Crop-Environment Relationships

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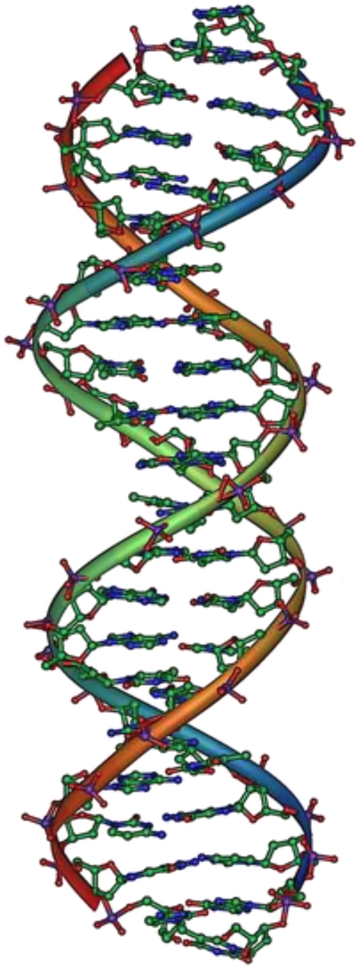
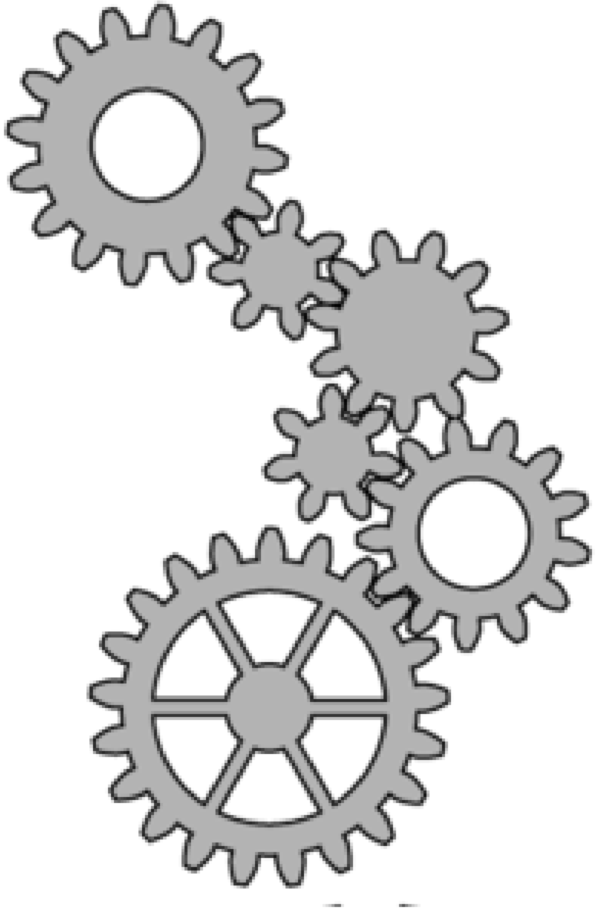
Types of Factors that Affect Crops



Successful farmers work to optimize each genotype-environment combination.

- **genes**
- **environment**



- location
- typical weather
- tunnel (+ other?)
- decisions
- microclimate in tunnel
- crop genetics

crop and farm outcomes

Of the environmental factors that affect crops, which will have a status that is most seriously out of line relative to the state needed to maximize yield and quality?

Liebig's Law of the Minimum

One factor most limits growth.

... the factor varies

... may be possible to identify and alter

http://en.wikipedia.org/wiki/Liebig%27s_law_of_the_minimum

Microclimate Management/ Season Extension

... limit "governors" of growth

... raise stave height,
barrel capacity

Temperature? Light?

