Frost Protection Principles

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Cooperative Extension
Agriculture & Natural Resources
Central Valley Region
Mean Annual Losses to Weather Hazards in the United States

$ per capita

Hazard

- Frost
- Flood
- Drought
- Hail
- Hurricane
- Tornado
- Windstorm
- Lightning
First, a good orchard thermometer in a proper thermometer shelter is a must.
Critical temperatures for damage ---

- Vary with the stage of bloom.

- Green tip -- 25° F
- Popcorn -- 27° F
- Full Bloom -- 28° F
Frost damage at bloom, ovaries are killed and turn brown

Small nuts – 30° F
Frost damage from a late spring freeze (April 9th) followed by nut drop
Frost damage from late spring freeze (April 20th). Fruit scarring, ovary killed, followed by fruit drop.

Small green fruits – 30°F
Arctic air mass… advection freeze in December 1990
Radiation

Day

Night
Methods of Heat Transfer

**Conduction** - from molecule to molecule

**Heat Source** → **Metal bar**

**Convection** - by movement of heated air

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

- Long wave loss from Earth
- Short wave gained from the sun

Earth
Properties of Water

- High Heat Capacity
- Most Dense at 39° F
- Contains Latent Heat
Latent Heat

- Heat Stored in Water
- Chemical Energy
- Hydrogen Bonds
Methods of Heat Transfer

Latent Heat - Chemical Heat

When water molecules evaporate, sensible heat is changed to latent heat and the temperature drops.

When water molecules condense, latent heat is changed to sensible heat and the temperature rises.

Evaporation

Condensation
High humidity slows the decline of overnight temperatures.
Water Vapor Concentration

- The higher the concentration the higher the humidity
- When water vapor is saturated, a thermometer will read the wet-bulb temperature
- A wet plant’s temperature cannot fall below the wet-bulb temperature
SLING PSYCHROMETER METHOD OF MEASURING RELATIVE HUMIDITY

WET BULB

DRY BULB

WET BULB DEPRESSION
Dew Point

- The dew point temperature is the temperature when relative humidity = 100%

- When surface temperatures reach dew point, condensation (dew) forms releasing sensible heat which slows temperature drop
Slowly add ice cubes to water in a shiny can to lower the can temperature.

Stir water with a thermometer while adding ice cubes to insure the same can and water temperature.

When condensation occurs on the outside, note the dew point temperature.
An inversion...

- Occurs when temperature increases with height
- Forms when air near the ground cools more rapidly than the air above
- Is associated with radiation freezes
VERTICAL TEMPERATURE IN ORCHARD UNDER INVERSION

- Top of Inversion
- Relatively Warm Air
- Critical Temperature
- Cold Air
Inversion Formation

Temperature (°F)

Temperature (°C)

Height (ft)

Height (m)

-5.0
0.0
5.0
10.0

20 25 30 35 40 45 50 55

16:00 h
8:00 h
4:00 h
0:00 h
20:00 h
16:00 h

Inversion Formation

[Graph showing temperature and height profiles with specific times]
Radiation vs Advection Frost

Feb. 24-25, 1987 Chico

Temperature at 5 ft

RADIATION → ADVECTION

PACIFIC STANDARD TIME

Wind Speed mph

20 22 00 02 04 06 08

20 25 30 35 40

0 5 10
Passive Frost Protection Elements

- Site Selection
- Ground Cover
- Soil Water Content
- Covers & Wraps
- Bacteria Control
Cold Air Drainage

- Cold air is heavier (more dense) than warm air
- It flows down hill like water
- Accumulates in low areas
Cold Air Drainage
Cold air drains to low spots
Freeze along Highway 65, Porterville, CA
Site Selection

- An important management decision
  - Avoid low (cold) sites
  - Plant on North slopes to delay bloom
  - Air drainage from the site
  - Assess the risk of freeze damage
Surface temperature affects the air and crop temperature

When the surface is warmer, the air and crop are warmer.

