UC Davis Biometeorology Group

Sprinkler Application Rates for Freeze Protection

FP004 Quick Answer

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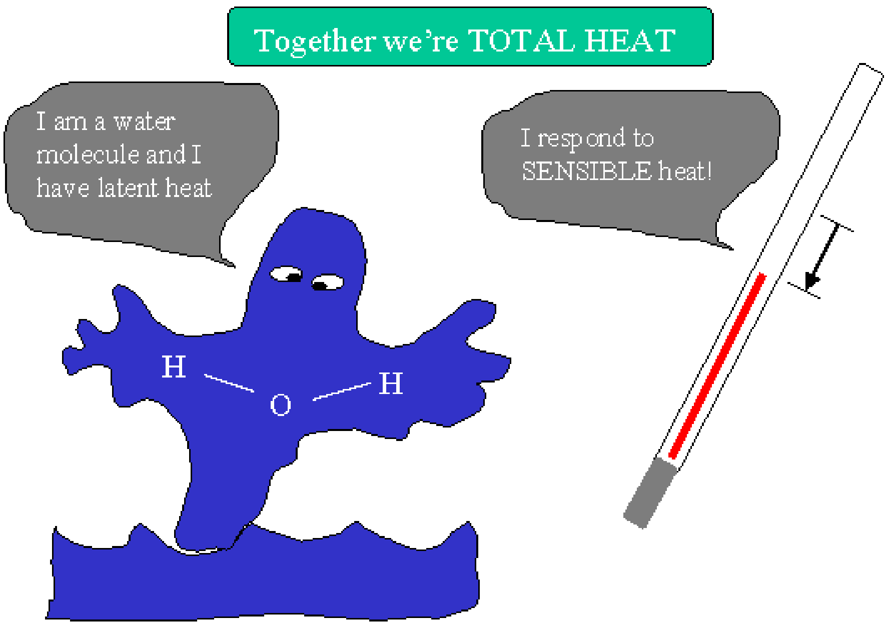
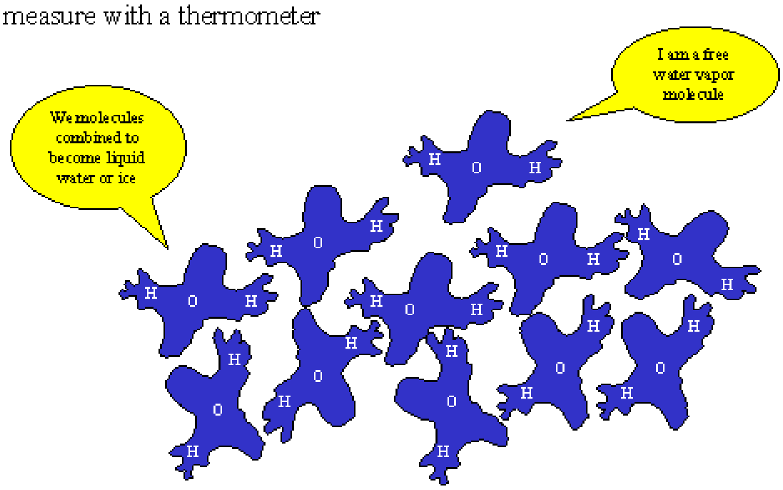
When sprinklers are used for freeze protection, the two main factors to consider are (1) the application rate required for protection and (2) the proper time to start and stop the sprinklers. Deciding when to start and stop the sprinklers is discussed in Quick Answer FP001. The required application rates are discussed here.



Latent and Sensible Heat

Individual water molecules consist of one oxygen and two hydrogen molecules. The molecules chemically join together by forming hydrogen bonds to make liquid water and ice. When in a liquid state, the molecules clump together, but the groups of molecules can move as a fluid. When the water freezes to ice, the groups of water molecules form a crystaline structure. The “phase” changes from water vapor to liquid water and from liquid water to ice are exothermic reactions. This means that chemical energy (latent heat) is converted to sensible heat, which is heat that we measure with a thermometer. The total heat content of the air is the sum of the sensible and latent heat. Actually, the energy content of humid air is much higher than dry air. At the same air temperature, this is why your ice cream cone will melt faster in a humid than a dry climate.

Water molecules form strong hydrogen bonds when in the liquid or solid state (ice). Radiative energy or sensible heat is used to break the hydrogen bonds and release individual water molecules. When the molecules form hydrogen bonds to make water or ice, the latent heat is released as sensible heat that you can measure with a thermometer



Phase Changes

For phase changes from water vapor to liquid water and from liquid water to ice, latent heat is converted to sensible heat and the temperature rises. For phase changes from ice to liquid water and from liquid water to water vapor, sensible heat is removed from the air to break the hydrogen bonds. The sensible heat is converted to chemical energy (latent heat) that is contained in the water molecules. This energy is stored “latent” heat, and it will be converted back to sensible heat when the water molecules condense out of the air. The energy needed to convert between the different phases of water in both directions is listed in Table 1.

