Cold hardiness and dormancy in fruit crops and possible controls

Jim Flore
Jim Flore
Mark Longstroth
Stan Howell
Michigan State University
Outline

- Climate change
- Dormancy
- Hardiness
- Types of Cold events and damage
  - Advective-high wind
  - Radiation-low wind
- Possible intervention for spring frost
  - Chemical
  - Mist-cooling
  - Irrigation
  - Covers
  - Wind machines
  - Orchard heaters
  - Landscape modification
Climate trends

• Temperature
• Ice in the great lakes
• Ice in relation to bud development
• More frequent frost?
• Rainfall during the year?
High Temperature Stress

Decadal Ratios of Record Highs, Lows

(From Meehl et al, 2009)
More rain in MI and less in CA... What about your state

Projected % Change in Precipitation
1950-2000 to 2021-2014

- MI: 3-4% higher
- CA, TX, Mexico: 1-5% lower

Effect on Fruit Crops
Depends on distribution
More or less disease
More or less fruit cracking

WILL YOU BENEFIT?
Peach Ridge Growth Stages (McIntosh)
1st Green to Full Bloom

- 1976
- 1980
- 1984
- 1988
- 1992
- 1996
- 2000
- 2004
- 2008
- 2012

Earliest
- 2012, Mar 16
- 2010, Mar 23
- 2000, Mar 23

Shortest
- 17 Days, 85

Longest
- 50 Days, 97

Latest GT
- 1977, Apr 28
- 1978, May 3
- 2010, Apr 28
- 2012, Apr 11

Dates:
- 2012, Apr 11
- 2010, Apr 28
- 2010, Mar 23
- 2000, Mar 23
- 2012, Mar 16
- 1978, May 3

Days:
- 26 Days 2012
- 32 Days 2011
Comparison of Lake Michigan ice cover and full bloom date for McIntosh in a Peach Ridge orchard, 1976-2010.

- Ice Cover
- Full Bloom Date

Ice cover data extrapolated from Figure 4b in Wang et al. (2010). Bloom data compliments Phil Schwallier.
Great Lakes Region (32°F threshold)

Frost-Free Season (days from normal)

Year

Great Lakes Region (32 °F threshold)
Length Spring Fall

1945, 2010, 2012 DD & Growth Stages

- **1945**
  - Mar 23
  - Apr 13
- **2010**
  - 1st Green: Mar 23
  - Full Bloom: Apr 28
- **2012**
  - Growing degree days
Dormancy and hardiness and Chilling requirement are all related

• Dormancy and hardiness are related but not exactly the same thing
• Dormancy – plant won’t grow even when conditions are favorable (yes/no)
• Chilling requirement – must be accomplished before growth can begin in the spring.
• Hardiness – ability to withstand cold temps without damage (degree).
• Growth and hardiness go in the opposite direction
CHERRY ANNUAL CYCLE

MORPHOLOGY
- Leaves
  - Leaf abscission
- Roots
- Trunk
- Fruit
  - Cell division
  - Pit hardening
  - Final swell
  - Abscission
- Harvest
- FBI
- F-Development
- Physiology
- Dormancy
  - Summer
  - Rest
  - Spring

Temp, low and high                temp, light, water, nutrition, biological    temp, nutrition

160-180 days

58-65 days
Cold Hardiness in Fruit Trees

- Short days
- Acclimation
- Killing frost
- Deep winter hardiness
- Endodormancy or rest
- De-acclimation

LT50

0°F
-10°F
-20°F
-30°F

Jul Aug Sept Oct Nov Dec Jan Feb Mar Apr May June
Cold Acclimation Process

• Photoperiod— ratio of light to dark (light quality)
• Temperature- near to slightly below freezing
• Short days followed by cool temperatures followed by temperatures just below freezing are best to acclimate trees.
• During short day acclimation period warm days and cool nights are best.
Cold Acclimation Cont’d

• Gradual exposure to colder temperatures increases hardiness
Hardiness develops from shoot to trunk.

