Cold hardiness and dormancy in fruit crops and possible controls

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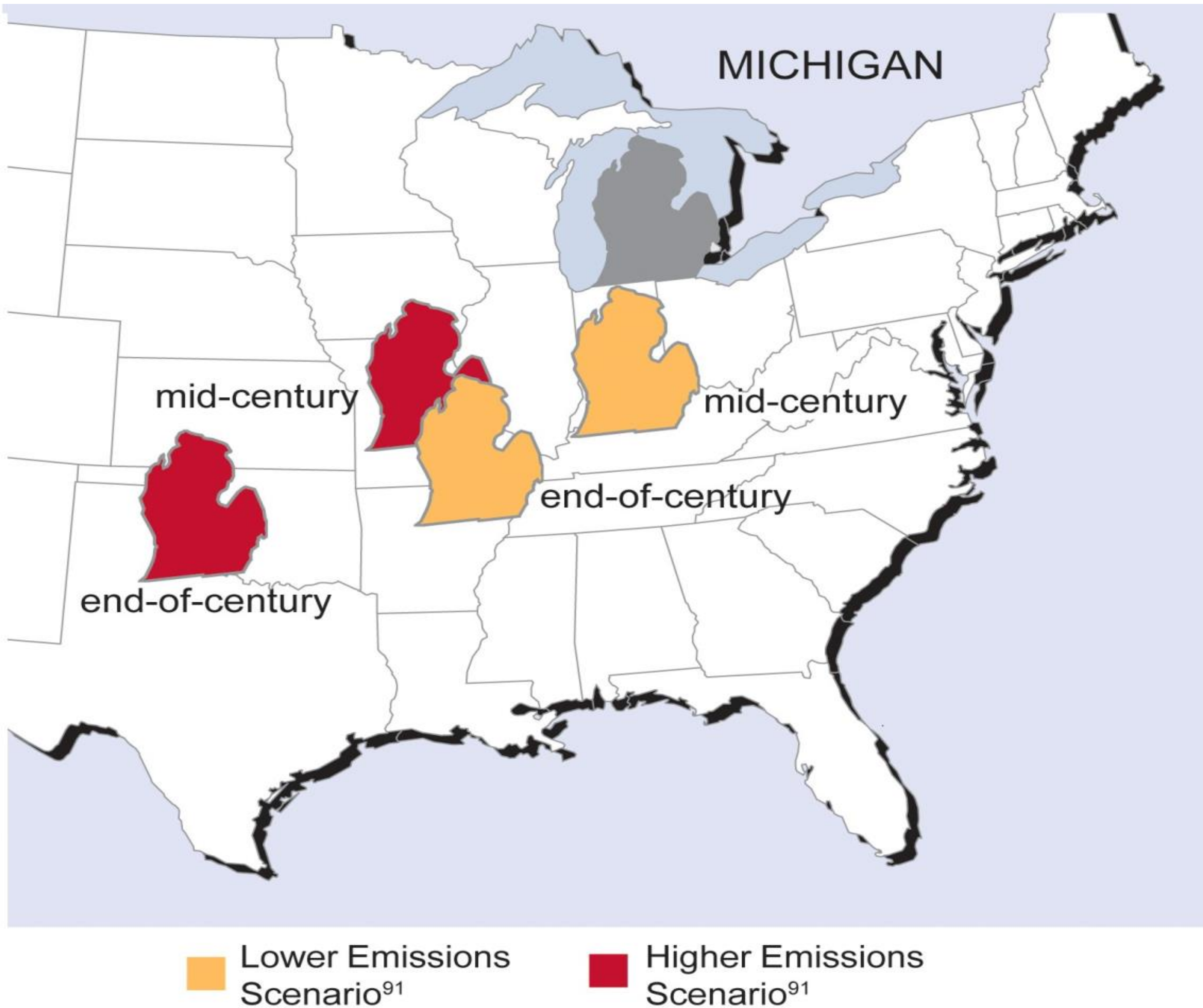
Outline

- 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

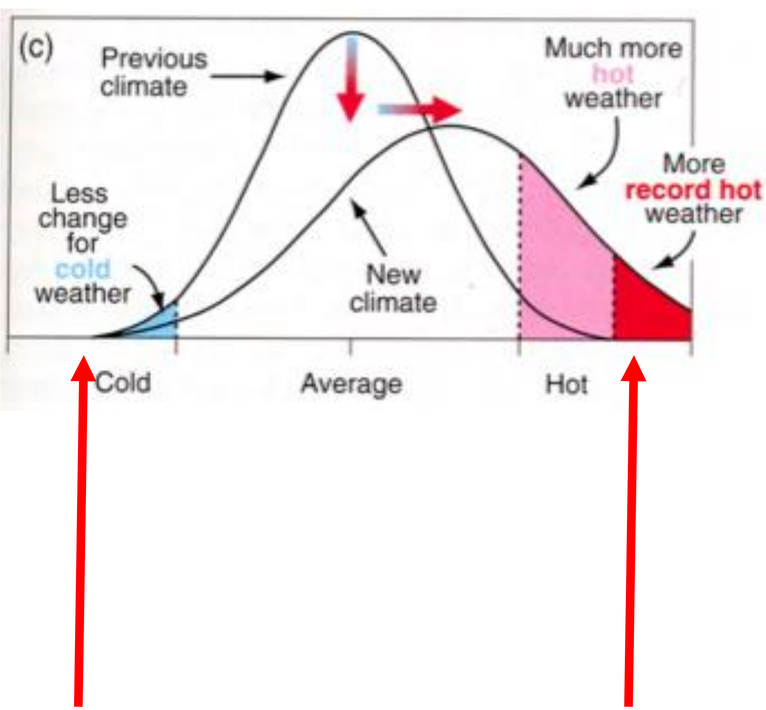
Climate trends

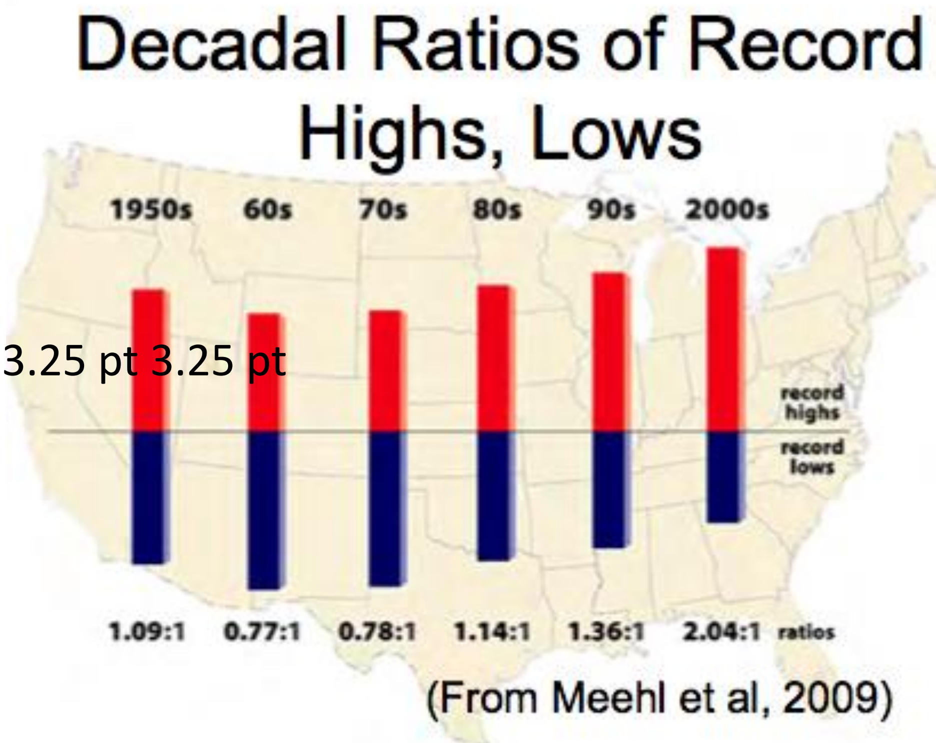
- Temperature
- Ice in the great lakes
- Ice in relation to bud development
- More frequent frost?
- Rainfall during the year?