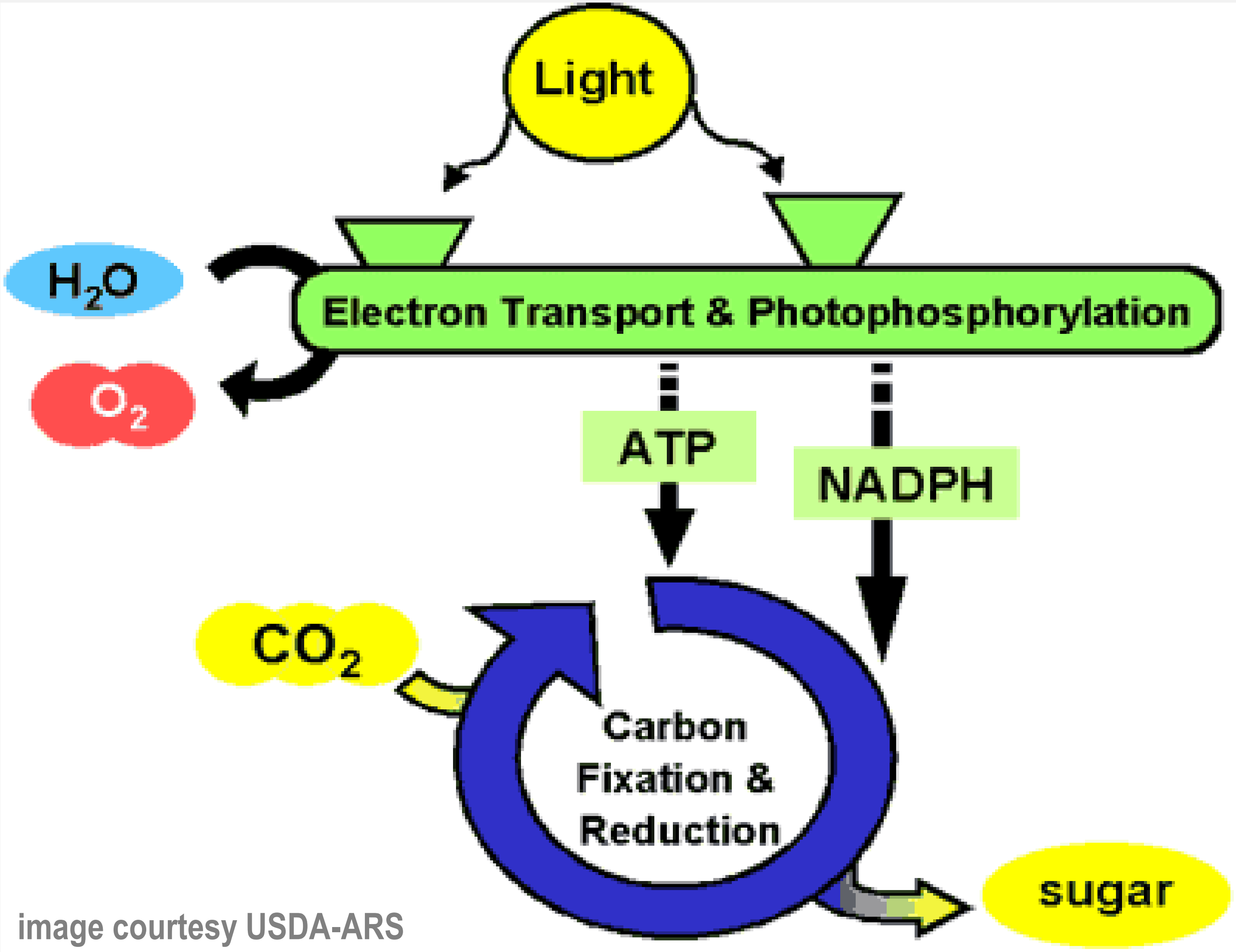
Farms and crop plants are manufacturing sites with required inputs, expected outputs and conditions that affect performance.

Plants as Living Factories

- the same building block for growth (increased size, weight) is used in maintenance
- like checking account, growth is difference between manufacturing (deposits) and maintenance (withdrawals)