**Table 1. Influence of twig tissue, rootstock and cultivar on the cold acclimation of peach, 1985.**

<table>
<thead>
<tr>
<th>1. Twig Tissue</th>
<th>9-3</th>
<th>9-9</th>
<th>9-23</th>
<th>10-7</th>
<th>10-21</th>
<th>11-4</th>
<th>10-11</th>
<th>x</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apical</td>
<td>-6.5 a</td>
<td>7.5 a</td>
<td>-9.0 a</td>
<td>-8.0 b</td>
<td>-13.0 b</td>
<td>-15.5 b</td>
<td>-18.5 b</td>
<td>-11.1</td>
</tr>
<tr>
<td>Middle</td>
<td>-6.0 a</td>
<td>7.5 a</td>
<td>-8.5 ab</td>
<td>-8.0 b</td>
<td>-14.0 b</td>
<td>-15.5 b</td>
<td>-19.0 b</td>
<td>-11.2</td>
</tr>
<tr>
<td>Basal</td>
<td>-3.5 b</td>
<td>6.0 b</td>
<td>-7.5 b</td>
<td>-9.0 a</td>
<td>-16.0 a</td>
<td>-16.5 a</td>
<td>-23.0 a</td>
<td>-11.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2. Rootstock (Redhaven Scion)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Halford</td>
<td>-4.5</td>
<td>-6.0</td>
<td>-8.0</td>
<td>-8.0</td>
<td>-14.0</td>
<td>-16.0</td>
<td>-19.2</td>
<td>-10.8b</td>
</tr>
<tr>
<td>Siberian C</td>
<td>-5.5</td>
<td>-6.0</td>
<td>-8.0</td>
<td>-8.5</td>
<td>-14.0</td>
<td>-16.5</td>
<td>-20.5</td>
<td>-11.3a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3. Cultivar (Halford Rootstock)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Redhaven</td>
<td>-4.5 b</td>
<td>-7.5 b</td>
<td>-8.0 b</td>
<td>-8.0</td>
<td>-9.5 a</td>
<td>-14.0 b</td>
<td>-19.0 b</td>
<td>-10.1b</td>
</tr>
<tr>
<td>Redskin</td>
<td>-5.5 a</td>
<td>-8.0 b</td>
<td>-8.0</td>
<td>-8.0</td>
<td>-7.5 b</td>
<td>-14.0 b</td>
<td>-20.5 a</td>
<td>-10.4b</td>
</tr>
<tr>
<td>Cresthaven</td>
<td>-5.0 ab</td>
<td>-9.0 a</td>
<td>-9.5 a</td>
<td>-8.0</td>
<td>-9.5 a</td>
<td>-15.5 a</td>
<td>-20.5 a</td>
<td>-11.0a</td>
</tr>
</tbody>
</table>

n.s. - not statistically significant.
* - significant at the 0.10 level of probability.
** - significant at the 0.05 level of probability.
*** - significant at the 0.01 level of probability.
Cold Hardiness in Fruit Trees

- Acclimation
- Endodormancy or rest
- Deep winter hardiness
- De-acclimation
- Reduced Growth

Short days
Killing frost
Importance of day length and temperature!!!

Fig. 5.8a,b. Seasonal hardening patterns of young apple trees at different photoperiods in (a) the field and (b) in a warm greenhouse. SD natural short days in autumn; LD long-day treatment (photoperiod 18 h using additional incandescent light). Air temperatures are daily maxima and minima. Arrow: First leaf-killing frost. (From Howell and Weiser 1970a)
An example of how a plant may experience different types of dormancy throughout a season:

**Figure 3.2.** Relative contribution of the various types of dormancy during a hypothetical dormant period for an apical bud. From Lang et al. (1987). *HortScience* **22**, 371–377.
Chilling Requirement

• Definition:
  • # of hours of temp between 0-10°C required to break endodormancy (regulated by physiological factors inside the affected structure)

• Advantages?

