Heat can be transferred by:

- **Conduction**: transfer of energy within an object or system. Metal is a good conductor, water is a good conductor, but air is a poor conductor of heat. Ice is a good conductor.
- **Convection**: Transfer of heat by movement and mixing of liquid or gas. Most air is warmed by convection.
- **Radiation**: Is the transfer of energy through free space without a transporting medium. We receive energy from the sun by radiation. Objects on earth also radiate energy back to space.

- **Changes in state**: When water molecules change state, from gas to liquid to ice, heat is released. This potential energy is called latent heat. It is not measured by a thermometer, until it is released by a change in state of the water.

When water condenses, cools or freezes, the temperature around the water rises as latent heat is released. Water changing to ice on the surface of a plant will add heat to that plant. Conversely, when ice melts, or water evaporates, the temperature around the water is cooled, as heat moves to the water. Water evaporating from the surface of a plant will draw heat from that plant.

Table 2. Heat exchange due to changes in state: Positive signs indicate the water is cooling or freezing and air is warming. Negative signs indicate water is warming or evaporating and air is cooling

Change in state	**Heat exchange (calories/gram)**
Water freezes at 0°C (32°F)	+79.7
Water evaporates at 0°C (32°F)	-597.3
Water condenses at 0°C (32°F)	+597.3

Energy Budgets

During the day, the sun warms the soil and solid objects, i.e. crops. When these objects become warmer than the air, they pass heat to the air by conduction. This warm air is less dense, and rises, and is replaced by cooler air from above. This mixing of air is how the lower atmosphere is warmed. Normally, air near the surface of the earth is warmer than the air above it. Crops also radiate heat to outer space. Some of this energy is reflected back to the earth by clouds and $C0_2$ in the atmosphere.

At night, there is no incoming radiation from the sun. If the atmosphere is clear, there is little heat reflected back to earth. The soil and crops continue to radiate energy out to space. Temperatures drop near the earth's surface, forming a layer of air that is colder at the bottom and warmer at the top. If a wind or breeze is present, the warm air and cooler air are mixed. But on a still night, especially when the air is dry, the air temperature at ground level is coolest, and the temperature increases with height up to a certain level. Because this situation is the opposite of normal daytime conditions, the term inversion is used to describe these conditions.

Objects can radiate heat faster than the air around them. Frost can form on the roof of a building or the hood of a car when air temperatures are still a degree or two above zero. Strawberry blooms can also radiate heat quite quickly on a clear night.

Important Facts about Weather

Although the terms "frost" and "freeze" are used interchangeably, they describe two distinct types of cold events.

An advective, or windborne freeze, occurs when a cold air mass moves into the area, and brings freezing temperatures. Significant wind occurs as the cold front moves in. the thickness of the cold air layer is 500-5000 feet deep. It is difficult to protect crops from frost injury when these conditions occur.

A radiation frost, occurs when a clear sky and calm winds allow an inversion to develop and temperature near the surface of the earth drop below freezing. The thickness of the cold air inversion is 30-200 feet (with warm air above).

Table 3. Characteristics of a radiation frost and an advective freeze

Radiation frost	**Advective freeze**
Calm winds (less than 5 mph)	Winds above 5 mph
Clear skies	Clouds may exist
Cold air 30-200 feet deep	Cold air mass 500-5000 feet deep
Inversion develops: air next to the ground is cooler than air above it.	Protection success limited
Cold air drainage occurs	-
Successful frost protection likely	-

Microclimate monitoring

Air temperatures referred to in weather reports and forecasts are measured 5 feet above the ground. Temperatures can be much colder at ground level and even colder in the low parts of the field. Cloud cover and wind speeds are also important factors to consider when determining the risk of frost.

Use max/min thermometers to monitor the low temperatures in your fields. Compare these to the forecast lows. In cloudy breezy weather, forecast lows are likely to be similar to the observed low in a region. On clear calm nights, especially in a strawberry field, the observed low can be much lower than the forecasted low.

You can also use max/min thermometers to compare the temperatures at several locations on your farm on a given night. After several observations you will know just how much colder each field is compared to your back yard. A frost alarm can be installed in a convenient location if you know how much colder it gets in the field.

Factors affecting the risk of frost
Cold air is heavier than warm air, and it sinks and flows across a field like water. It also piles up where obstructions block its flow to a lower area. Road banks, hedge rows, berms are examples of obstructions to cold air flow. Cold air will drain from elevated areas, to lower storage areas, such as a large body of water. Strawberry fields on sloping fields, or in generally elevated areas, are less prone to frost damage. Be aware of frost pockets within the field.

Remove obstructions at the lower end of the field to improve air drainage. Windbreaks should be designed to slow the wind, not block all air movement. To allow air drainage through a windbreak about 50% air space at the bottom of the windbreak is recommended.

