UNDERSTANDING AND UTILIZING WATER FOR FROST PROTECTION

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Water contains latent heat, which can provide positive frost protection when properly applied. This offers a viable alternative to expensive and scarce fossil fuels which have traditionally been burned to provide heat.

The latent heat in water cannot be measured with a thermometer alone because it includes heat that is stored and given up as water changes phases from vapor to liquid, and again as it changes from liquid to ice.

The major methods of applying water are by flood and sprinkler irrigation. Flood irrigation depends largely on the heat released as the applied water cools; ordinarily little ice is formed. The amount applied and its effectiveness depends on the water temperature at the source; the warmer the water the less volume is needed.

Sprinkler applications often result in ice formation - which releases the latent heat of crystallization- as well as utilizing the heat released based on the difference in temperature of the water at the time of application and its subsequent cooling to the freezing point.

As long as sufficient water is *continuously* and *uniformly* applied by sprinkler according to the two phase rule, the temperature of the water ice mixture and the plant tissue under it will not go below 32°.

Overhead sprinklers in vineyards have been designed to apply 50-55 gallons per minute per acre and depend primarily on the heat released as ice forms. Fifty gallons of water cooled from 52° F through ice crystallization will release over 60,000 Btu's of heat, an amount great enough to deal with the most difficult conditions likely to be encountered.

The heat exchange as water condenses from the air (condensation) and as it evaporates into the air (vaporization) is a double edged sword. Condensation releases heat and vaporization absorbs heat. This is a relatively small factor but is significant when the air is dry (low dew point). On rare occasions under marginal freeze conditions, turning on sprinklers at the last minute has caused damage that would not have otherwise occurred. Sprinklers should be turned on and off when the *wet-bulb* thermometer temperature is at or above 32° F.

Definitions and Equivalents

1. **Btu** - Heat energy needed to raise the temperature of 1 lb. of water 1° F or released as the water cools 1° F.

    1 gallon of water = 8.345 lbs.
    1 gallon of water gains or loses 8.34 Btu for each 1° F change in temperature.

2. **Heat of Vaporization** = Heat *absorbed* by water when a liquid changes to a vapor.

    1 lb. water at 32° F + 1072 Btu → 1 lb. water vapor 32° F

3. **Heat of crystallization (freezing)** = Heat *released* when a liquid crystallizes to form a solid.

1 lb. of water at 32° F → 1 lb. of ice at 32° F + 144 Btu

4. **Heat of Condensation (opposite of heat of vaporization)** - Heat *released* when vapor converts from vapor to liquid.

1 lb. of water vapor at 32° F → 1 lb. water at 32° F + 1072 Btu

5. **Two Phase Rule** - As long as both the liquid and solid forms of water are present together and kept mixed, the temperature of the mixture will not go below 32° F at atmospheric pressure.

6. **Temperature** - A measure of the energy state of matter. When heat added to the system is equal to heat lost by the system, the temperature remains constant. The rate of temperature rise or fall is a measure of the unbalance between heat input and heat lost.

CONCEPTS AND COMPARISONS

It is theoretically possible to estimate the total potential heat loss from an acre of vineyard and the heating potential of various frost protection systems. Having said that, it must also be admitted that doing so would be tremendously complicated and has not been attempted here. What is being attempted is to introduce the concept of matching potential heat loss with potential heat input and to compare the potential of several heat sources. No attempt has been made to deal with the efficiencies of either orchard heating or water application methods.

Potential heat loss by vineyards under high radiation conditions

Soil (moist)	13,333 to 20,000 Btu/min
Biomass (vines)	340 to 450 Btu/min
System Total	13,640 to 20,450 Btu/min

Heat Content of several sources

Fossil fuels	
kerosene	137,000 Btu/gal = 2,283 Btu/min at 1 gal/hr.
#2 Diesel	135,000 Btu/gal = 2,250 Btu/min at 1 gal/hr.
LP Gas	95,500 Btu/gal = 1,592 Btu/min at 1 gal/hr.

Latent heat contained in 50 gallons of water at several temperatures

Initial Temperature	Btu's Released by Cooling to 32°	Btu's Released by Ice Crystallization	Total Latent Heat Potential
40°	3,336 Btu	60,000 Btu	63,336 Btu
60°	11,676	60,000	71,676
80°	20,016	60,000	80,016

Matching heat input with outgo. In all comparisons 30,000 Btu/min is assumed to be the outgo.

a. The number of ***orchard headers*** required, each assumed to burn at the rate of one gallon of #2 diesel oil per hour.

$$\frac{\underline{30{,}000\ (\text{Btu/min})\ /\ \text{acre of heat loss}}}{2{,}250\ (\text{Btu/min})\ /\ \text{heater}} = 13.3 \text{ heaters per acre}$$

b. ***Furrow irrigation***

Assume water temperature drop of 28° F from 60° F to 32° F
Btu released by each gallon = (8.34 Btu/gal)/F° x 28° F = 233.5 Btu/gal

$$(\text{gal/min})/\text{acre}) = \frac{30{,}000\ (\text{Btu/min})/\text{acre}}{234\ \text{Btu/gal}} = 128\ \text{GPM/acre}$$

c. ***Overhead sprinkler with ice formation***

Assume water temperature drop of 28° as in example b. plus the conversion of 25% of the water to ice.

Heat release/gal due to water cooling	233 Btu
Heat release/gal with 25% ice crystallization	<u>300 Btu</u>
Total latent heat potential per gallon	533 Btu

$$(\text{gal/min})/\text{acre} = \frac{30{,}000\ (\text{Btu/min})\ /\ \text{acre}}{833\ \text{Btu/gal}} = 56\ \text{GPM/acre}$$