• Disadvantages?
**Chilling Requirements**

**Low-chilling**
- Longer productive season
- More susceptible to late frost damage

**High-chilling**
- Protected against late frost
- Shorter growing season

**Figure 15-3** Approximate chilling requirements to break winter rest for fruit and nut species. The ranges shown for each species indicate the differences between low- and high-chilling cultivars within the species. Grape will grow with very little chilling but will begin growth much faster after long chilling. [Partially based on data of Chandler, Kimball, Philp, Tufts, and Weldon, 1937]
What Controls the time of Spring Bloom

Temperature! We must understand dormancy and hardiness

- Early (Environment) Acclimation
- Deep (Chilling hours 32F-50F) heat no effect.
- Late (GDH) De-acclimation

- States of Dormancy
After Rest (endodormancy)

- Development is driven by GDH
- Accumulation of heat units begin well before any visible signs of growth by the bud.
- The buds lose hardiness as they begin to develop.
- Therefore freezing injury occurs at an ever increasing temperature
Cold Hardiness in Montmorency

<table>
<thead>
<tr>
<th>Jul</th>
<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp, low and high</td>
<td>temp, light, water, nutrition, biological</td>
<td>temp, nutrition</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SOURCE LIMITATION

• DECREASE IN COLD HARDINESS

• Grower dogma “starve them in the fall to get them to harden off”

• HOWELL AND STACKHOUSE 1972
  • EARLY LOSS OF LEAVES REDUCED HARDINESS, REDUCED BUD SET THE FOLLOWING SPRING CAUSED BY MID SUMMER DEFOLIATION
Fig. 4. Effects of time and amount of defoliation during 1970 on the acclimation of tart cherry buds in the autumn of 1971.
Fig. 7. Effects of time and amount of defoliation during 1970 on the deacclimation of tart cherry twigs in the spring of 1972.

Fig. 8. Effects of time and amount of defoliation during 1970 on the deacclimation of tart cherry buds in the spring of 1972.
Influence of Shade

Table 2. The effect of various degrees of shade on shoot length, shoot cross-sectional area, shoot carbohydrate content, shoot water content, and hardness of wood and buds on November 29, 1979 of ‘Redhaven’ peach. Treatment began June 20, 1979.

<table>
<thead>
<tr>
<th></th>
<th>Shoot length (cm)</th>
<th>Shoot cross-sectional area (mm²)</th>
<th>Soluble carbohydrate (mg/g dry wt)</th>
<th>Water content (% H₂O)</th>
<th>Hardness (T₅₀) Wood</th>
<th>Hardness (T₅₀) Flower buds</th>
<th>Hardness (T₅₀) Vegetative buds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full sun</td>
<td>100</td>
<td>36.8</td>
<td>13.2 a²</td>
<td>109.3 a²</td>
<td>-22.5 a</td>
<td>-17.5 a</td>
<td>-17.5 a</td>
</tr>
<tr>
<td></td>
<td>36</td>
<td>44.8</td>
<td>11.9 ab</td>
<td>110.8 a</td>
<td>-22.5 a</td>
<td>-17.0 a</td>
<td>-17.5 a</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>44.0</td>
<td>10.2 ab</td>
<td>107.5 a</td>
<td>-16.0 b</td>
<td>-12.5 b</td>
<td>-15.0 b</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>41.0 NS</td>
<td>7.5 b</td>
<td>97.6 b</td>
<td>-13.0 c</td>
<td>--- x</td>
<td>-13.0 c</td>
</tr>
</tbody>
</table>

²Mean separation by Duncan’s multiple range test, 5% level.

³T₅₀ calculated using the Spearman-Kärber equations and mean separation within a column by the modified Friedman test, 5% level.

*Insufficient number of replicates for analysis.