Soil moisture and compaction can have a significant effect on temperature. A moist compact soil will store more heat than a loose dry soil and therefore has more heat to transfer to the crop at night. Cultivation just before a frost can increase the risk of injury, because the soil is looser and drier after cultivation. Soil under a grassy cover crop will hold more heat if the grass is mowed short.

Irrigation for Frost Protection
Most growers rely on sprinkler irrigation for frost protection. When water from sprinklers turns to ice, the heat released protects the plant from injury. As long as a thin layer of water is present, on the bloom or on the ice, the blossom is protected. (This is important. It's not the layer of ice that provides the protection. It's the water constantly freezing that keeps the temperature above the critical point.)

System specifications

- Make sure the sprinkler irrigation system has the capacity to irrigate the whole field at one time.
- Use sprinkler heads designed for frost protection. These have low output nozzles, made of metal rather than plastic, and the spring is covered to prevent freeze-up. Sprinkler rotation should be rapid, at least 1 revolution per minute. The back nozzle should be plugged (Figure 4).
- Spacing of risers should not exceed 30-60% (depending on wind conditions) of the area wetted by each sprinkler. Generally an off-set pattern provides more uniform coverage than a square or rectangle, but this really depends on the nozzle and sprinkler you are using. The Center for Irrigation Technology has developed a program called SPACE, which predicts the distribution of water from the sprinklers, and calculates the efficiency of different designs. Tools like this are used by irrigation supply specialists who can help design your system.
- Traditional spacing is 60' by 60', not as many sprinklers required, but it takes longer for sprinklers to cover area. In areas where many advective freezes occur, with winds, a spacing of 30' x 30' is recommended.
- Need enough water on hand to irrigate for several nights in a row.

For example: For 1 acre, you need about 60 gallons per minute, to irrigate 0.125 inch/acre/hr. This is 3600 gallons per hour. If irrigation is required for 10 hours, you need 36000 gallons per night. Plan to irrigate for several nights in a row.

Figure 4: Sprinkler used for frost protection with back nozzle plugged

How much water to apply
The amount of water applied per hour is based on the amount of wind and the temperature (Table 4). Higher water application rates are required on windy nights, or when humidity is low because considerably more energy is removed when a gram of water evaporates than is added when a gram of water freezes (Table 2). A rate of 0.1 inch/hour is considered adequate to protect to -4.4°C (24°F) with no wind. When the water is frozen on the plant the ice should be clear, which indicates that there was enough water applied. If the ice is cloudy or milky white, the water application rate is not fast enough to protect the flower (Figure 5). In this case you can increase the water application rate by reducing the sprinkler spacing or changing to higher flow rate nozzles. At wind speeds above 16 km/hr or at temperatures below -6.7°C (20°F) sprinkler irrigation can do more harm than good because of rapid freezing.

Figure 5: Strawberry bloom coated in clear ice

When to start irrigation

To successfully use irrigation for frost protection, growers need information about the dew point. Dew point is especially important in determining the irrigation start-up point.

The dew point

The dew point is the temperature at which moisture condenses from the air to form dew. The dew point is related to relative humidity: when the air is humid the dew point occurs at a higher temperature than when the air is dry. Once dew begins to form, the air temperature begins to drop more slowly. When temperatures reach freezing, the dew turns to frost.

Dew points are available from agricultural weather forecasts, e.g.

- Environment Canada - provides current dew points and other current weather conditions, for certain locations
- Farmzone.com - provides forecasted dew points

Table 4. Inches of Water/Acre/Hour to Apply for Protection at Specific Air Temperatures and Wind Speeds (Martsoff and Gerber, Penn State University)

Wind speed at crop height (km/hr)	-2.8°C (27°F) air temperature at canopy	-4.4°C (24°F) air temperature at canopy	-6.7°C (20°F) air temperature at canopy	-7.8°C (18°F) air temperature at canopy
0 - 2	0.10	0.10	0.16	0.20
3 - 6	0.10	0.16	0.30	0.40
7 - 14	0.10	0.30	0.60	0.70
15 - 19	0.10	0.40	0.80	1.00
20 - 35	0.20	0.80	-	-

What is the significance of dew point?

Growers can use dew points to estimate how quickly the temperature might drop in any given night. Once dew begins to form, the air temperature drops more slowly because heat is released. Frequently, the nighttime temperature drops to the dew point, but not much below it. Sometimes the dew point is referred to as the basement temperature.

If the air is dry, then the dew point will be low. If the dew point is below 0°C (32°F), frost forms instead of dew. Black frosts occur when temperatures are below freezing but above the dew point. Don't wait for frost to form before starting the irrigation system (especially when the humidity is low).

Table 5: Suggested starting temperatures for irrigation, based on dew point. The lower the dew point, the sooner you should start to irrigate.

