Understanding and preventing frost damage

Richard L Snyder
University of California
Cooperative Extension

http://biomet.ucdavis.edu
Intercellular Ice Crystal Formation

Prillieux (1869) cited by Levitt (1980)
INA Bacteria

() Water Freezes below the Melting Point (0°C or 32°F)

() In the temperature range for Frost Damage (-5 to 0°C or 23 to 32°F), INA bacteria cause 99% of Ice Nucleation
In A, water with *P. syringae* placed at arrow and deionized water at black spot. Black spot is colder because of evaporation. Ice forms first at the bacteria and propagates through the leaf (B-E). Two minutes after exothermic response dissappates, the deionized water freezes.

Wisniewski, Lindow and Ashworth (1997)
Methods of Heat Transfer

Conduction - from molecule to molecule

Convection - by movement of heated air

Radiation - energy passing from one object to another without a connecting medium

Heat Source

Metal bar

Long wave loss from Earth

Short wave gained from the sun

Earth
Methods of Heat Transfer

Latent Heat - Chemical Heat

Energy is released to the environment as liquid water cools and freezes. Energy is removed from the environment if liquid water evaporates!
Inversion Formation

Temperature (°C)

Height (ft)

Temperature (°F)

Height (m)
Passive Protection

- Bacteria Control
- Site Selection
- Soil Water Content
- Ground Cover
Control of INA Bacteria

- Kill the Bacteria
- Competitive Bacteria
- Remove Ground Cover
Site Selection
Cold Air Drains to Low Spots
COLD AIR DRAINAGE
DIVERT COLD AIR
REMOVE COLD-AIR DAMS

Cold

VERY COLD

Cold Air
SOIL WATER CONTENT

Dry Soil
\( T_{\text{surface}} \downarrow \)
Reflects More
Less Heat Capacity
Less Conduction

Wet Soil
\( T_{\text{surface}} \uparrow \)
Less Reflection
More Heat Capacity
More Conduction

Temperature

Height
\[ \text{Diffusivity} = \frac{\text{Conductivity}}{\text{Heat Capacity}} \]
COVER CROP

Reflects Sunlight
Dries Soil
Less Conduction

Less Reflection
Wetter Soil
More Conduction

With Cover
$T_{surface} \downarrow$

No Cover
$T_{surface} \uparrow$

colder

warmer

Height

Temperature
Active Protection

- Sprinklers
- Heaters
- Surface Water
- Wind Machines
- Helicopters
Sprinklers

(*) Heat from freezing water
(*) More energy from freezing than lost to evaporation

<< Dew pt ↓ & Wind Spd ↑ ⇒ Evap ↑

(*) Start & stop based on $T_{\text{wet}}$

<< $T_{\text{wet}} > T_{\text{crit}}$
# Energy Exchange

<table>
<thead>
<tr>
<th>Process</th>
<th>cal g(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>20(^\circ)C to 0(^\circ)C (68(^\circ)F to 32(^\circ)F)</td>
<td>20</td>
</tr>
<tr>
<td>Freezing at 0(^\circ)C (32(^\circ)F)</td>
<td>80</td>
</tr>
<tr>
<td>Evaporation</td>
<td>-597</td>
</tr>
</tbody>
</table>
Cool and Freeze 6 $\times$ Evaporation.
Ice should be clear and dripping wet
SLING PSYCHROMETER METHOD OF MEASURING RELATIVE HUMIDITY

WET BULB

WET BULB DEPRESSION

DRY BULB
$$e_s(T_w) = e$$

$$T$$

$$T_w$$
Application Rate 49.5 gpm/Acre = 0.11 in./hr = 2.8 mm h⁻¹

Wind Velocity = 3.4 mph = 1.5 m s⁻¹

Leaf edge Temperature (°C)

Time (s)

Wet bulb Temperature
## Typical Impact Sprinkler Application Rates Wine Grapes

<table>
<thead>
<tr>
<th>$T_{\text{min}}$</th>
<th>Wind Speed</th>
<th>30 s</th>
<th>60 s</th>
</tr>
</thead>
<tbody>
<tr>
<td>°F</td>
<td>mph</td>
<td>gpm A$^{-1}$</td>
<td>gpm A$^{-1}$</td>
</tr>
<tr>
<td>28.9</td>
<td>0.0-1.1</td>
<td>36.0</td>
<td>45.0</td>
</tr>
<tr>
<td>26.1</td>
<td>0.0-1.1</td>
<td>49.5</td>
<td>58.5</td>
</tr>
<tr>
<td>23.0</td>
<td>0.0-1.1</td>
<td>67.5</td>
<td>76.5</td>
</tr>
<tr>
<td>28.9</td>
<td>2.0-3.1</td>
<td>45.0</td>
<td>54.0</td>
</tr>
<tr>
<td>26.1</td>
<td>2.0-3.1</td>
<td>58.5</td>
<td>67.5</td>
</tr>
<tr>
<td>23.0</td>
<td>2.0-3.1</td>
<td>81.0</td>
<td>90.0</td>
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</tbody>
</table>
Sprinklers