Table 3. Correlation coefficients for percent full sun, shoot length, shoot cross-sectional area, soluble solids, and water content vs. wood, flower, and bud hardness for ‘Redhaven’ peach and ‘Montmorency’ sour cherry.
Can we Delay Bloom

- Bio-regulators
- Cultural practices
- Mist-cooling
Bio-regulators

• Fall before
  • Ethephon (2-4 days, + winter hardiness)
  • GA (little effect)
  • Alar (delay 4-6 days)

• Before spring bud break
  • Oils (soybean oil) 2-4 days peach CHES (Flore)
  • ABA
  • Compounds that reflect heat, light
Mist cooling to delay Bloom

- Apply water at intervals = evaporation
  - Rate of evaporation increases cooling
  - Evaporation depends on: temp, humidity, wind
- Andersen and Seeley (HortReviews, V 15)
  - Delay in bloom up to 3 weeks
  - Greater effect in dry climates
  - Delay ripening
  - More disease
  - Less fruit set
## Data from New Zealand
(Hewett and Young, NZ Journal of Ag. Res. 1980)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Days delay FB 1975</th>
<th>Days delay FB 1976</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple Delicious</td>
<td>6</td>
<td>18</td>
</tr>
<tr>
<td>Peach</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td>Apricot</td>
<td>10</td>
<td>8</td>
</tr>
</tbody>
</table>

1975 activated at 44.6 F, 1976 46.4 F
1975, 46.7 in water; 1976; 19.2 in water
Why hasn’t it been adopted?

- Too much water applied (30-40 inches)
- Greater disease
- Lower Fruit set
- Lower quality
- Cost
The Solid Set Canopy Delivery System

• Equipment in place
• Better control of application
Solid-Set Canopy Delivery Systems
SSCRI team lead by Matt Greishop
¾ inch hose on bottom wire

Dan-Jain Micro-sprayers inserted on a T perpendicular to ground & parallel to tree row
Why now, isn’t this old work?

• Old systems based on sprinklers (minimum of $\frac{1}{4}$ inch per hour) and time clocks (5 min on rmon off) had disadvantages (disease, poor set, and excessive water use).

• Why now?
  • Newer delivery systems based on mist application using the SSCD (solid state canopy delivery system) to apply pesticides
  • Modern weather stations that accurately measure temperature, humidity, and wind speed (factors that effect evaporation)
  • Modern control systems based on environment that gives maximum cooling from evaporation.
Apple trials at St. Joseph Charlotte Hillsdale
Pictures taken on May 16, 2014
1. No mist
2. Red Delicious, SSCD turned off on May 16 (Treatment 2)
3. SSCD system turned off on May 13 (Treatment 1)
<table>
<thead>
<tr>
<th>Orchard Location</th>
<th>Variety</th>
<th>Study</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>bloom date</td>
<td>GDD (deg C)</td>
<td>Fruits per flowering spur</td>
<td>bloom date</td>
</tr>
<tr>
<td>St. Joseph</td>
<td>Gala</td>
<td>Control</td>
<td>10-May</td>
<td>204</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td></td>
<td>treatment 2</td>
<td>16-May</td>
<td>260</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>treatment 1</td>
<td>18-May</td>
<td>292</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>Red Delicious</td>
<td>Control</td>
<td>12-May</td>
<td>211</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>treatment 2</td>
<td>16-May</td>
<td>260</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td></td>
<td>treatment 1</td>
<td>19-May</td>
<td>311</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Honey Crisp</td>
<td>Control</td>
<td>14-May</td>
<td>230</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>treatment 2</td>
<td>19-May</td>
<td>311</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>treatment 1</td>
<td>22-May</td>
<td>370</td>
<td>32</td>
</tr>
<tr>
<td>Charlotte</td>
<td>Honey Crisp</td>
<td>Control</td>
<td>16-May</td>
<td>218</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Treatment</td>
<td>22-May</td>
<td>318</td>
<td>52</td>
</tr>
</tbody>
</table>
Air, control bud and misted bud temperature at St. Joseph MI
Cherry flowers on May 2, 2013 at SWMREC, Benton Harbor, MI
Non misted bloomed May 2 and misted on May 13
Table- Bloom date and GDD (from green tip on non-misted) of sweet cherry at SWMREC, GDD using minimum and maximum air temperature.