Dew Point	Suggested starting air temperature
-1.1°C (30.2˚F)	0°C (32.0˚F)
-1.7°C (28.9˚F)	0.5°C (32.9˚F)
-2.8°C (26.9˚F)	1.1°C (34.0˚F)
-3.8°C (25.2˚F)	1.6°C (34.9˚F)
-4.4°C (24.1˚F)	2.7°C (36.9˚F)
-5.5°C (22.1˚F)	3.3°C (37.9˚F)
-6.7°C (19.9˚F)	3.8° C (38.8˚F)
-8.3°C (17.1˚F)	4.4°C (39.9˚F)

Wet bulb temperature

Sometimes the term wet bulb temperature is used to determine when to start up irrigation systems. The wet bulb temperature represents the temperatures a wet surface will cool to as the water evaporates. A wet bulb thermometer is covered with clean muslin soaked in distilled water. Air is passed over the bulb; the water evaporates, reducing the temperature around the thermometer.

If wet bulb temperatures are available, these can be used directly to determine when irrigation should begin, and when the system can be shut off. Start irrigation just before the wet bulb temperature reaches the critical temperature (Table 1).

When to stop irrigation

Irrigation can be stopped when ice on the plants begins to melt, usually after sunrise. Monitor carefully to make sure that the ice continues to melt and the temperature remains above freezing. Changes in wind speed could change temperatures near the plant surface. Irrigation should be started up again if water begins to freeze.

Ice does not have to be completely melted. The plant temperature will warm up as the sun rays hit the field. When the ice can be sloughed off the plant, you know that plant temperatures are above freezing and the water next to the pant has started to melt. At this point, you can turn off the irrigation water, usually around 7:30 or 8 am.

The best way to know when to turn off the irrigation is to monitor plant tissue temperatures beneath the ice. Digital thermometers, attached to thermocouples inserted into the plant tissue can indicate when plant temperatures begin to warm up above the critical temperature.

Negative side effects

One negative side effect of irrigation for frost protection is increased potential for disease outbreaks. Angular leaf spot is a bacterial disease that is spread by splashing rain or irrigation, and seems to get established in frosty conditions. Anthracnose, which can cause fruit rot, generally likes warm humid weather. However, even during cool periods, it will spread by water splashing on the plants and, after establishing itself, it will thrive when warm weather arrives (Figure 6).

Root rots, such as red stele, thrive in saturated soil conditions. Outbreaks of red stele and other root rots have occurred after long periods if irrigation for frost protection. The sites most suited for frost protection by irrigation are well drained sites with sand or sandy loam soils.

Figure 6a: Angular leaf spot

Figure 6b: Anthracnose fruit rot

Figures 6a, 6b: Splashing water can spread diseases like angular leaf spot and anthracnose fruit rot

Figure 7a: Standing water and water-saturated soil in a strawberry field

Figure 7b: Water-saturated soils favour root diseases such as red stele.

Disease and fungus can be limited by reducing the water applied. Water volumes can be reduced by:

- Low application rates / nozzles
- Stopping when ice begins to melt, not when all the ice is melted.
- Monitor the weather to irrigate only when needed.
- Using row covers. This can delay the start up time for irrigation by several hours.

Row Covers

Row covers reduce evaporative cooling and the rate of cooling under the cover. According to vendor's information, the heavier weight covers (1.5-2 oz/yd^2) can protect 4-6 degrees, but this varies both with the weight and between manufacturers. They do buy time on a frosty night.

When frost protecting with irrigation and row covers, you need to know plant temperature under the cover. Start when temperatures under the cover drop to 0.6 - 1.1°C. Irrigate right over the cover. Stop when plant temperatures start to climb. Digital thermometers attached to thermocouples, inserted in the flower buds before the frost event, are necessary for successful protection with covers.

Research suggests that 2 layers of 1 oz cover provide more protection than 1 layer of 2 oz material. Research on the use of low impact sprinklers, i.e. mini-wobblers, is in progress. These sprinklers, widely used in the ornamental industry, wet a smaller diameter, use lower pressures, and are less prone to freezing. By using irrigation and row covers it may be possible to frost protect in adverse conditions.

Related Links

- Environment Canada
- Farmzone.com
- Frost/Freeze Protection for Horticultural Crops,North Carolina State University Horticulture Information, Leaflet 705
- Rainbird Agricultural Irrigation - Technical resources, specifications
- Center for Irrigation Technology Technical resources, SPACE program
- Biometeorology Program, Atmospheric Science, University of California - web site with tables, theory, course on biometeorology
- Berry agent, North Carolina State University

(***Source**: OMAFRA Factsheets at:* *www.omafra.gov.on.ca/english/crops/facts/frosprot_straw.htm*)