Slide from Bruno Basso, MSU; Adapted from Hayhoe et al, 2010

High Temperature Stress



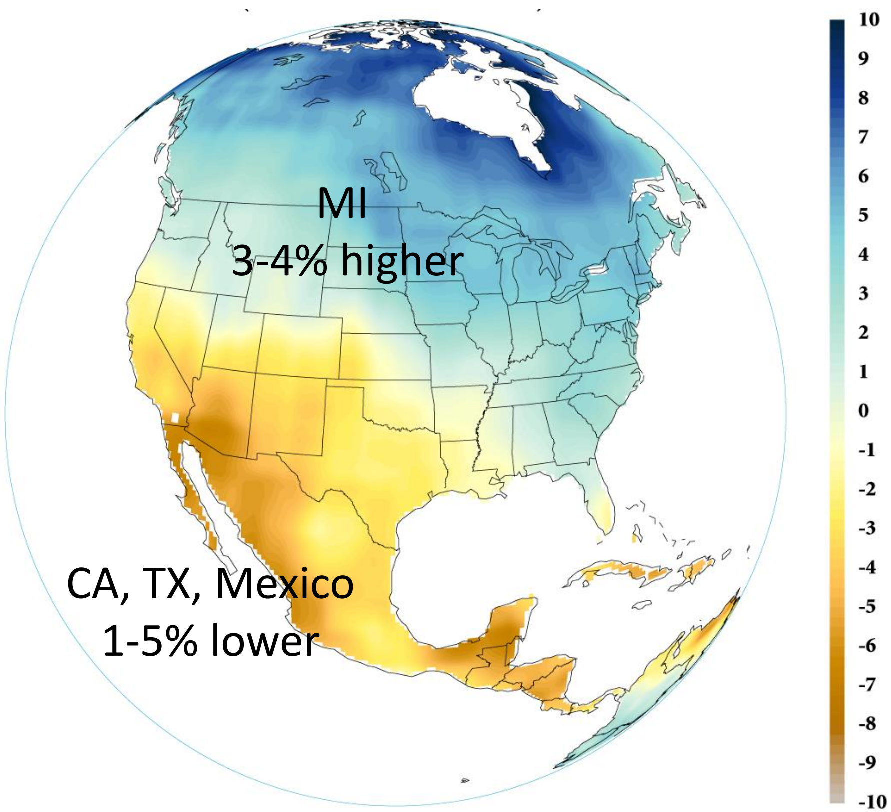


3.25 pt 3.25 pt

Slide adapted from Jeff Andreson, MSU

More rain in MI and less in CA… What about your state

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



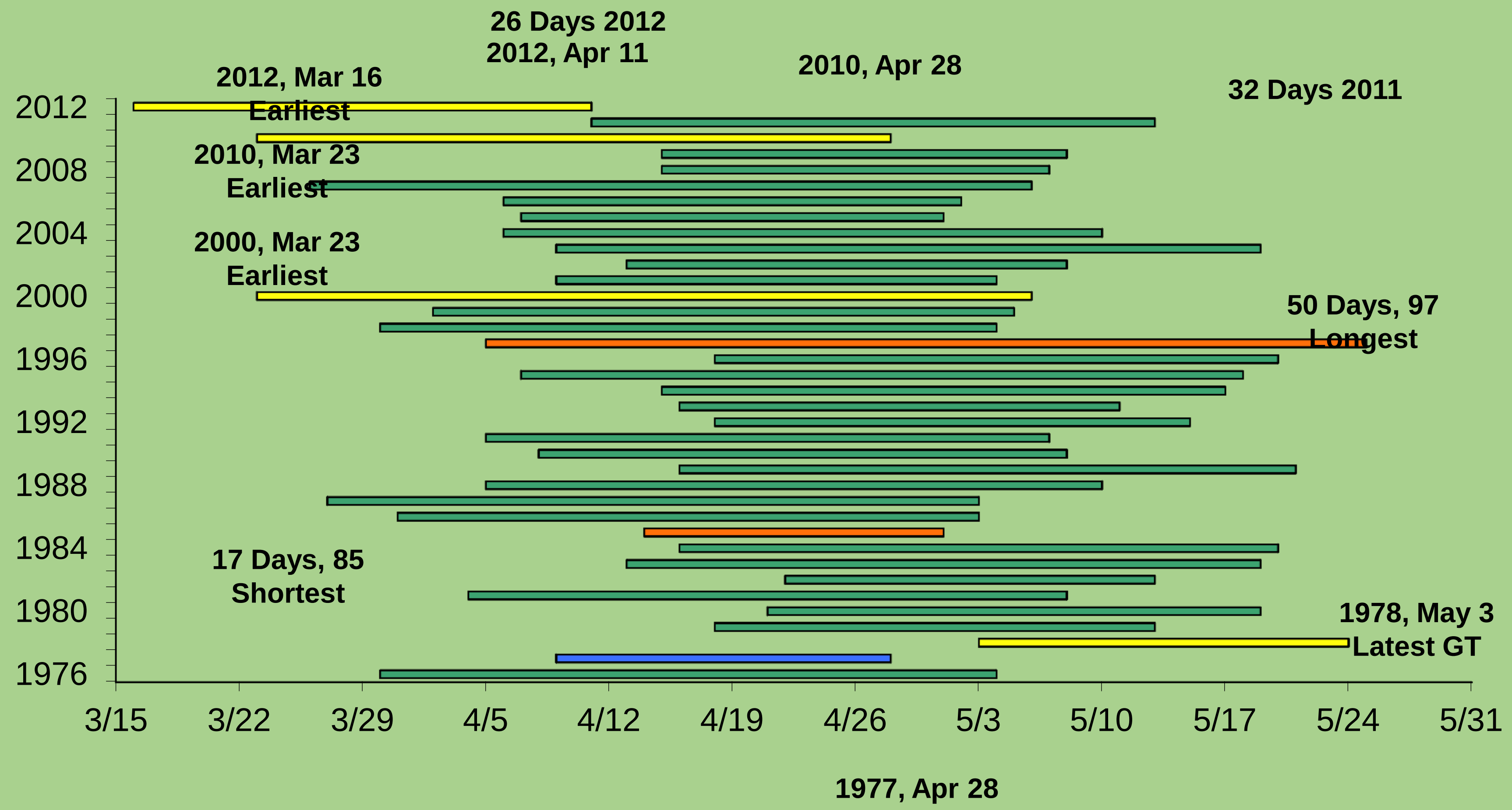
Lamont-Doherty Earth Observatory; NOAA; NCAR

Figure by G. Vecchi

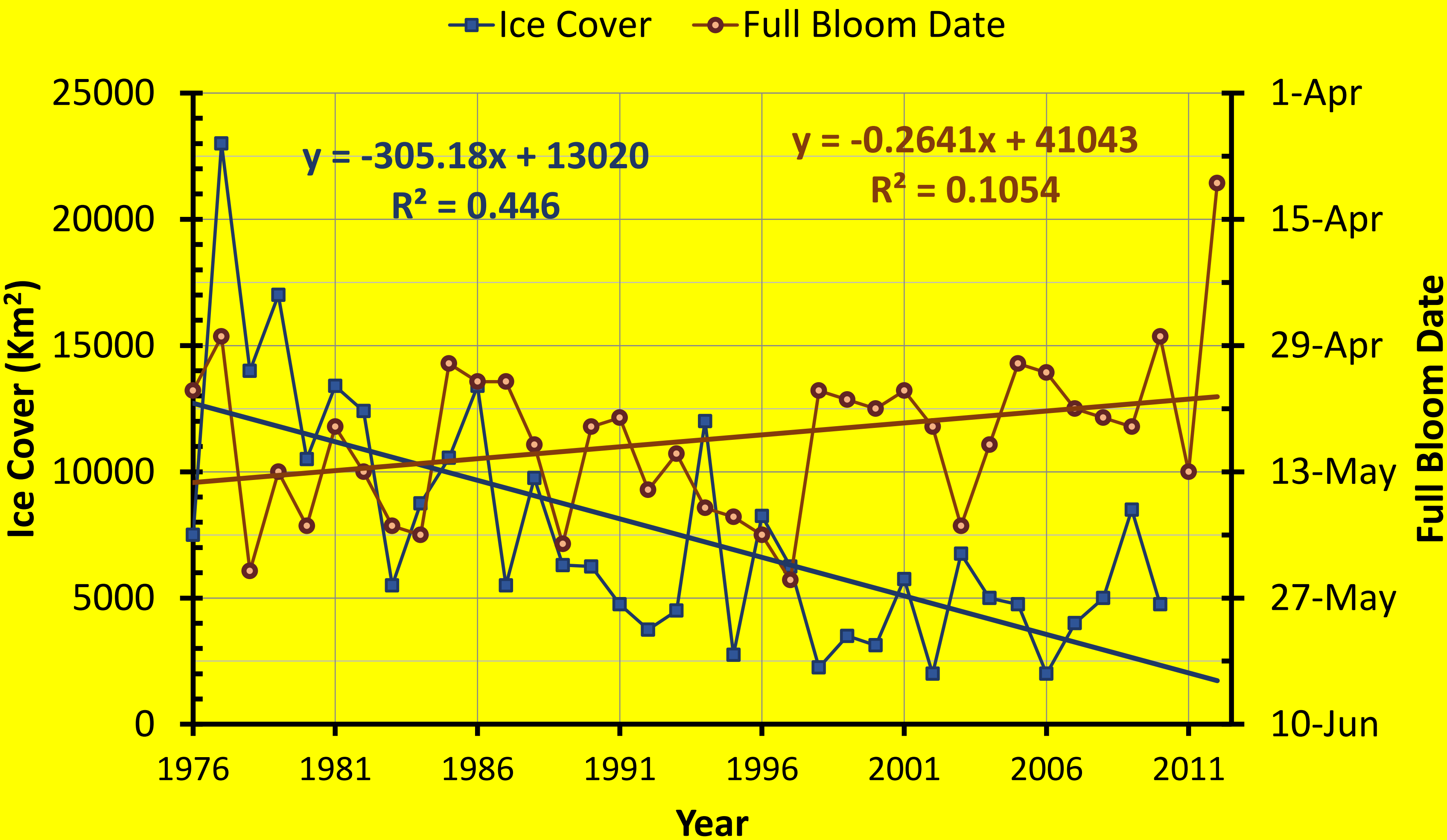
Effect on Fruit Crops
Depends on distribution
More or less disease
More or less fruit cracking

WILL YOU BENEFIT?

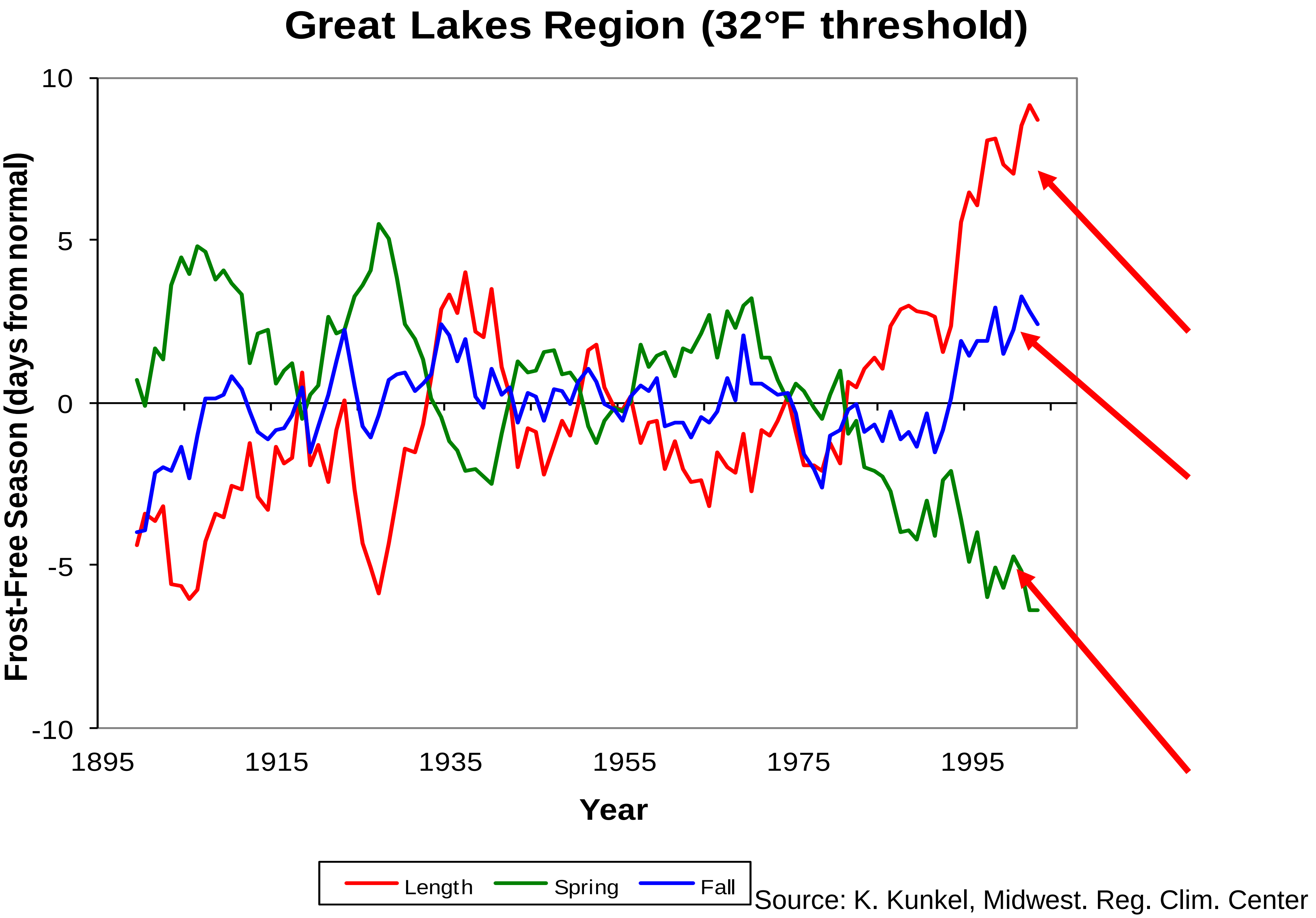
Peach Ridge Growth Stages (McIntosh)
1st Green to Full Bloom