<table>
<thead>
<tr>
<th>Year</th>
<th>Study</th>
<th>Bloom date</th>
<th>GDD</th>
<th>Mist duration (Hours)</th>
<th>Mist volume (ac-in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>No mist</td>
<td>2-May</td>
<td>150</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mist</td>
<td>13-May</td>
<td>258</td>
<td>39</td>
<td>5.35</td>
</tr>
<tr>
<td>2014</td>
<td>No mist</td>
<td>7-May</td>
<td>134</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mist</td>
<td>16-May</td>
<td>238</td>
<td>52</td>
<td>10.5</td>
</tr>
</tbody>
</table>
Montmorency 2014,15
2015 misting resulted in 6-8 day in full bloom on Montmorency
Cold Protection

Think about frost protection all year around not just the day before the freeze.

• Passive measures,
  • Site Selection
  • Improve air drainage
  • Manage ground cover

• Active Measures
  • Wind Machines
  • Sprinkler Systems
# Types of Freezes

<table>
<thead>
<tr>
<th>Radiation Freeze</th>
<th>Adveective Freeze</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winds less than 5 MPH</td>
<td>Winds higher that 5 MPH</td>
</tr>
<tr>
<td>Clear sky</td>
<td>May be cloudy</td>
</tr>
<tr>
<td>Cold air mass 30 to 200 ft.</td>
<td>Cold air 400 ft to 1,500 ft</td>
</tr>
<tr>
<td>Inversion develops</td>
<td>No Inversion</td>
</tr>
<tr>
<td>Cold air in the low spots</td>
<td></td>
</tr>
<tr>
<td>White frost or black frost</td>
<td>Usually black frost</td>
</tr>
<tr>
<td>Easier to protect</td>
<td>Difficult to protect</td>
</tr>
</tbody>
</table>
Clear calm night

- Warm ground radiates heat away to the sky.
- Cool ground also chills the air above it.
Clear breezy night

- Warm ground radiates heat away to open sky.
- Winds mix cooler air near the ground with warmer air above.
Orchard Site Selection

• Choose Frost Free Sites
• Sites with good air drainage.
• Plant early or cold sensitive varieties in best sites.
• Or plant high value varieties in best sites.
• You may need to leave skips for air drainage or run rows down slope to facilitate good air drainage.
• Also prune most sensitive latest in the spring. For example pear and apple before cherry and peach.
Avoid Frost Pockets

cold air flows downhill

Adapted from graphic by Andrew Bootsma, Agrometeorological Resources Specialist, Land Resource Research Institute, Agriculture Canada
Minimum Temperature (C) on Apr 30, 2008
The Frost Line

Photo: Mark Longstroth
Improve Air Drainage

20 - 30 m
Storing Heat Before a Freeze

- Ground cover influences temperature.
- Mowed cover crop is warmer than unmowed.
- Clean cultivated warmer than grass.
- Packed warmer than loose.
- Wet warmer than dry.
Effect of Ground Cover and Water

Effect of Different Soil Surfaces on Temperatures at 4 ft

<table>
<thead>
<tr>
<th>Soil Surface</th>
<th>Temperature Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare, Firm, Moist Soil</td>
<td>Warmest</td>
</tr>
<tr>
<td>Moist Soil, Shredded Cover crop</td>
<td>0.5 F colder</td>
</tr>
<tr>
<td>Moist Soil, Low Cover crop</td>
<td>1 to 3 F colder</td>
</tr>
<tr>
<td>Dry Firm Soil</td>
<td>2 F colder</td>
</tr>
<tr>
<td>Freshly Disked Soil</td>
<td>2 F colder</td>
</tr>
<tr>
<td>High Cover crop</td>
<td>2-4 F colder</td>
</tr>
</tbody>
</table>

Source: Mark Longstroth
Extension Educator MSU, SW Michigan
It is going to get cold enough to hurt me!