Table 1. Change in sensible heat content during the indicated water phase change processes.

Process	Cal/gm	Joules/gm	Process	Cal/gm	Joules/gm
Condensation at 0^{o}C (32^{o}F)	+597	+2500	Evaporation at 0^{o}C (32^{o}F)	-597	-2500
Cooling Liquid 20^{o}C to 0^{o}C 68^{o}F to 32^{o}F	+20	+84	Warming Liquid 0^{o}C to 20^{o}C (32^{o}F to 68^{o}F)	-20	-84
Freezing 0^{o}C (32^{o}F)	+80	+335	Melting at 0^{o}C (32^{o}F)	-80	-335

From Table 1, it is clear that cooling 1.0 gram of water from 20^{o}C to 0^{o}C (68^{o}F to 32^{o}F) and freezing it will convert about 419 Joules of energy from latent to sensible heat. Unfortunately, evaporating 1.0 gram of water will convert about 2500 Joules of energy from sensible to latent heat. Considerably more energy is removed by evaporation than is supplied by cooling and freezing of an equal quantity of water. Actually, in order to break even, about six times as much water must be cooled and frozen than evaporated. Fortunately, evaporation rates are relatively low during freeze nights, and sufficient water can usually be frozen to supply more heat from cooling and freezing than is lost to evaporation. However, a higher application rate is needed to compensate for greater evaporation on nights with stronger wind speeds and lower humidity.

Application Rate Requirements

The application rate required for over-plant sprinkling depends on the sprinkler rotation rate, wind speed, and the dew point temperature. The wind speed and dew point temperatures are important because the evaporation rate increases with the wind speed and with decreasing dew point temperatures (a measure of water vapor content of the air). Sprinkler rotation rates are important because the temperature of wet plant parts initially rises as the water freezes and releases heat, but then it falls to near the wet-bulb temperature due to evaporation before the plant is hit again with another pulse of water. Often the wet-bulb temperature is below the critical damage temperature, so damage can result if there is too much time between hitting the plants with a pulse of water. The idea is to rewet the plants frequently so that the interval of time when the plant temperature is below the critical damage temperature is short. Generally, the rotation rate should not be longer than 60 seconds; and 30 seconds is better. Sprinkler application rate recommendations for grapevines are given in Tables 2 and 3. Application rates for other tall crops are similar. Distribution uniformity and good coverage of the plants with water is important. Application rates are somewhat lower for low-growing crops because it is easier to obtain good wetting of the vegetation when it is shorter.

Table 2. Application Rates for Overhead Sprinklers for Frost Protection of Grapevines (English units)

Temperature	Wind Speed	30 s rotation	60 s rotation	30 s rotation	60 s rotation
^oF	Mph	in/hr	in/hr	gpm/A	gpm/A
29	0.0-1.1	0.08	0.10	36	45
26	0.0-1.1	0.11	0.13	50	59
23	0.0-1.1	0.15	0.17	68	77
29	2.0-3.0	0.10	0.12	45	54
26	2.0-3.0	0.13	0.15	59	68
23	2.0-3.0	0.18	0.20	81	90

Table 3. Application Rates for Overhead Sprinklers for Frost Protection of Grapevines (metric units)

Temperature	Wind Speed	30 s rotation	60 s rotation	30 s rotation	60 s rotation
^oC	$m\ s^{-1}$	$mm\ h^{-1}$	$mm\ h^{-2}$	$lpm\ ha^{-1}$	$lpm\ ha^{-2}$
-1.7	0.0-0.5	2.0	2.5	334	418
-3.3	0.0-0.5	2.8	3.3	468	551
-5.0	0.0-0.5	3.8	4.3	635	718
-1.7	0.9-1.4	2.5	3.0	418	501
-3.3	0.9-1.4	3.3	3.8	551	635
-5.0	0.9-1.4	4.6	5.1	768	852

Because lower branches are often wetted, the same application rates are used for under-tree impact sprinklers. Lower application rates are needed for micro-sprinklers that do not directly wet the plants. The effectiveness of the sprinklers again depends on the evaporation rate, which increases with wind speed and at lower dew point temperatures. The best way to test your system is to operate the sprinklers during various freezing conditions when the crop is dormant and/or harvested. If there is a liquid-ice mixture in the wetted area, then the application rate is sufficient that no damage is being done and it is probably adequate to provide some protection. If all of the water freezes and it has a milky white appearance, the application rate is too low for the weather conditions. The ice appears milky white because it is freezing too fast and trapping air inside the ice. If this happens, operating the sprinklers may cause more damage than good. Again, it is best to test the application rate for a variety of wind and dew point conditions during the crop dormancy. Then, if the conditions are too severe for the application rate, don’t use the sprinklers.

Last updated on June 22, 2000