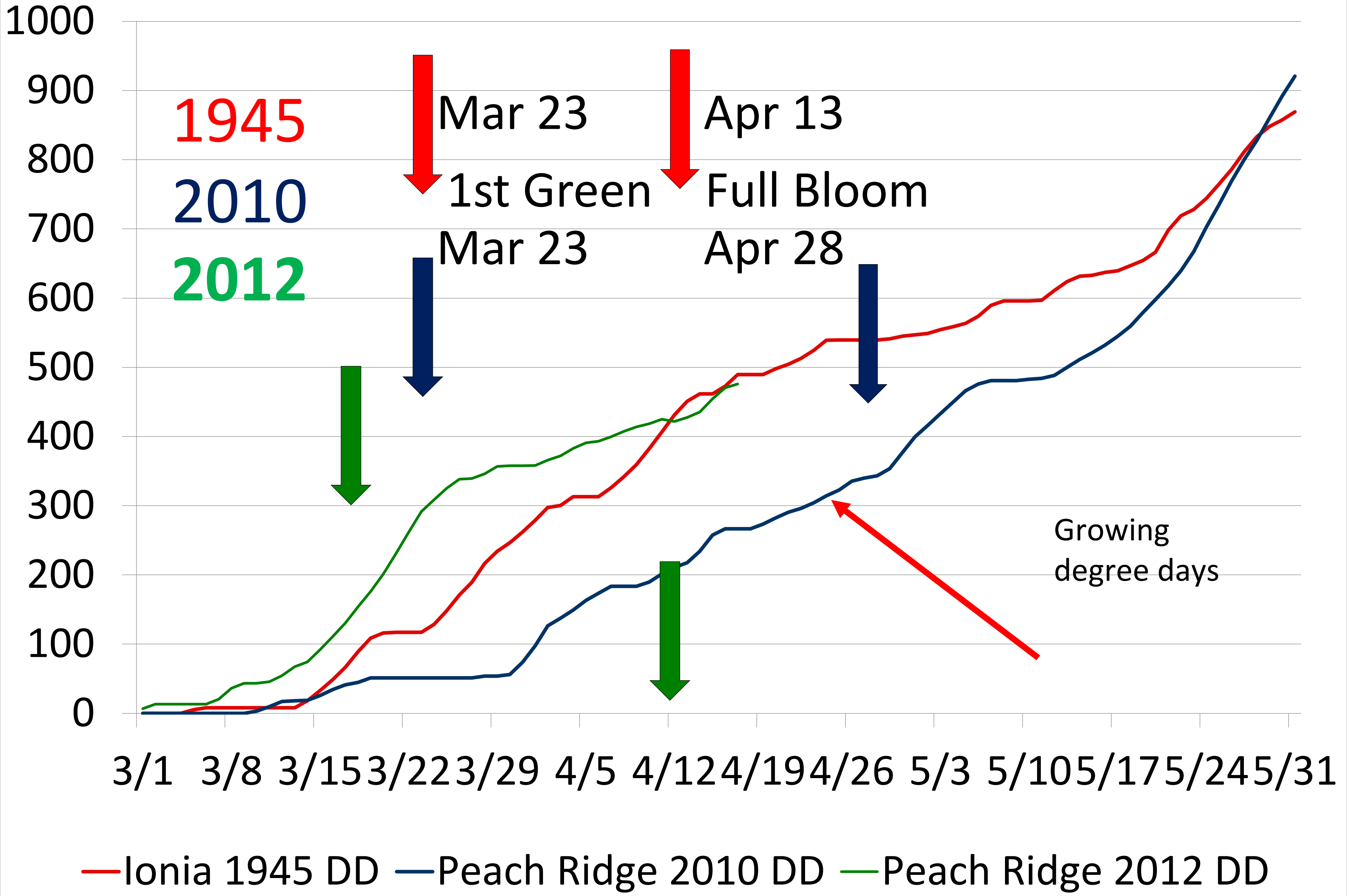
Comparison of Lake Michigan ice cover and full bloom date for McIntosh in a Peach Ridge orchard, 1976-2010.



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)
10
5
0
-5
-10
1895
1915
1935
1955
1975
1995
Year
Length
Spring
Fall
Source: K. Kunkel, Midwest. Reg. Clim. Center

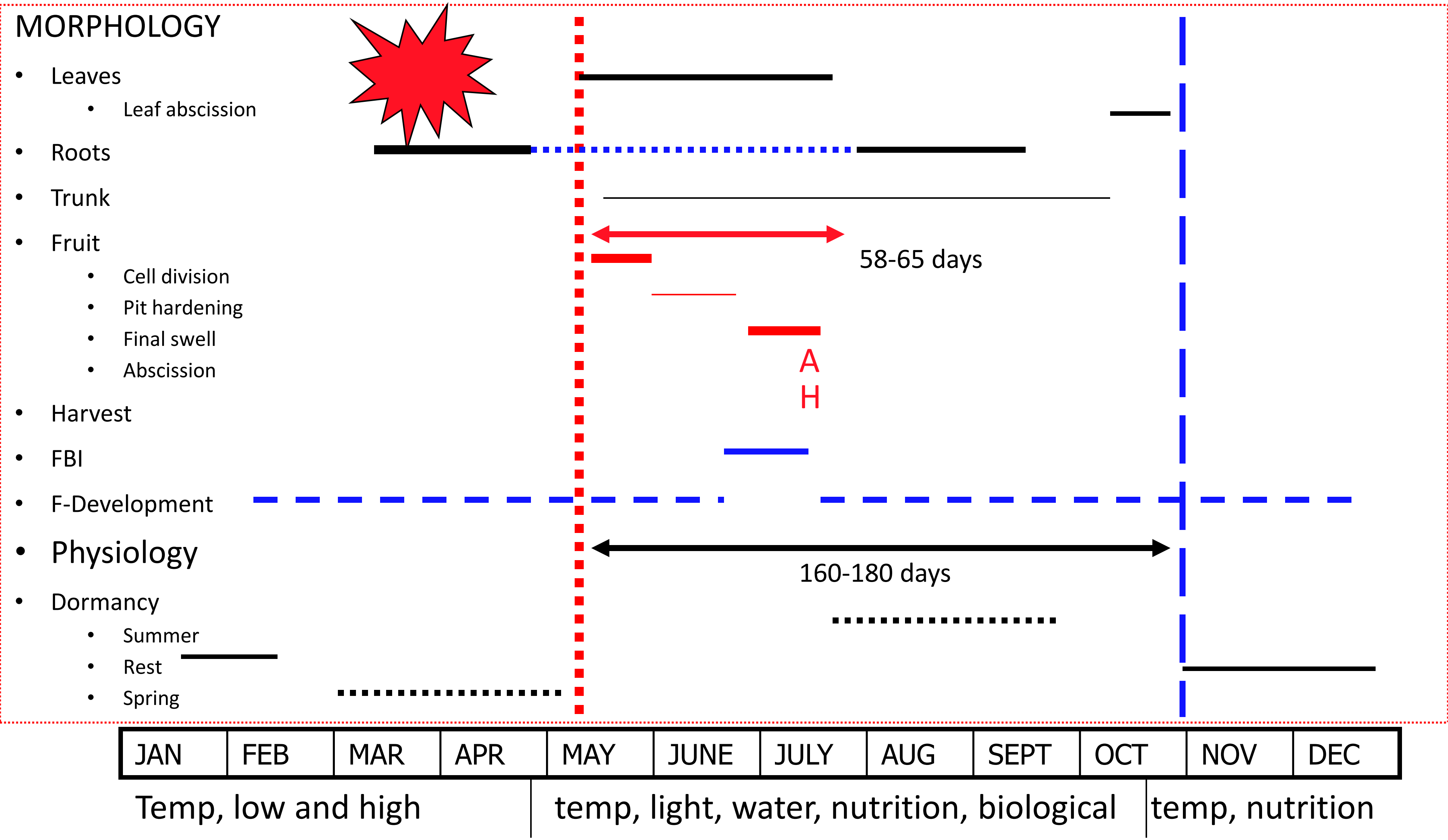
1945, 2010, 2012 DD & Growth Stages



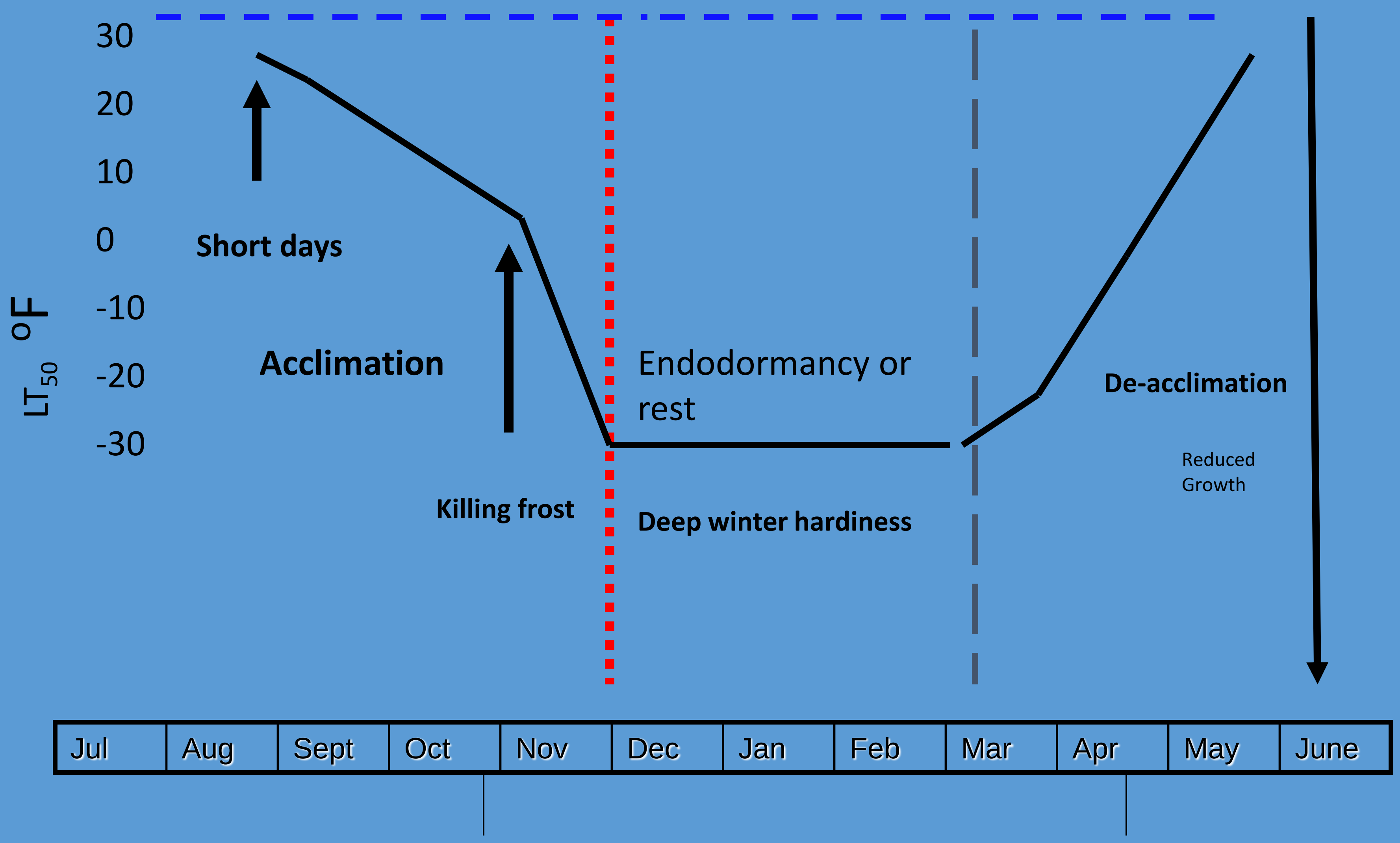
Dormancy and hardiness and Chilling requirement are all related