• What Can I Do!
• For a radiation freeze there are good options.
• Not everything works all the time.
• All systems work well in radiation freezes with a strong inversion.
• For a wind freeze there is crop insurance.
Frost Protection

• Add Heat
• By Conduction
• By Radiation
• Avoid Convection

Photo: Mark Longstroth
Critical Temperatures for Frost Damage on Fruit Trees

Marion Murray, IPM Project Leader

The following table, developed by Washington State University, lists Fahrenheit temperatures for each stage of development at which 10% and 90% bud kill occurs after 30 minutes exposure. The percentage bud kill which causes crop reduction will vary with each crop. For example, to have a full crop of cherries requires well over 50% bud survival in most years, while apples, pears, and peaches may only need 10-15% bud survival.

<table>
<thead>
<tr>
<th></th>
<th>Silver Tip</th>
<th>Green Tip</th>
<th>Half-Inch Green</th>
<th>Tight Cluster</th>
<th>First Pink (Pink)</th>
<th>Full Pink (Open Cluster)</th>
<th>First Bloom (King Bloom)</th>
<th>Full Bloom and Post-bloom</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>15</td>
<td>18</td>
<td>23</td>
<td>27</td>
<td>28</td>
<td>28</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>90%</td>
<td>2</td>
<td>10</td>
<td>15</td>
<td>21</td>
<td>24</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Swollen Bud (Scale Separation)</th>
<th>Bud Burst (Blossom Buds Exposed)</th>
<th>Green Cluster (Tight Cluster)</th>
<th>White Bud (First White, Popcorn)</th>
<th>Full White</th>
<th>First Bloom (King Blossom)</th>
<th>Full Bloom</th>
<th>Petal Fall (Post-bloom)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>15</td>
<td>20</td>
<td>24</td>
<td>25</td>
<td>26</td>
<td>27</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>90%</td>
<td>0</td>
<td>6</td>
<td>15</td>
<td>19</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>APRICOT</td>
<td>First Swell (Bud Swell)</td>
<td>Tip Separation (Swollen Bud)</td>
<td>First White</td>
<td>First Bloom</td>
<td>Full Bloom</td>
<td>In the Shuck (Petal Fall)</td>
<td>Shuck Split (Post-bloom)</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>-------------------------</td>
<td>-----------------------------</td>
<td>-------------</td>
<td>-------------</td>
<td>------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>15</td>
<td>20</td>
<td>24</td>
<td>25</td>
<td>27</td>
<td>27</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>90%</td>
<td>---</td>
<td>0</td>
<td>14</td>
<td>19</td>
<td>22</td>
<td>24</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>CHERRY</td>
<td>Swollen Bud (First Swell)</td>
<td>Bud Burst (Green Tip)</td>
<td>Tight Cluster</td>
<td>White Bud (First White, Popcorn)</td>
<td>First Bloom</td>
<td>Full Bloom</td>
<td>Post-bloom</td>
<td></td>
</tr>
<tr>
<td>SWEET</td>
<td>10%</td>
<td>17</td>
<td>25</td>
<td>26</td>
<td>27</td>
<td>28</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td></td>
<td>90%</td>
<td>5</td>
<td>14</td>
<td>17</td>
<td>24</td>
<td>25</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>TART</td>
<td>10%</td>
<td>15</td>
<td>26</td>
<td>26</td>
<td>28</td>
<td>28</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td></td>
<td>90%</td>
<td>0</td>
<td>22</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>PEACH</td>
<td>Swollen Bud (First Swell)</td>
<td>Calyx Green</td>
<td>Quarter-inch Green (Calyx Red)</td>
<td>Pink (First Pink)</td>
<td>First Bloom</td>
<td>Full Bloom</td>
<td>Post-bloom</td>
<td></td>
</tr>
<tr>
<td>NECTARINE</td>
<td>10%</td>
<td>18</td>
<td>21</td>
<td>23</td>
<td>25</td>
<td>26</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td></td>
<td>90%</td>
<td>1</td>
<td>5</td>
<td>9</td>
<td>15</td>
<td>21</td>
<td>24</td>
<td></td>
</tr>
</tbody>
</table>
Overhead Sprinklers

