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FROST PROTECTION FOR SMALL FRUIT CROPS

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Historically, the first recorded efforts at frost protection were by ancient grape growers who burned their pruning waste to prevent freeze damage to their grape vines. Early man eventually found that one of his best methods of frost protection was good site location. If at all possible, this is the first and most important step for frost or freeze protection of a small fruit crop.

The site selected should slope to provide for good air drainage away from the site (i.e., to lower elevations). Most spring freezes are radiant freezes which occur on clear cloudless nights when there is little or no wind. After sunset, heat is lost from the soil and plants and radiates back to the sky. The air is chilled and the cold air, being heavier than the warm air, flows down and pools or collects in the lower area (frost pockets). Often the temperature will be 4 to 5^{0}F lower in these frosty areas compared to that on higher surrounding areas. Note, too, that areas surrounded by a continuous timberline of higher trees can also form a frost pocket, even though the site is elevated or has a slight slope because the "high walls" of the tree line prevent the free flow of cold air off the site.

Critical temperatures

There is no one temperature at which frost damage occurs uniformly. With most small fruit plants, damage due to freezes and frost increases after bud break in the spring until flowering or fruit set. The damage thresholds also vary with the type of crop.

Strawberries. Table 1 shows the critical temperatures associated with frost and freeze damage. The duration of temperature for damage can be 20 minutes to 2 hours depending on wind, humidity, and cultivar.

Table 1. Critical air temperatures for damage to strawberry buds, flowers and fruit.

Buds Emerge	Buds Closed	Flowers Open	Small Green Fruit
10^{0}F	22-27^{0}F	30^{0}F	28^{0}F

Source: Funt, R., et al. (1985)

Grapes. **Table 2** shows that at different stages of plant development, a difference of only 2°F in the ambient air temperature can be enough to kill half the buds and shoots.

Table 2. Critical air temperatures for damage to grape buds and shoots.

Damage Level	Dormant buds enlarged	Dormant buds swollen	Shoot burst	First leaf	Second leaf
50% killed	6.8°F	25.9°F	28.0°F	28.4°F	28.9°F
None killed	--	--	30.2°F	30.2°F	30.2°F

Source: Wolf, Poling (1995) Mid-Atlantic Wine Grower's Guide

Brambles. Red, purple and black raspberries can tolerate low winter temperatures to about-20°F, -10°F and -5°F, respectively, while black berries can tolerate only about 0° F. These temperatures are estimates only and assume that the plants are fully dormant at the time of exposure. Low temperatures can occur when the bramble plant is no longer fully dormant. Red raspberries can break dormancy after 800 to 1,600 hours of temperatures below 40°F, which may occur well before our usual winter season is over in Maryland. Blackberries can break dormancy after only 300-600 hours of temperatures below 40°F which explains why cold injury to these plants is much more common in this area. Some cold damage in blackberries may not be apparent until after fruit set when a damaged vascular tissues cannot deliver the water required and plants appear to wilt and die quickly.

Whenever temperatures warm after the cold temperature requirement has been met, the plant begins to lose its dormancy and, thus, its tolerance to cold temperatures. Winter injury is frequently the result of fluctuating winter temperatures, rather than absolute low temperatures. This fluctuation occurs more toward the later winter to early spring time when solar radiation on clear days can raise the internal temperatures of the canes several degrees higher than ambient air temperatures. when the sunset and air temperatures become colder still, the "overheated" canes can be severely stressed by the rapid *change* in temperature, not necessarily a very low temperature. For this reason, summer-fruiting cultivars should be planted on north -facing slopes, if possible, to minimize exposure to the heating effect of direct winter sunlight. South and southwest-facing slopes are the worst locations.

Blueberries. When blueberries are in full bloom, the flowers can be injured by temperatures slightly below freezing (30°F). The exact temperature that damages flowers depends on the rate of temperature change, wind speed, humidity, sugar content of nectar, flower orientation, etc. Under certain conditions, open blueberry flowers can tolerate temperatures as low as 23°F. The earliest-flowering varieties are most susceptible to frost injury, so avoid planting these on frost prone sites.

Types of freezes

Radiative freezes are the most common that we can experience in the spring. They occur on calm, clear nights, when we have no cloud cover. Heat is lost or radiated from the earth's surface to the sky above out to outer space. They usually occur a day or two after the passage of a cold front.

Advective freezes are represented by the classic "Alberta clipper", a cold front with lots of cold air and wind. They have also been called windborne freezes. This type of freeze is the hardest to protect against. It is characterized by cold, dry winds and, in many cases, the dew point is below freezing. They are large cold air masses with strong winds. Many times the best strategy is to do nothing when we are confronted by a severe advective freeze situation.

Environmental factors affecting frost protection efforts

Air temperature information to be used for initiating or stopping frost control practices should be determined at the crop level on the site to be protected. A temperature report from an instrument at eye level one quarter mile or more from the site is not comparable to measurements made within a few inches of the ground in the strawberry foliar canopy.