- 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



Cold Hardiness in Fruit Trees



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

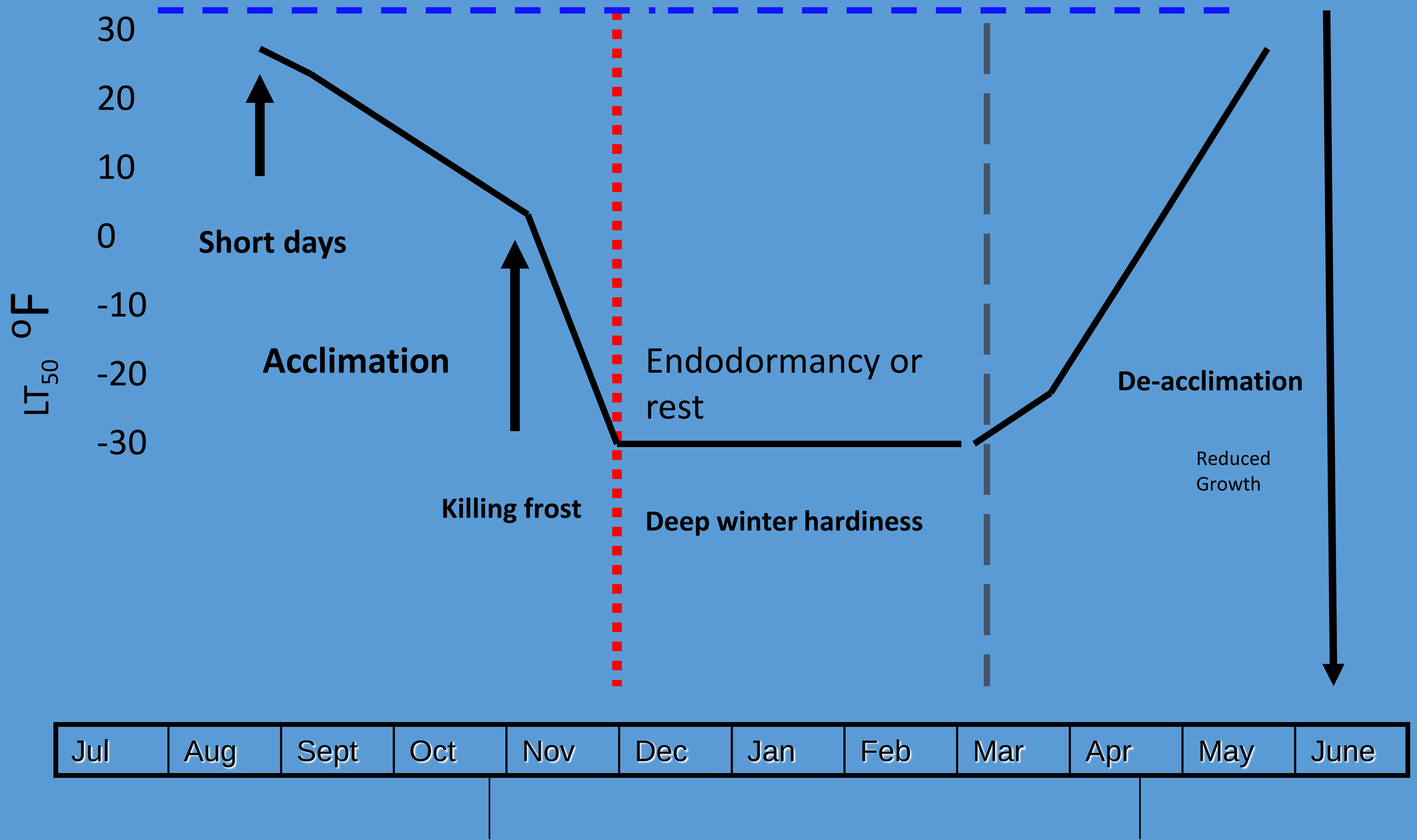
Hardiness develops from shoot
to trunk.

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

	9-3	9-9	9-23	10-7	10-21	11-4	10-11	x̄
1. Twig Tissue								
Apical	-6.5 a	7.5 a	-9.0 a	-8.0 b	-13.0 b	-15.5 b	-18.5 b	-11.1
Middle	-6.0 a	7.5 a	-8.5 ab	-8.0 b	-14.0 b	-15.5 b	-19.0 b	-11.2
Basal	-3.5 b	6.0 b	-7.5 b	-9.0 a	-16.0 a	-16.5 a	-23.0 a	-11.6
	***	**	***	*	***	***	***	n.s.
2. Rootstock (Redhaven Scion)								
Halford	-4.5	-6.0	-8.0	-8.0	-14.0	-16.0	-19.2	-10.8b
Siberian C	-5.5	-6.0	-8.0	-8.5	-14.0	-16.5	-20.5	-11.3a
	***	n.s.	n.s.	n.s.	n.s.	n.s	**	**
3. Cultivar (Halford Rootstock)								
Redhaven	-4.5 b	-7.5 b	-8.0 b	-8.0	-9.5 a	-14.0 b	-19.0 b	-10.1b
Redskin	-5.5 a	-8.0 b	-8.0 b	-8.0	-7.5 b	-14.0 b	-20.5 a	-10.4b
Cresthaven	-5.0 ab	-9.0 a	-9.5 a	-8.0	-9.5 a	-15.5 a	-20.5 a	-11.0a
	***	*	*	n.s.	*	*	*	**

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



Importance of day length and temperature!!!

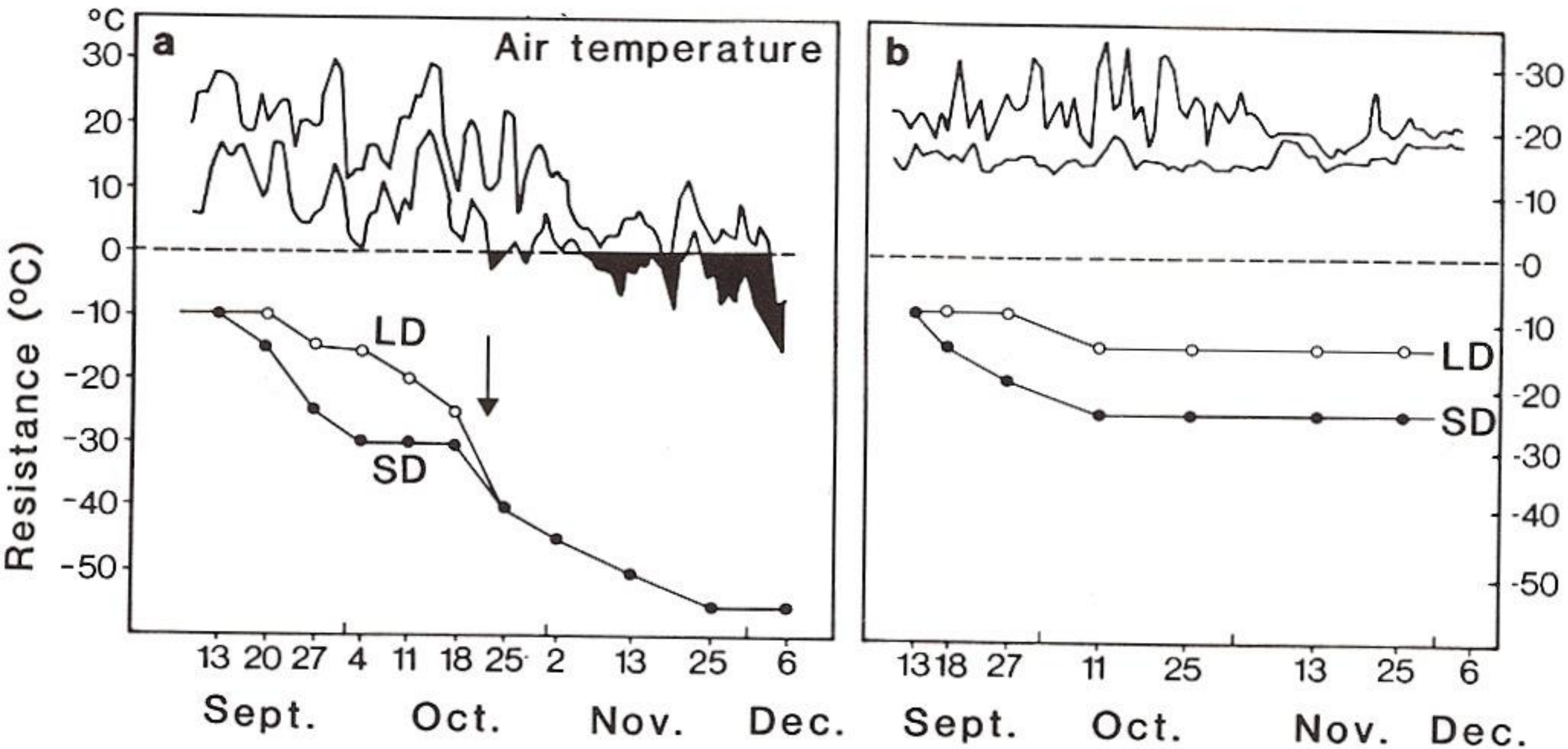


Fig. 5.8a,b. Seasonal hardening patterns of young apple trees at different photoperiods in (**a**) the field and (**b**) in a warm greenhouse. *SD* natural short days in autumn; *LD* long-day treatment (photoperiod 18 h using additional incandescent light). Air temperatures are daily maxima and minima. *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:

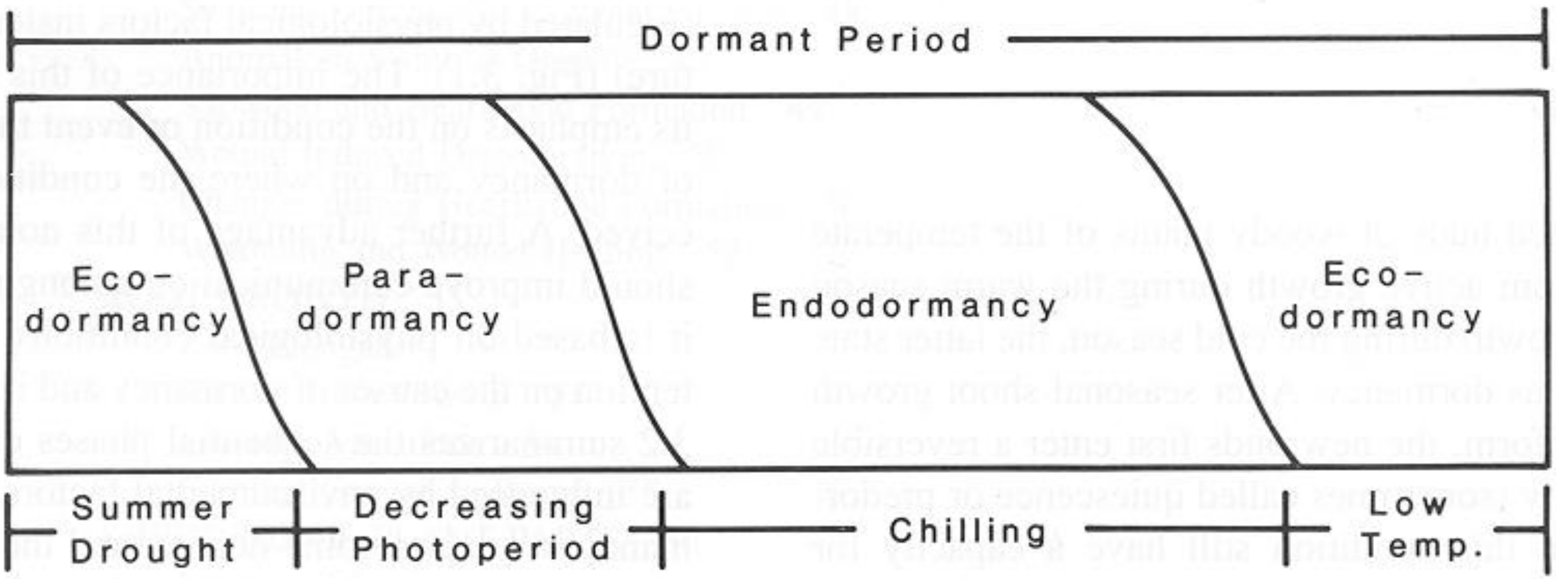


FIGURE 3.2. Relative contribution of the various types of dormancy during a hypothetical dormant period for an apical bud. From Lang *et al.* (1987). *HortScience* **22**, 371–377.