Impact

Targeted
# Targeted Vs Impact

<table>
<thead>
<tr>
<th>Sprinklers</th>
<th>gpm A(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Targeted</td>
<td>15.0</td>
</tr>
<tr>
<td>Impact</td>
<td>55.1</td>
</tr>
</tbody>
</table>

Equal protection at 21.6\(^\circ\)F (\(-5.8\)^\circ C)

Higher cost and more labor to keep the sprinklers properly oriented.

Fetzer (near Monton)
Starting and Stopping

Start and stop when the wet-bulb temperature is higher than the critical damage temperature
Dew point Temperature

Slowly add ice cubes to the water to lower the can temperature. Stir the water with a thermometer while adding the ice cubes to insure the same can and water temperature. When condensation occurs, note the dew point temperature.
Select a wet-bulb equal to the critical damage temperature and select the start and stop air temperature corresponding to the dew-point.

<table>
<thead>
<tr>
<th>Dew-point</th>
<th>Wet-bulb Temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>32.0</td>
<td>32.0</td>
</tr>
<tr>
<td>30.2</td>
<td>30.2 33.3</td>
</tr>
<tr>
<td>28.4</td>
<td>28.4 31.3 34.3</td>
</tr>
<tr>
<td>26.6</td>
<td>26.6 29.5 32.4 35.4</td>
</tr>
<tr>
<td>24.8</td>
<td>24.8 27.5 30.4 33.4 36.3</td>
</tr>
<tr>
<td>23.0</td>
<td>23.0 25.7 28.6 31.3 34.3 37.2</td>
</tr>
<tr>
<td>21.2</td>
<td>23.9 26.6 29.3 32.2 35.2 38.1</td>
</tr>
<tr>
<td>19.4</td>
<td>24.6 27.3 30.2 33.1 36.0 39.0</td>
</tr>
<tr>
<td>17.6</td>
<td>25.5 28.2 30.9 33.8 36.7 39.7</td>
</tr>
<tr>
<td>15.8</td>
<td>26.1 28.9 31.6 34.5 37.4 40.5</td>
</tr>
</tbody>
</table>
SURFACE IRRIGATION

- Flood or Furrow
- Heat is released as the Water Cools
- Avoid freezing
SURFACE IRRIGATION

- Start early enough
- Do not reuse cold water
- Run water near tree skirts
- Maximize the area
- Good flow rate
Heaters

- Radiation
- Heats the air
- Convective currents
Welcome to the Biometeorology Group at UC Davis

The Biometeorology Group at UC Davis is concerned with the physical processes that govern exchanges between biological surfaces and the lower atmosphere. Such exchanges include momentum, sensible heat and water vapor, and various gases and particulate matter for both individual organisms and communities.

Students in this specialty participate in modeling, observation and theoretical studies of these exchanges, with special emphasis upon the turbulent nature of the atmospheric surface layer.

Current projects include estimating turbulent parameters and dispersion coefficients for a California regional air quality study, and determining, by eddy covariance and mean advection methods, and the carbon exchange between the atmosphere and a 500-year-old, 65 m high forest at the Wind River Canopy Crane Research facility (WRCCRF).

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Frost Protection
Frost Protection

When to Turn Sprinklers On and Off for Frost Protection
FP001 Quick Answer—This quick answer provides information on using a psychrometer or temperature and dew point data to determine when to start and stop sprinklers for frost protection.

Predicting Temperature Trends during Freeze Nights
FP002 Quick Answer—This quick answer gives a method for predicting the change in temperature during a calm, radiation freeze night.

A Simple Method to Measure the Dew Point Temperature
FP003 Quick Answer—This quick answer provides information on how to measure the dew point for use in estimating minimum temperature and for starting and stopping sprinklers for frost protection.

Sprinkler Application Rates for Freeze Protection
FP004 Quick Answer—This quick answer provides information on the sprinkler application (precipitation) rates needed to protect crops from freezing.

Principles of Frost Protection
FP005 Quick Answer—This quick answer provides information on the general principles of well-known frost protection methods. A PDF file of the WEB page can be uploaded from this Quick Answer. In addition, a shorter version is available.

Programs for Estimating Frost Night Minimum Temperatures and Temperature Trends [new 7 Mar 2007]
The FFST Excel application programs FFST_E.xls and FFST_M.xls are available from this link. The FFST application helps users to determine an empirical equation for estimating minimum temperatures during radiation frost nights. Note that the program will provide good estimates if there is little or no wind; no significant cold air.
The End

Thanks

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