Wind speeds of more than a few miles per hour can make frost protection harder, especially if it is an advective or frontal type freeze.

Dew point is the temperature at which water in the air (humidity) condenses to form dew. When the air temperature falls below freezing, frost forms instead of dew and the potential for damage increases.

Soil moisture is an important component of frost protection since a moist soil well retain the heat of the day better than a dry soil. It will radiate this captured heat back to the environment over a longer period of time as it has more heat to radiate back than dry soil.

Ground cover. A bare, undisturbed moist soil with no ground cover can give you 2 to 3^0 F of increased temperature versus a sod or grass covered soil.

Surrounding terrain and air drainage. Cold air will collect and drain to the lowest spot to which it can travel unimpeded. Obstructions at the bottom of a slope such as a timberline can cause the cold air flowing down the slope to "dam up", producing a frost pocket along the wooded border.

Air temperature inversions occur when cold air is trapped near the soil surface and the crop below warmer air above.

Environmental modifications for frost control

The best site location for frost protection and environmental modification is a site downwind or closely surrounded by a large body of water. In Maryland, sites that are within a few miles east of the Chesapeake Bay or necks that jut out into the Bay have a natural environmental modifier. In the fall and early winter, the water stays warmer than the surrounding land, making the winters less severe. In the late winter and the early spring, the water is colder than the surrounding land which delays early bud development on sensitive crops so that the incidence of damaging frosts is reduced. Bloom is not as early as it is further inland and the temperature variation between the daily minimum and maximum temperatures is not as great. A site with some elevation will help too, as cold air drains away to the lowest point if unimpeded.

Selection of the correct elevation is important, especially in the more mountainous areas of western Maryland. The crop should be planted above the spring freeze line and below the winter freeze line. Below the spring line, cold settling air may kill open blooms. Above the winter freeze line, low winter temperatures can injure or kill trees. Southern slopes are generally warmer than those facing north.

Methods for frost protection

Heating or burning may require burning permits issued by local jurisdiction. It is the oldest method for frost protection, but is not practical for very low growing small fruit crops like strawberries. In general lots of small fires are better than one large one and it will take twice as many heaters or small fires on border rows as for interior rows.

Wind machines are useful when a temperature inversion occurs in that the air mixing they cause pulls down the warm air from above to replace the colder air trapped near the soil surface. They only work if a temperature inversion occurs and there is no wind as with radiant type freezes.

Two systems have the most potential for frost and freeze protection in strawberries: row covers and sprinkler irrigation. Frost protection has become more critical with the advent of annual "plasticulture" for strawberry production in Maryland. The rise of black polyethylene covered beds and floating row covers for winter protections leads to spring blooms coming as much as two or three weeks earlier than the normal June matted row production. This is not to say that frost protection isn't needed for June matted row production, but only to emphasize that active efforts at frost protection are a must for strawberries grown using plasticulture to obtain good yields for an earlier, and more profitable, spring fruit market.

Row covers. Floating row covers of 0.6 oz or heavier rating can give 2 or 3^{0}F protection in a frost situation. Heavier covers such as 1/8-inch nursery foam can provide more protection, but are not readily available or economical for strawberries in most situations. At the Wye Research and Education Center, we have been able to get as much as 11°F protection using nursery foam covers in the fall of the year for day neutral varieties and use it exclusively as our frost protection option.

Sprinkler irrigation for frost protection has been used successfully from Canada to Florida. It works best on low growing crops. This option needs to be approached carefully, however, because it is a two edged sword. Used properly, irrigation can save a crop, but when it is not used properly the crop injury level can be more than if it were not used at all. The real danger here is when conditions such as those associated with advective freezes develop and evaporative cooling occurs at crop level.

Why does sprinkler irrigation work for frost protection? When water changes from a liquid to a solid (i.e., a freeze), it gives off heat at the rate of 144/BTU per pound. The flip side is that when ice melts to form a liquid, it takes up heat. For this reason, ***once irrigation is started for frost protection, do not stop it until all the ice is gone or damage from evaporative cooling can occur.*** Enough water must be applied uniformly over the entire area to be protected so that the heat of fusion overcomes or offsets evaporative as well as radiative and convective heat losses to maintain the temperature near 32°F, the melting point of ice (or freezing point of water). Plant tissue will not be damaged at 32°F because of dissolved substances in the cell walls reduce the tissue freezing point to slightly below 32°F. As long as a film of water is over the ice which encases the stem and flowers, we can protect against frost damage. Evaporative cooling and environmental conditions such as high wind and low dew point decrease the effort of irrigation for frost protection and may cause more damage than might have occurred by doing nothing.

Frost protection using irrigation works only if the system is already set up and fully functional prior to the event. It should be tested to insure it works and that you have an adequate supply of water. One acre-inch of water equals 27,154 gallons. To protect a 10 acre block with solid set sprinklers using 0.2 inches per hour, then 54,308 gallons of water are needed for each hour of operation or 270,000 gallons over a five hour protection period. The system not only needs to be started *before* the critical temperatures for frost damage are reached, but *before* ice freezing in the pump or lines can be a problem. Do not shut off the system if there is any chance water will freeze in the pump. The temperature at the pump or water source is good to know.