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

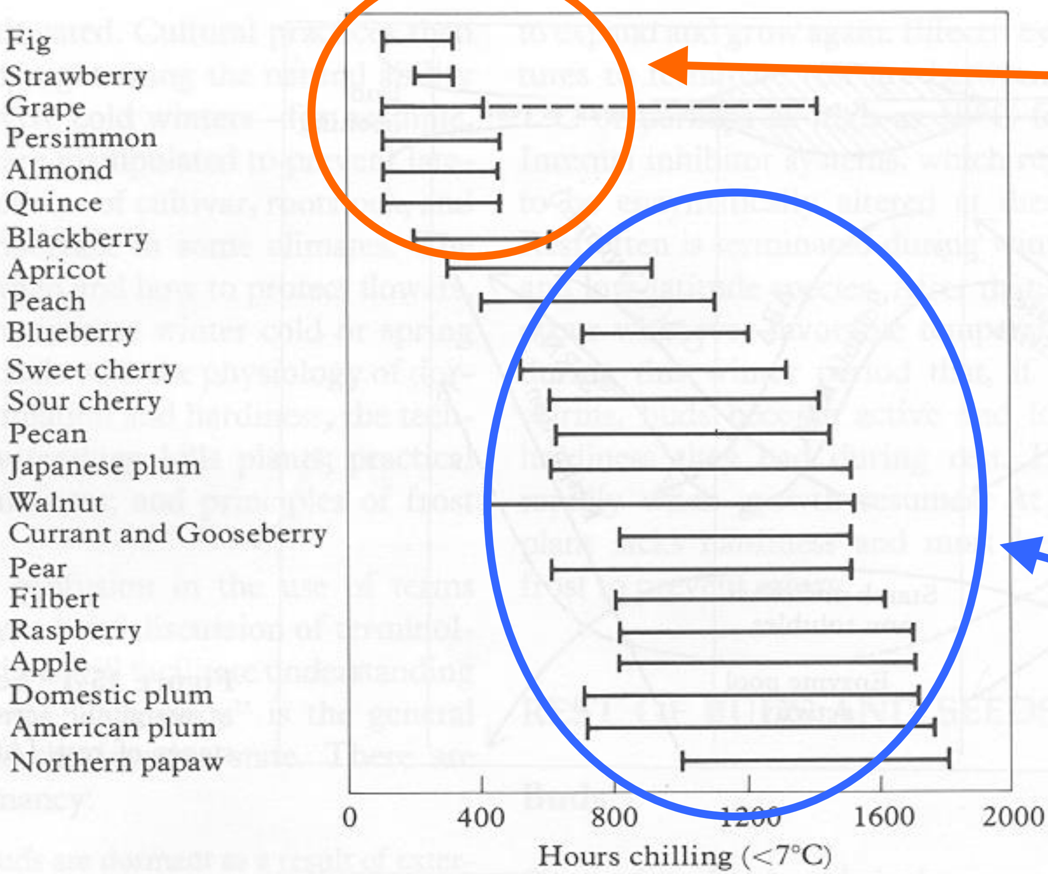


Figure 15-3 Approximate chilling requirements to break winter rest for fruit and nut species. The ranges shown for each species indicate the differences between low- and high-chilling cultivars within the species. Grape will grow with very little chilling but will begin growth much faster after long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

<u>Low-chilling</u>

+ Longer productive season

- more susceptible to late frost damage

<u>High-chilling</u>

+ protected against late frost

- Shorter growing season

What Controls the time of Spring Bloom

Temperature! We must understand dormancy and hardiness

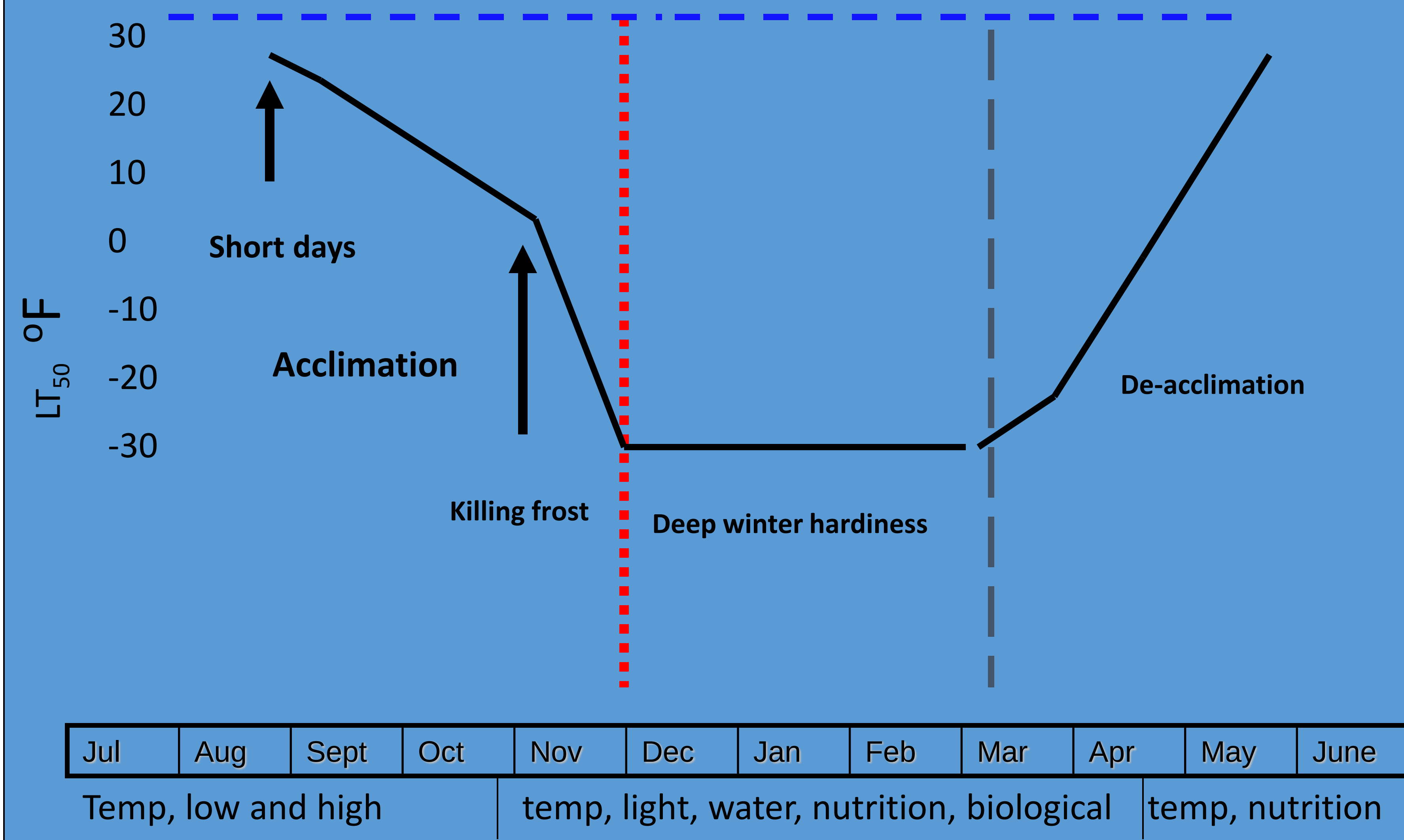
- Early (Environment) Acclimation
- Deep (Chilling hours 32F-50F) heat no effect.
- Late (GDH) De-acclimation

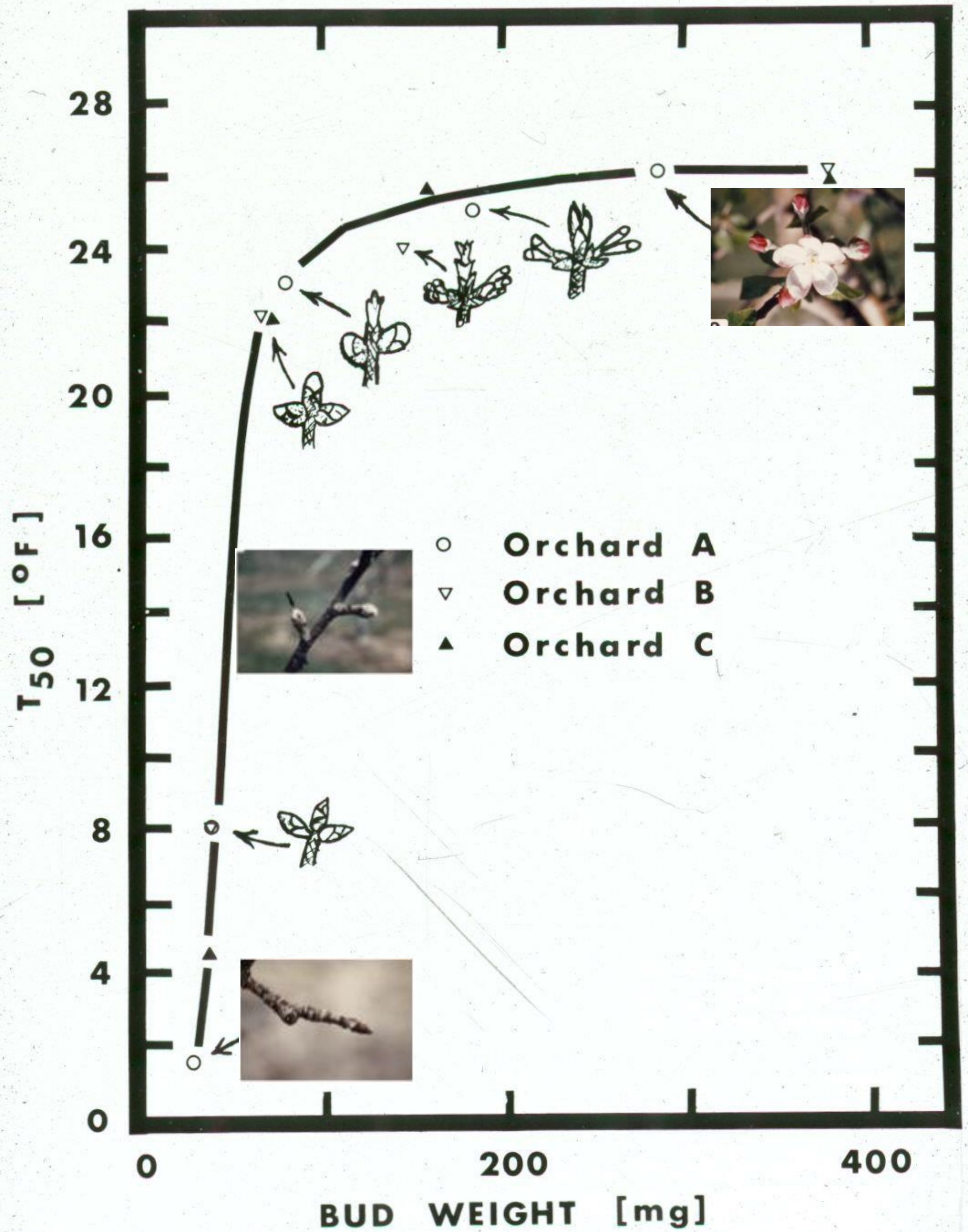
- States of Dormancy

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





T50 [°F]
28
24
20
16
12
8
4
0
0
200
400
BUD WEIGHT [mg]
Orchard A
Orchard B
Orchard C