• Many Michigan Blueberry growers use sprinkler irrigation systems to reduce freeze damage. Sometimes using them causes more harm than good.
Change of State of Water

• It takes energy to melt ice or boil water
  • Melting Ice **Cools**
  • Vaporizing Water **Cools**

• Freezing water to ice or condensing water vapor gives up energy
  • Freezing Water **Warms**
  • Condensing Water **Warms**
Change of State of Water

• It takes energy to melt ice or boil water
  • Melting Ice **Cools** = requires 1200 BTU/gal.
  • Vaporizing Water **Cools** = requires 9000 BTU/gal.

• Freezing water to ice or condensing water vapor gives up energy
  • Freezing Water **Warms** = gives up 1200 BTU/gal.
  • Condensing Water **Warms** = gives up 9000 BTU/gal.

• 8.3 BTU per gallon for each degree F
Irrigation and Cold Protection

• When used properly, water can provide partial or complete crop cold protection.

• Improper use of water can increase cooling causing greater damage than if no water were used at all.

• It is important to know principles involved in using water for cold protection.
# Application Rates For Different Wind and Temperature Conditions

<table>
<thead>
<tr>
<th>MIN. TEMPERATURE (°F)</th>
<th>WIND SPEED IN M.P.H.</th>
<th>Application rate (inches per hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 to 1</td>
<td>2 to 4</td>
</tr>
<tr>
<td>Expected</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27°F</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>26°F</td>
<td>0.10</td>
<td>0.16</td>
</tr>
<tr>
<td>24°F</td>
<td>0.12</td>
<td>0.24</td>
</tr>
<tr>
<td>22°F</td>
<td>0.16</td>
<td>0.30</td>
</tr>
<tr>
<td>18°F</td>
<td>0.20</td>
<td>0.40</td>
</tr>
<tr>
<td>15°F</td>
<td>0.26</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Source: Mark Longstroth Extension Educator
MSU, SW Michigan
Dew Point

• The temperature when the air is saturated with water and dew will form.
• Depends on the amount of water vapor in the air, or air mass.
• Low relative humidities mean low dew points and low dew points make frosts or freezes more likely.
When to Start?

Under low dew point conditions,

Started sprinklers at:

- 34°F for dew point 26°F or above
- 35°F for dew point 24°F
- 36°F for dew point 22°F

<table>
<thead>
<tr>
<th>Dew Point</th>
<th>Irrigate at</th>
</tr>
</thead>
<tbody>
<tr>
<td>26 F</td>
<td>34</td>
</tr>
<tr>
<td>25 to 24</td>
<td>35</td>
</tr>
<tr>
<td>23 to 22</td>
<td>36</td>
</tr>
<tr>
<td>21 to 20</td>
<td>37</td>
</tr>
<tr>
<td>19 to 17</td>
<td>38</td>
</tr>
<tr>
<td>16 to 15</td>
<td>39</td>
</tr>
</tbody>
</table>

Source: Mark Longstroth Extension Educator
MSU, SW Michigan
Overhead Sprinkling
Ice Must Stay Wet!!

The temperature of a plant covered in ice will drop below a dry plant if the ice dries.

Evaporation from the ice will cool the plant to the dew point.
Under Tree Sprinklers

- More common in Orchard Systems.
- Releases heat under the canopy.
- Works best under an Inversion which traps heat in the orchard below the inversion.
- Compatible with wind machines.
- Could pre heat water!
- Less likely to damage crop if system fails.
Micro-sprinkler Ice
Wind Machines

Advantages

• Work well if inversion is low enough (10-20 m)
• Can protect large area depending on strength of inversion.
• Temperature difference and height.
• Can provide about 2 to 5°C of protection.
• Can work in winter for calm conditions.

Disadvantages

• Don’t work in winds > 8 kph.