Most overhead frost protection sprinkler systems are designed to deliver 0.1 to 0.2 acre-inches of water per hour and are useful for radiant freeze or frost protection when wind speeds are light and temperatures are not below the mid-twenties. Table 3 provides a guide for determining the application rates for frost protection at various temperature and wind speed levels.

Table 3. Application rate of water recommended for cold protection under different wind and temperature conditions [2]

Minimum Temperature Expected	Wind speed in miles per hour			
	0 to 1	2 to 4	5 to 8	10 to 14
	Application rate (acre inches of water per hour)			
27°F	0.10	0.10	0.10	0.10
26°F	0.10	0.10	0.14	
24°F	0.10	0.16	0.30	0.40
22°F	0.12	0.24	0.50	
20°F	0.20	0.30	0.60	0.80
18°F	0.20	0.40	0.70	1.00

[2]Extension Circular 287, Florida Agricultural Extension Service by Gerber and Martsolf.

If the dew point is below freezing, irrigation must be started sooner at a higher temperature (i.e., *before* freezing occurs). According to Sprinkle Irrigation 5th edition, a common recommendation is to start the system when the temperature at plant level falls to 34°F. Under conditions with wind or low humidity, it is possible to form ice when the air temperature is several degrees above the freezing point because of evaporative cooling. When these high evaporative cooling conditions (wind+low humidity) exist, the droplets reaching the plant could be super cooled (i.e., below 32°F) and some injury could occur to the plants when the system is first started. Because of this, it is suggested that the wet bulb temperature is a better indication of when the irrigation system should be turned on.

The assumption is made that the wet bulb temperature is equal to the critical plant temperature. It is necessary to use dew point temperatures as the indicator of moisture in the air instead of wet bulb or relative humidity, because these two change with the air temperature The suggested starting air temperatures should provide 2 to 3°F safety for starting up the system to keep the wet bulb above the critical plant temperature. See Table 4 for suggested starting air temperatures for various critical plant temperatures and dew points. You can also see Table 5 for approximate dew point temperatures calculated for air temperatures.

Table 4. Recommended temperatures for starting cold protection irrigation with various critical plant damage temperatures and dew points.

Critical Temperature (Wet Bulb)		Dew Point		Suggested Starting Air Temperature	
°F	°C	°F	°C	°F	°C
32	0	32	0	34	1.1
32	0	31	-0.6	35	1.6
32	0	29	-1.7	36	2.2
32	0	29	-2.2	37	2.8
32	0	26	-3.3	38	3.3
32	0	24	-4.4	40	4.4
32	0	22	-5.6	41	5.0
32	0	20	-6.7	42	5.6
32	0	18	-7.9	43	6.1
30	-1.1	30	-1.1	32	0.0
30	-1.1	29	-1.7	33	0.6
30	-1.1	27	-2.8	34	1.1
30	-1.1	25	-3.8	35	1.6
30	-1.1	24	-4.4	37	2.8
30	-1.1	22	-5.6	38	3.3
30	-1.1	20	-6.7	39	3.9
30	-1.1	17	-8.3	40	4.4

Source: Sprinkler Irrigation, 5th edition

Table 5. Approximate dew point temperatures calculated from air temperature and relative humidity values.[2]

Dry Bulb Temperature	Percent Relative Humidity			
	25%	50%	75%	100%
20°F	-8°F	6°F	14°F	20°F
25°F	-4°F	10°F	19°F	25°F
30°F	2°F	15°F	24°F	30°F
35°F	5°F	20°F	28°F	35°F
40°F	9°F	24°F	33°F	40°F
45°F	13°F	28°F	38°F	45°F
50°F	17°F	32°F	42°F	50°F

[2] Adapted from G.E.S. Handbook No. 1, Cooperative Extension Service, University of Georgia by Myers.

Additional cautions for frost/freeze protection

- Overhead irrigation for frost protection is a sensitive procedure that can result in major damage to the plants if not handled properly.
- Do not attempt irrigation unless you have confidence in the dependability and volume of your water system.
- If there is less than 10 percent bloom, the "risks" associated with irrigation may outweigh the benefits.
- Once watering begins, it should not be stopped until all ice is gone or damage from evaporative cooling can occur.
- For windy conditions (10 mph), move main water supply lines closer (from 60 to 40 foot centers) and increase the volume of heads (from 0.15 to 0.25+ inches per hour). When wind speeds exceed 10 mph, the risks for crop damage from evaporative cooling due to inadequate water supply or even distribution of the water may outweigh the potential benefits.
- Irrigation can be applied directly over row covers used for frost protection. Here again, water needs to be applied until the ice melts off and then as soon as possible after the frost/freeze the covers need to be removed to allow for pollination and drying.

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