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

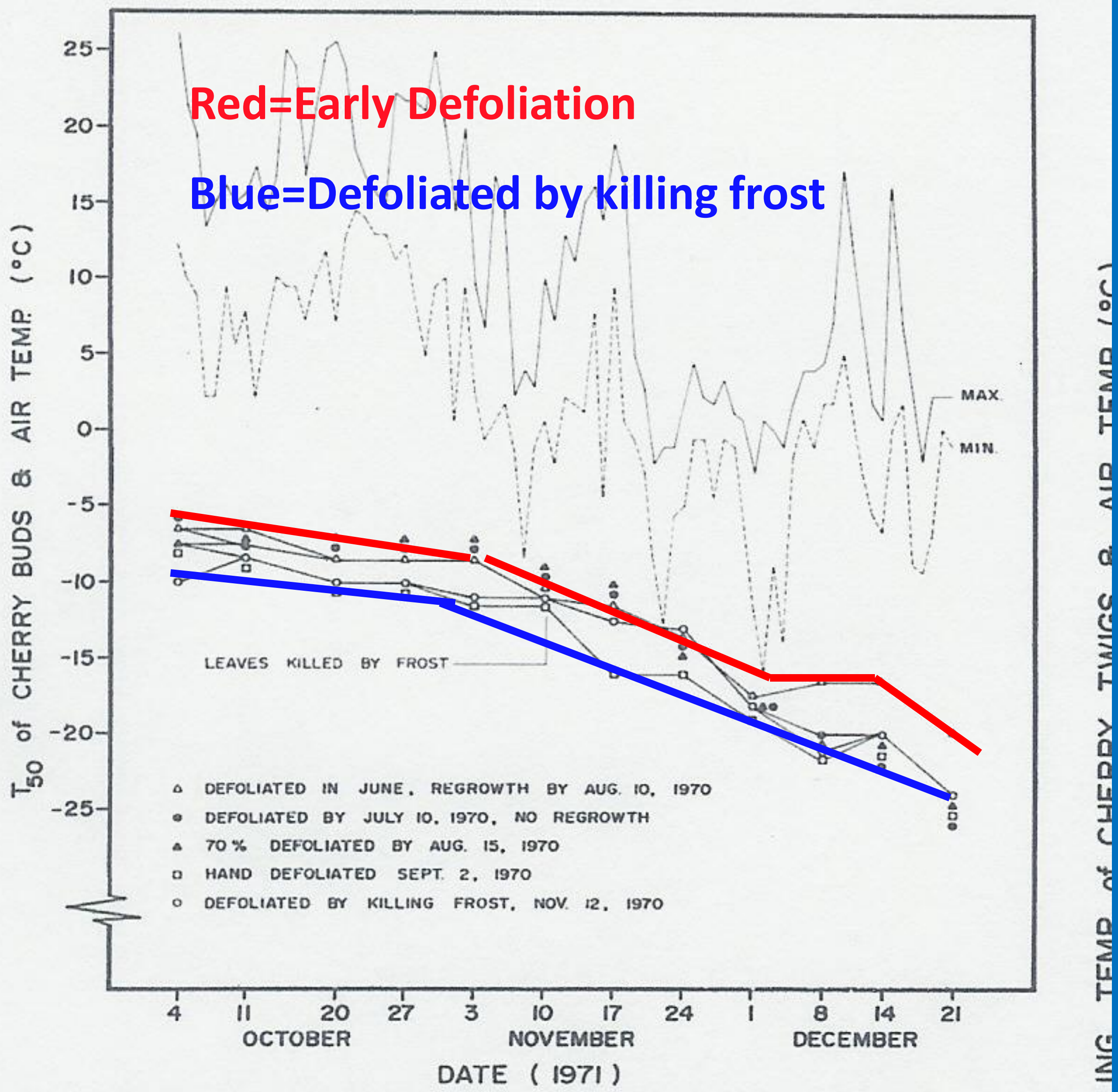


Fig. 4. Effects of time and amount of defoliation during 1970 on the acclimation of tart cherry buds in the autumn of 1971.

DATE (1972)

Fig. 7. Effects of time and amount of defoliation during 1970 on the deacclimation of tart cherry twigs in the spring of 1972.

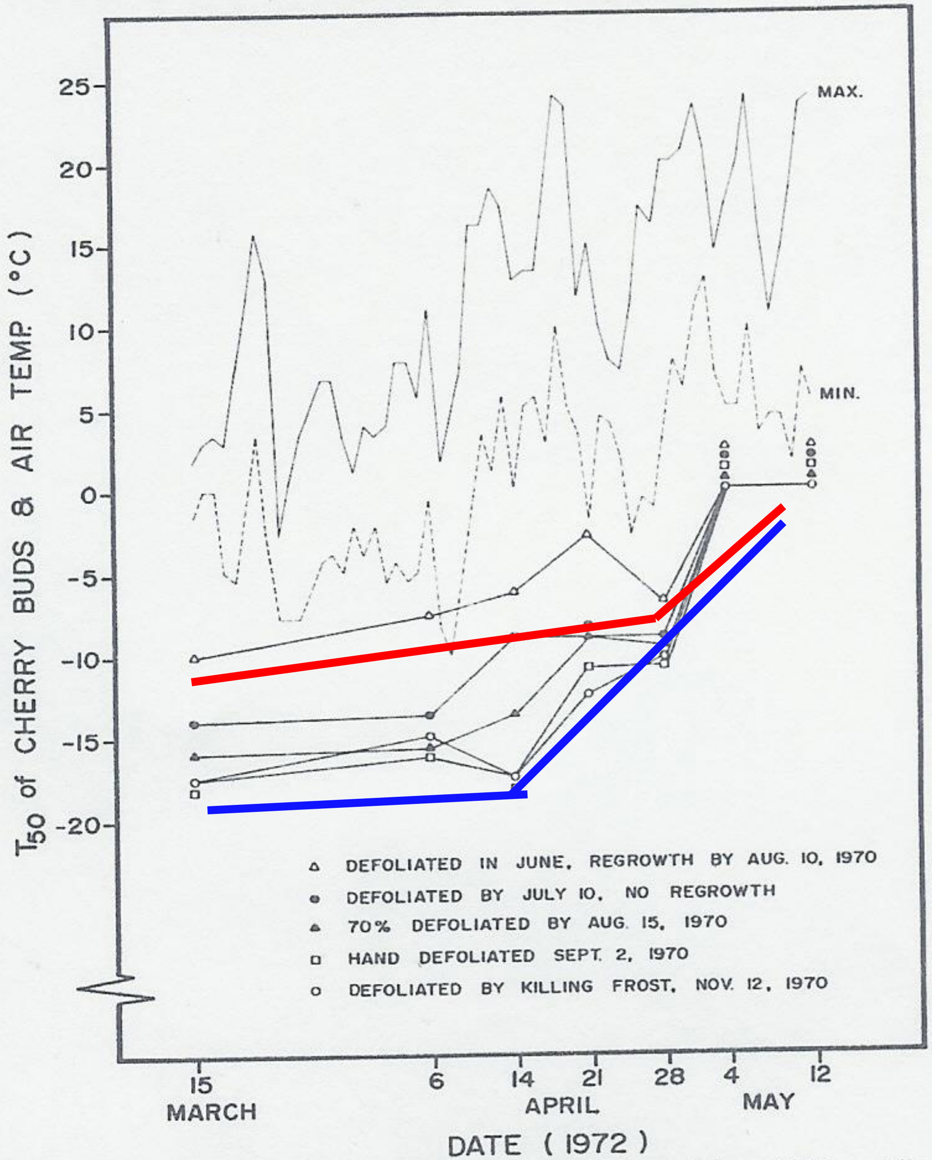


Fig. 8. Effects of time and amount of defoliation during 1970 on the deacclimation of tart cherry buds in the spring of 1972.

$^yT_{50}$ calculated using the Spearman-Kärber equations and mean separation within a column by the modified Friedman test, 5% level.

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 hardiness of wood and buds on November 29, 1979 of 'Redhaven' peach. Treatment began June 20, 1979.

Full sun (%)	Shoot length (cm)	Shoot cross-sectional area (mm^2)	Soluble carbohydrate (mg/g dry wt)	Water content (% H_2O)	Hardiness (T_{50})^y Wood	Flower buds	Vegetative buds
100	36.8	13.2 a^z	109.3 a^z	51.6	−22.5 a	−17.5 a	−17.5 a
36	44.8	11.9 ab	110.8 a	48.2	−22.5 a	−17.0 a	−17.5 a
21	44.0	10.2 ab	107.5 a	48.3	−16.0 b	−12.5 b	−15.0 b
9	41.0 NS	7.5 b	97.6 b	46.0 NS	−13.0 c	---^{x}	−13.0 c

^{z}Mean separation by Duncan's multiple range test, 5% level.
$^yT_{50}$ calculated using the Spearman-Kärber equations and mean separation within a column by the modified Friedman test, 5% level.
^{x}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 hardiness 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)

Crop	Days delay FB 1975	Days delay FB 1976
Apple Delicious	6	18
Peach	13	8
Apricot	10	8

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

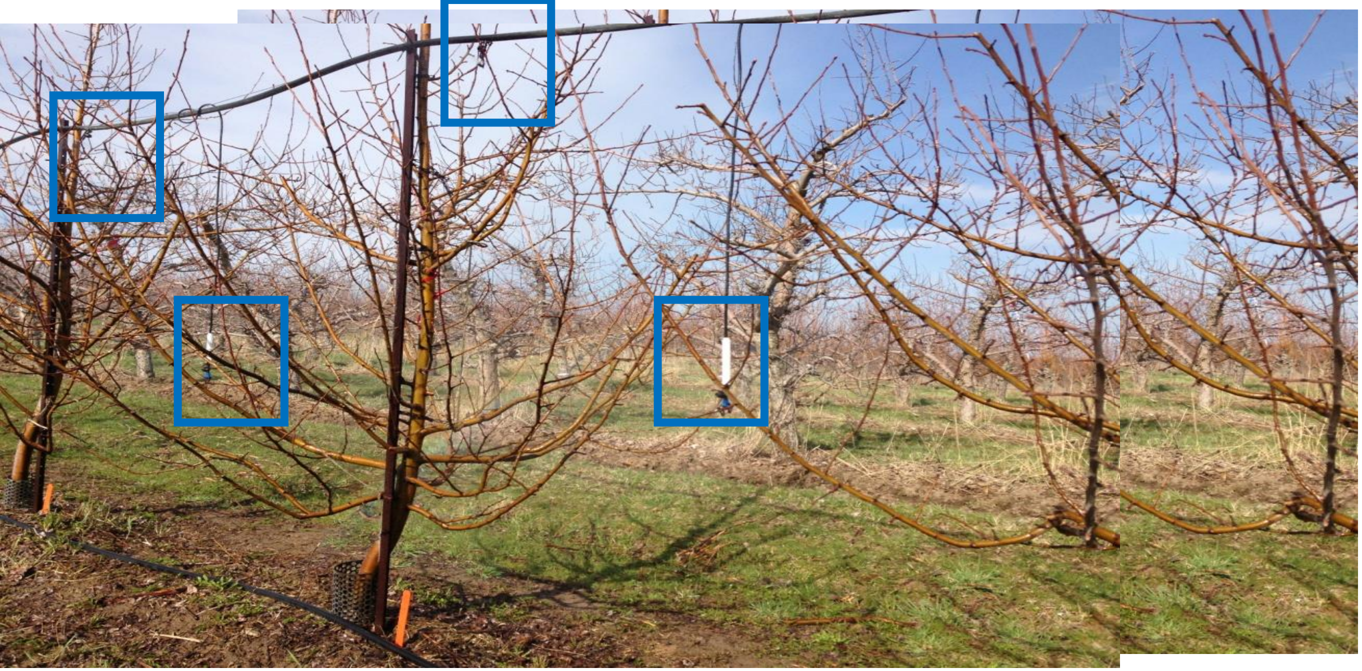
Solid-Set Canopy Delivery Systems SSCRI team lead by Matt Greishop


Top line hose (1" Diam)
Stop-Drip Device
Dan-Jain Micro-sprayer


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 ¼ 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 environtmenta that gives maximum cooling from evaporation.