Height

32°F (0°C) 32°F (0°C)

Temperature

colder warmer
Ground covers....

keep mowed short for the warmest orchard condition
Ground Covers

- Reflect sunlight
- Dry the soil & evaporate water
- Reduce soil heat conduction
- Result in colder minimum temperatures
Loose, recently cultivated soil creates the coldest orchard floor condition
Ground Cover Summary

- Fallow, bare firm moist soil is warmest
- Cut covers short with a mower or chemically mow
- Don’t cultivate
- Rewet dry soil
Soil Water Content

Reflects More
Low Heat Capacity
Low Conductivity

Dry Soil
$colder$

Less Reflection
Higher Heat Capacity
More Conductivity

Wet Soil
$warmer$

$T_{surface}$

32°F (0°C)

Temperature
Soil water

- Wet the top foot
- Wet the entire surface
- Be near field capacity
- Water 1-2 days ahead of a freeze to help store heat in the soil
Covers and wraps on young trees

Reduce:
- Radiation loss
- Convection loss

Management must:
- Keep insulation dry
- Cover all the way to the ground
Freeze damage has been seen on tender, fall planted, containerized almond trees.
Bacteria Control

- Proteins in *Pseudomonas syringae* bacterial cell walls stimulate the formation of ice crystals.
- This is known as ice nucleation.
*Ice Nucleation*

- Water can supercool or freeze below the Melting Point (0°C or 32°F).
- In the temperature range for frost damage, bacteria cause 99% of ice nucleation.
Ice Nucleation

- Kill the bacteria w/ copper
- Competitive bacteria
- Remove ground cover
Active Frost Protection methods

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

- Warm the trees through radiation and convection
- Inversions
- Small fires
- Low spots

UC Return Stack Orchard Heater – developed by Ag Engineering at UC Davis
Heaters

Temperature (°F)

Height (ft)

Temperature (°C)

Height (m)

30 (-1.1)

35

30 (-1.1)
SMALL FIRES ARE MORE EFFECTIVE THAN LARGE FIRES

- Temperature Lapse Rate
- Lost Heat
- Inversion

Small Fire
Large Fire
Heater placement

wind

Low Spot
Wind Machines
No Wind Machine

With Wind Machine

Temperature (°C)

Height (ft)

Height (m)

Temperature (°F)
Wind machines work best in small narrow valleys with strong inversions
February 3-4, 1993

Fan start time effect
Clear and calm night

10 m (33 ft)

Temperature (°C)

Pacific Standard Time

0:15
1:45
3:15

No wind machine
Temperature profiles (30 m from wind machine) before and after the wind machine was turned on.
Helicopters…
are similar to wind machines

- Push warm air down into the crop
- An inversion is required
Helicopter Test

Temperature (°F) Temperature (°C)

After Miller et al. (1951)
**Helicopters**

- Frequent passes
- Talk to the pilot
- Load with water
- Use marker lights
- Monitor temperature
Sprinklers

- Heat gain is from freezing water and the release of latent heat
- Must add more energy from freezing than is lost to evaporation
- Start based on wet-bulb (critical damage temperature)
Freezing releases 7.5 times the amount of heat that evaporation consumes.

Ice should be clear and dripping wet.
Sprinklers… solid set, movable aluminum pipes, or drag lines replaced orchard heaters
Micro-sprinklers work too if flow rate is sufficient
### Application rates for freeze protection of tall crops

<table>
<thead>
<tr>
<th>Temperature (°F)</th>
<th>Wind Speed (mph)</th>
<th>30 s rotation (in/hr)</th>
<th>60 s rotation (in/hr)</th>
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Appl. Rate = 2.8 mm s$^{-1}$
Wind Vel. = 6.9 m s$^{-1}$

Leaf edge Temperature (°C)

Time (seconds)
Nuts in the tree top above the cold air

No nuts in the middle canopy above the sprinkler pattern... shoot growth instead

Nuts in the bottom canopy where sprinklers provided coverage & protection
### Turn on Temperatures for Sprinklers

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When to turn off sprinklers?

- Turn off when the wet bulb temp. upwind of the protected orchard is above the critical damage temperature.
- Or, when all the ice melts.
Surface irrigation

- Either flood or furrow
- Provides protection thru latent heat released as the water cools
Surface irrigation

- Concentrate the flooding in furrows under the tree canopy
- Use a fast flow rate to prevent freezing
- Don’t reuse cold water
- Maximize the area wetted before the expected frost night to store more heat during the day
- Start early
Foggers

- Provide protection by creating an insulating blanket that reduces net radiation losses.

The Mee System – uses high pressure water and small orifices to produce a fog curtain.

Vapor Gun – propane burner used to vaporize water.
Summary: of all the options available today ---

- Under tree sprinkling is probably the most effective and practical
  - Solid set irrigation, movable pipe, or micro-sprinklers can provide benefits
  - 40 gpm/acre is an application rate that will be effective in most frost conditions we experience
Acknowledge my cooperator of many years

Dr. Richard Snyder, Extension Biometeorologist, UC Davis.

For more information visit his dept. web site:

http://lawr.ucdavis.edu/coopextn/biometeorology/