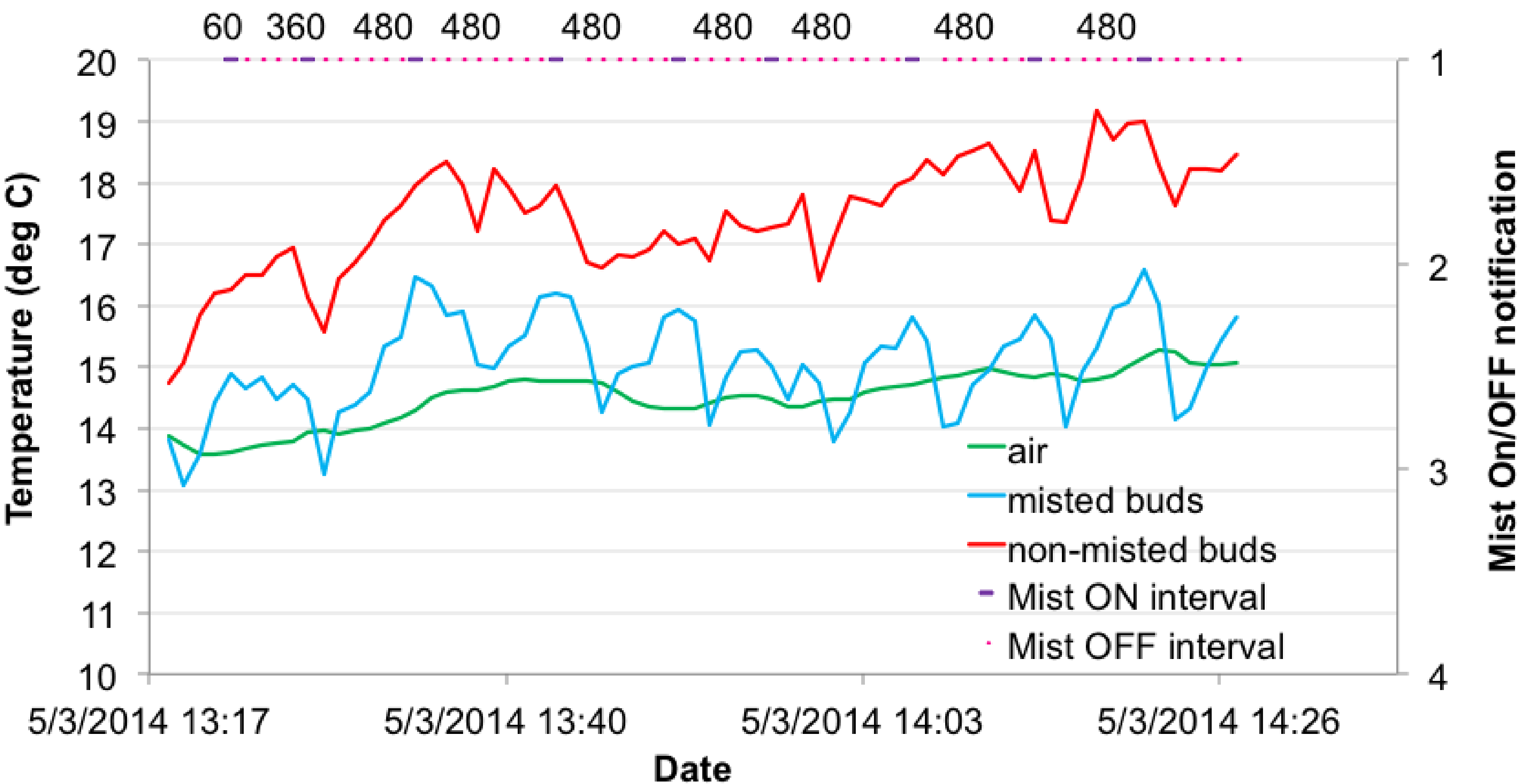
Apple trials at
St. Joesph
Charlotte
Hillsdale

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)

Orchard Location	Variety	Study	2013			2014			2015		
			bloom date	GDD (deg C)	Fruits per flowering spur	bloom date	GDD (deg C)	Fruits per flowering spur	bloom date	GDD (deg C)	Fruits per flowering spur
St. Joseph	Gala	Control	10-May	204	69	15-May	175	44	8-May	162	54
		treatment 2	16-May	260	40	20-May	227	44	15-May	224	66
		treatment 1	18-May	292	48	23-May	262	62			
	Red Delicious	Control	12-May	211	40	16-May	188	100	8-May	171	22
		treatment 2	16-May	260	29	22-May	254	47	17-May	259	48
		treatment 1	19-May	311	32	25-May	285	66			
	Honey Crisp	Control	14-May	230	45	20-May	227	84	9-May	171	31
		treatment 2	19-May	311	47	26-May	301	94	17-May	259	30
		treatment 1	22-May	370	32	28-May	333	84			
Charlotte	Honey Crisp	Control	16-May	218	51	20-May	203	70	10-May	192	48
		Treatment	22-May	318	52	26-May	288	75	16-May	254	31

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.

Year	Study	Bloom date	GDD	Mist duration (Hours)	Mist volume (ac-in)
2013	No mist	2-May	150		
	Mist	13-May	258	39	5.35
2014	No mist	7-May	134		
	Mist	16-May	238	52	10.5

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

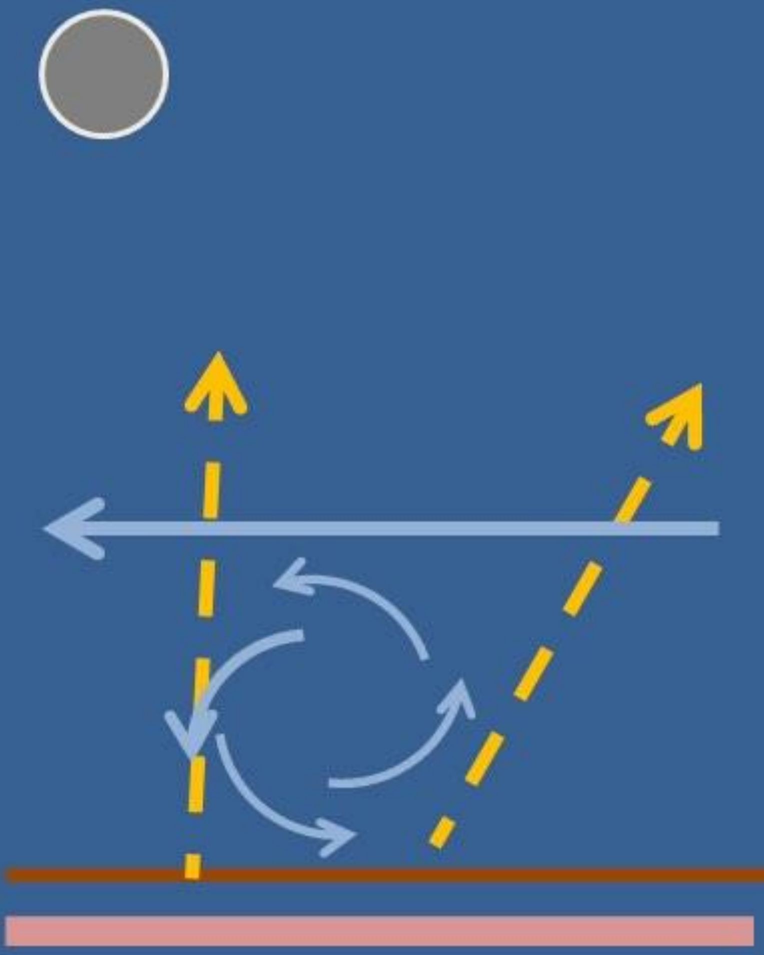
Types of Freezes

Radiation Freeze	Advective Freeze
Winds less than 5 MPH	Winds higher that 5 MPH
Clear sky	May be cloudy
Cold air mass 30 to 200 ft.	Cold air 400 ft to 1,500 ft
Inversion develops	No Inversion
Cold air in the low spots	
White frost or black frost	Usually black frost
Easier to protect	Difficult to protect

Clear calm night

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

Clear breezy night

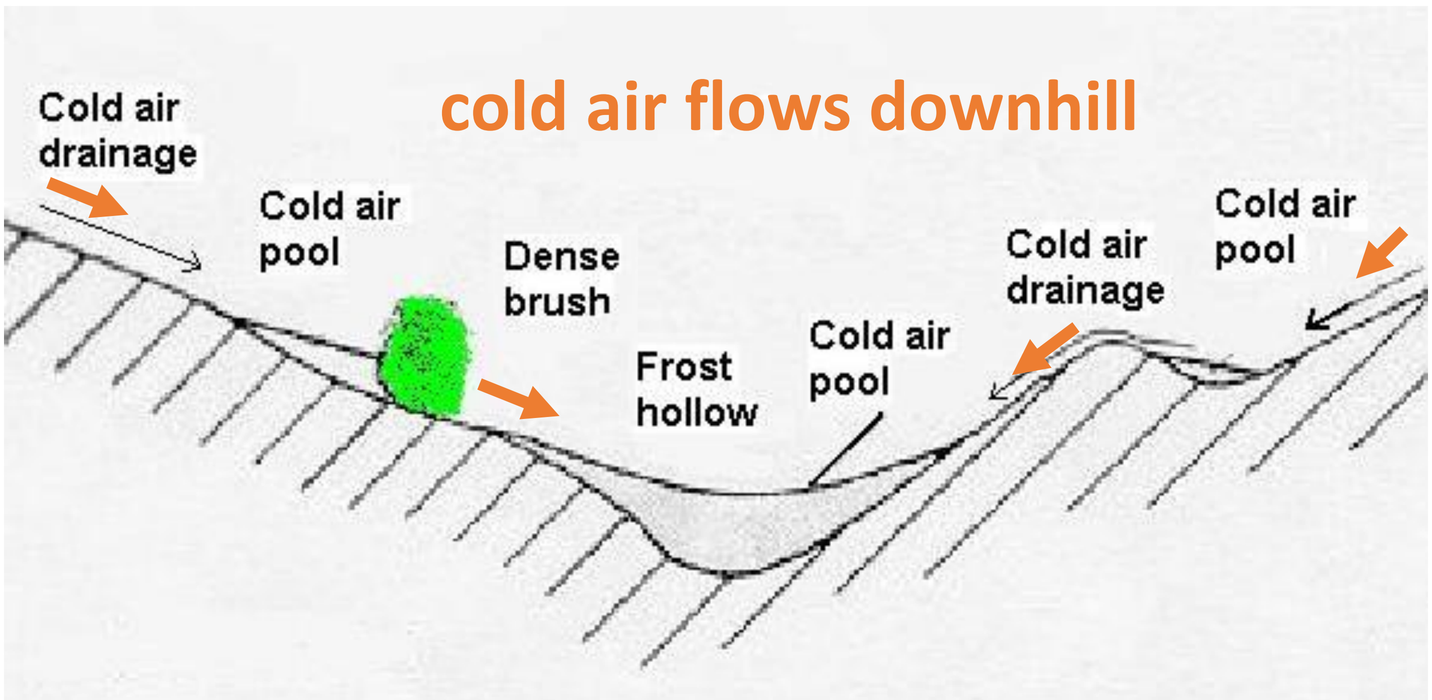


- Warm ground radiates heat away to open sky.
- Winds mix cooler air near the ground with warmer air above.

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

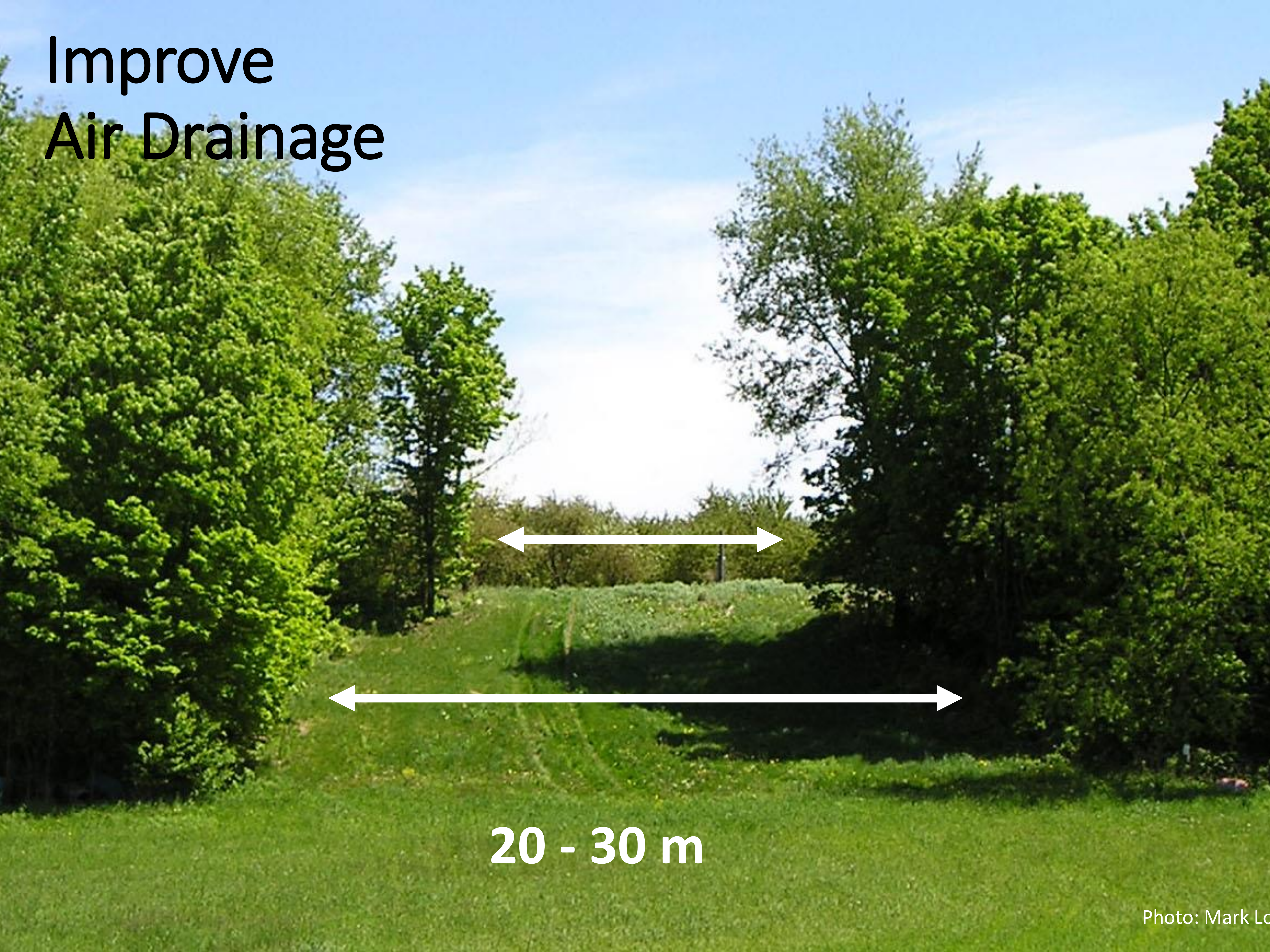


Adapted from graphic by Andrew Bootsma, Agrometeorological Resources Specialist, Land Resource Research Institute, Agriculture Canada

Minimum Temperature (C) on Apr 30, 2008

The Frost Line

Photo: Mark Longstroth


Improve
Air Drainage
20 - 30 m
Photo: Mark Lo

Storing Heat Before a Freeze


Photo: Mark Longstroth

- Ground cover influences temperature.
- Mowed cover crop is warmer than unmowed.
- Clean cultivated warmer than grass.
- Packed warmer than loose.
- Wet warmer than dry.

Source: Mark Longstroth
Extension Educator MSU,
SW Michigan

Effect of Ground Cover and Water

Effect of Different Soil Surfaces on Temperatures at 4 ft	
Bare, Firm, Moist Soil	Warmest
Moist Soil, Shredded Cover crop	0.5 F colder
Moist Soil, Low Cover crop	1 to 3 F colder
Dry Firm Soil	2 F colder
Freshly Disked Soil	2 F colder
High Cover crop	2-4 F colder

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

Published by Utah State University Extension and Utah Plant Pest Diagnostic Laboratory IPM-012-11 February 2011

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.

APPLE

	Silver Tip	Green Tip	Half-Inch Green	Tight Cluster	First Pink (Pink)	Full Pink (Open Cluster)	First Bloom (King Bloom)	Full Bloom and Post-bloom
10%	15	18	23	27	28	28	28	28
90%	2	10	15	21	24	25	25	25

PEAR

	Swollen Bud (Scale Separation)	Bud Burst (Blossom Buds Exposed)	Green Cluster (Tight Cluster)	White Bud (First White, Popcorn)	Full White	First Bloom (King Blossom)	Full Bloom	Petal Fall (Post-bloom)
10%	15	20	24	25	26	27	28	28
90%	0	6	15	19	22	23	24	24

APRICOT







	First Swell (Bud Swell)	Tip Separation (Swollen Bud)	First White	First Bloom	Full Bloom	In the Shuck (Petal Fall)	Shuck Split (Post-bloom)
10%	15	20	24	25	27	27	28
90%	---	0	14	19	22	24	25

CHERRY







SWEET	Swollen Bud (First Swell)	Bud Burst (Green Tip)	Tight Cluster	White Bud (First White, Popcorn)	First Bloom	Full Bloom	Post-bloom
10%	17	25	26	27	28	28	28
90%	5	14	17	24	25	25	25
TART							
10%	15	26	26	28	28	28	
90%	0	22	24	24	24	25	

PEACH NECTARINE







	Swollen Bud (First Swell)	Calyx Green	Quarter-Inch Green (Calyx Red)	Pink (First Pink)	First Bloom	Full Bloom	Post-bloom
10%	18	21	23	25	26	27	28
90%	1	5	9	15	21	24	25

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 <u>Cools</u>
  - Vaporizing Water <u>Cools</u>
- Freezing water to ice or condensing water vapor gives up energy
  - Freezing Water <u>Warms</u>
  - Condensing Water <u>Warms</u>

Change of State of Water

- It takes energy to melt ice or boil water
  - Melting Ice <u>Cools</u> = requires 1200 BTU/gal.
  - Vaporizing Water <u>Cools</u> = requires 9000 BTU/gal.
- Freezing water to ice or condensing water vapor gives up energy
  - Freezing Water <u>Warms</u> = gives up 1200 BTU/gal.
  - Condensing Water <u>Warms</u> = 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

MIN. TEMPERATURE EXPECTED	WIND SPEED IN M.P.H. 0 to 1	2 to 4	5 to 8
	Application rate (inches per hour)		
27^{o}F	0.10	0.10	0.14
26^{o}F	0.10	0.16	0.30
24^{o}F	0.12	0.24	0.50
22^{o}F	0.16	0.30	0.60
18^{o}F	0.20	0.40	0.70
15^{o}F	0.26	0.50	0.90

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

Dew Point	Irrigate at
26 F	34
25 to 24	35
23 to 22	36
21 to 20	37
19 to 17	38
16 to 15	39

Source: Mark Longstroth Extension Educator
MSU, SW Michigan

Overhead Sprinkling

Photo: Brookside Farms

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.
- Compatable with wind machines.
- Could pre heat water!
- Less likely to damage crop if system fails.

Micro-sprinkler Ice

Mike Wittenbach, 2012

Inversion

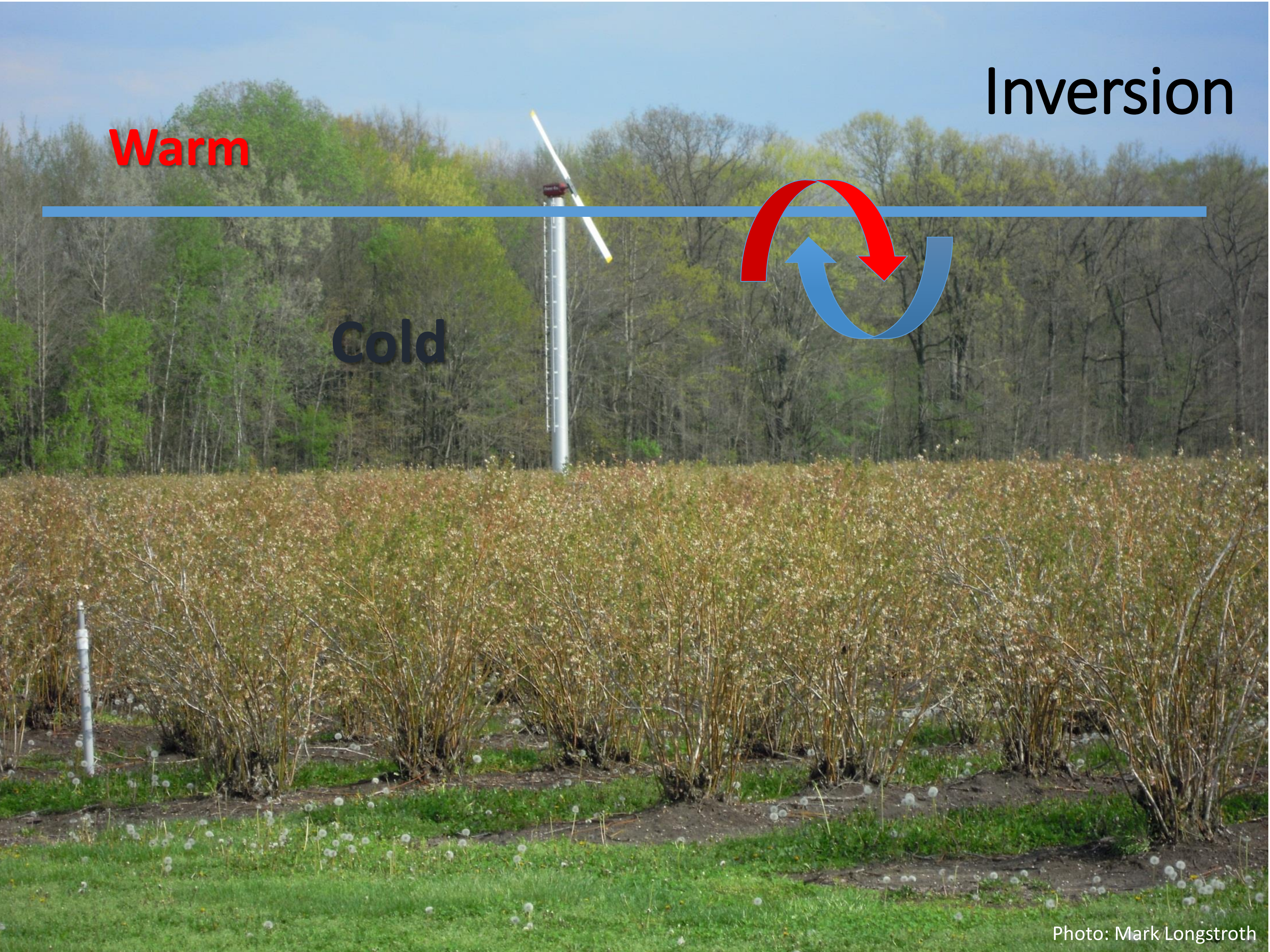


Photo: Mark Longstroth

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.