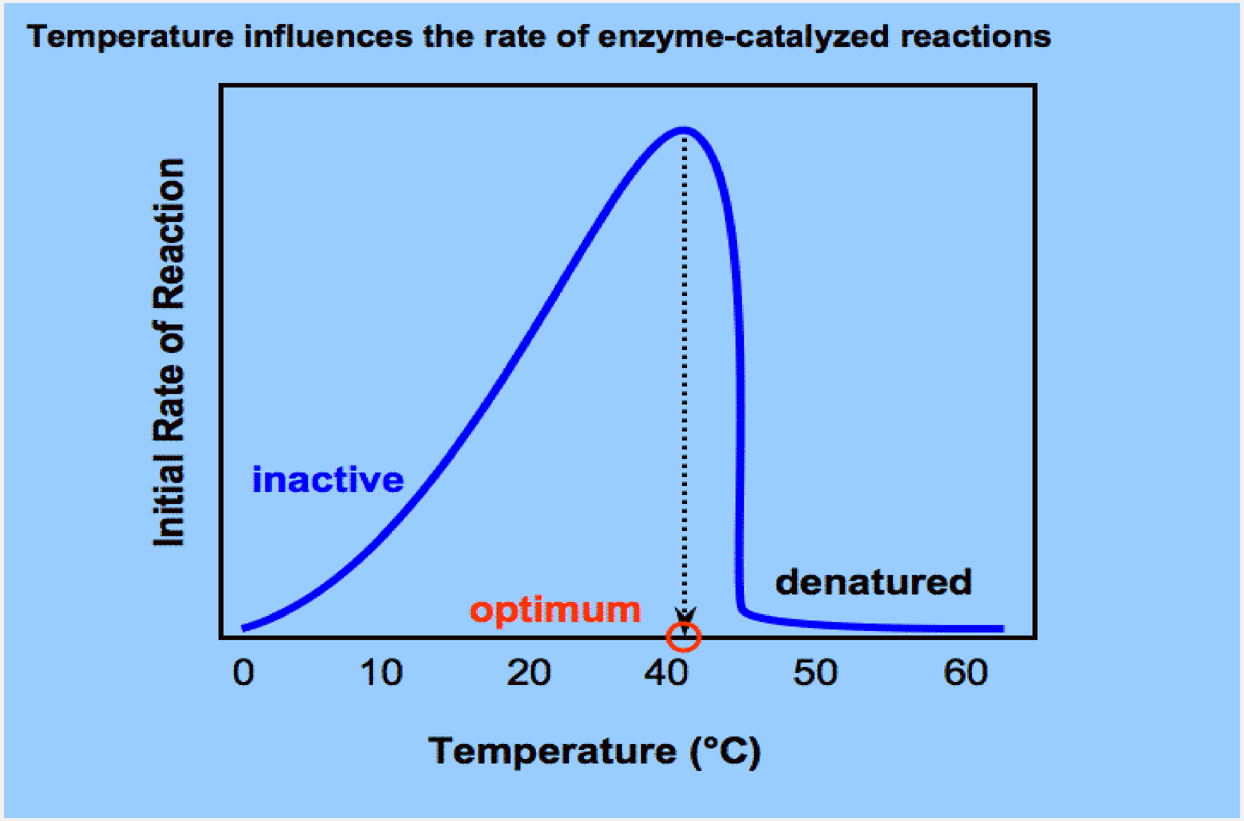
The manufacturing process.

Photosynthesis provides the building blocks for growth, yield.



1. Temperature and Growth

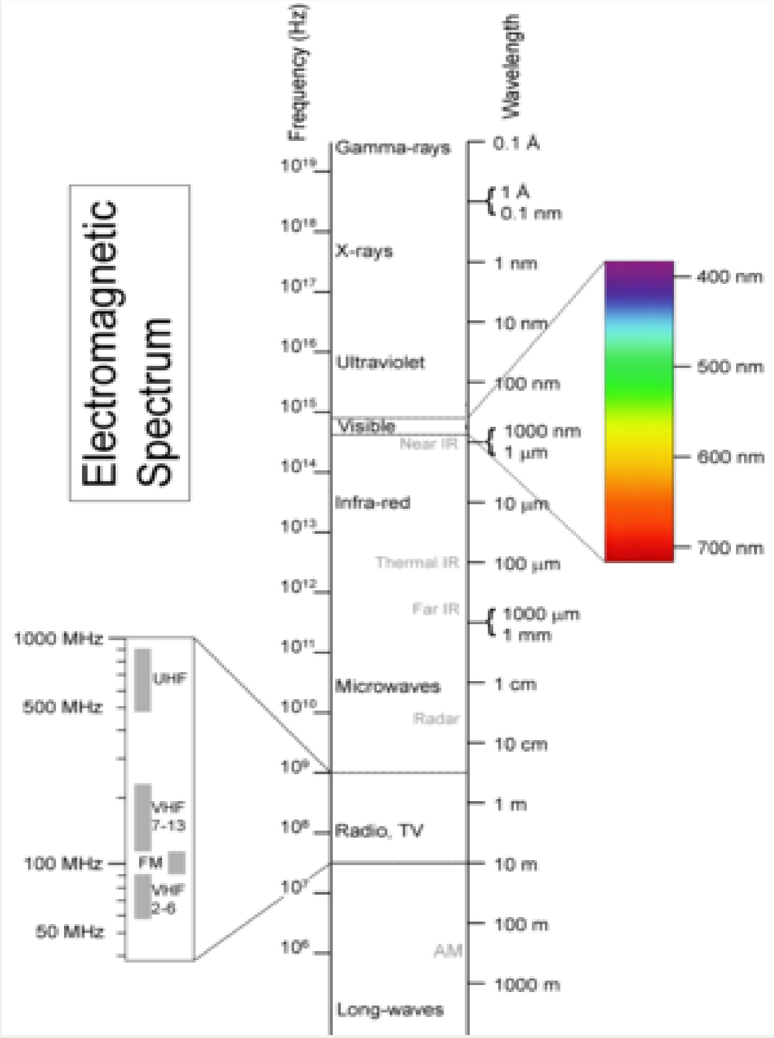
- engine rpms - enzymes and Q10
- > optimal temperatures damaging



http://plantphys.info/plant_physiology/enzymekinetics.shtml

2. Light and Growth

- plants use only a portion of the light available (400-700 nm)
- infared energy raises temperature
- short wavelength energy can damage plant machinery

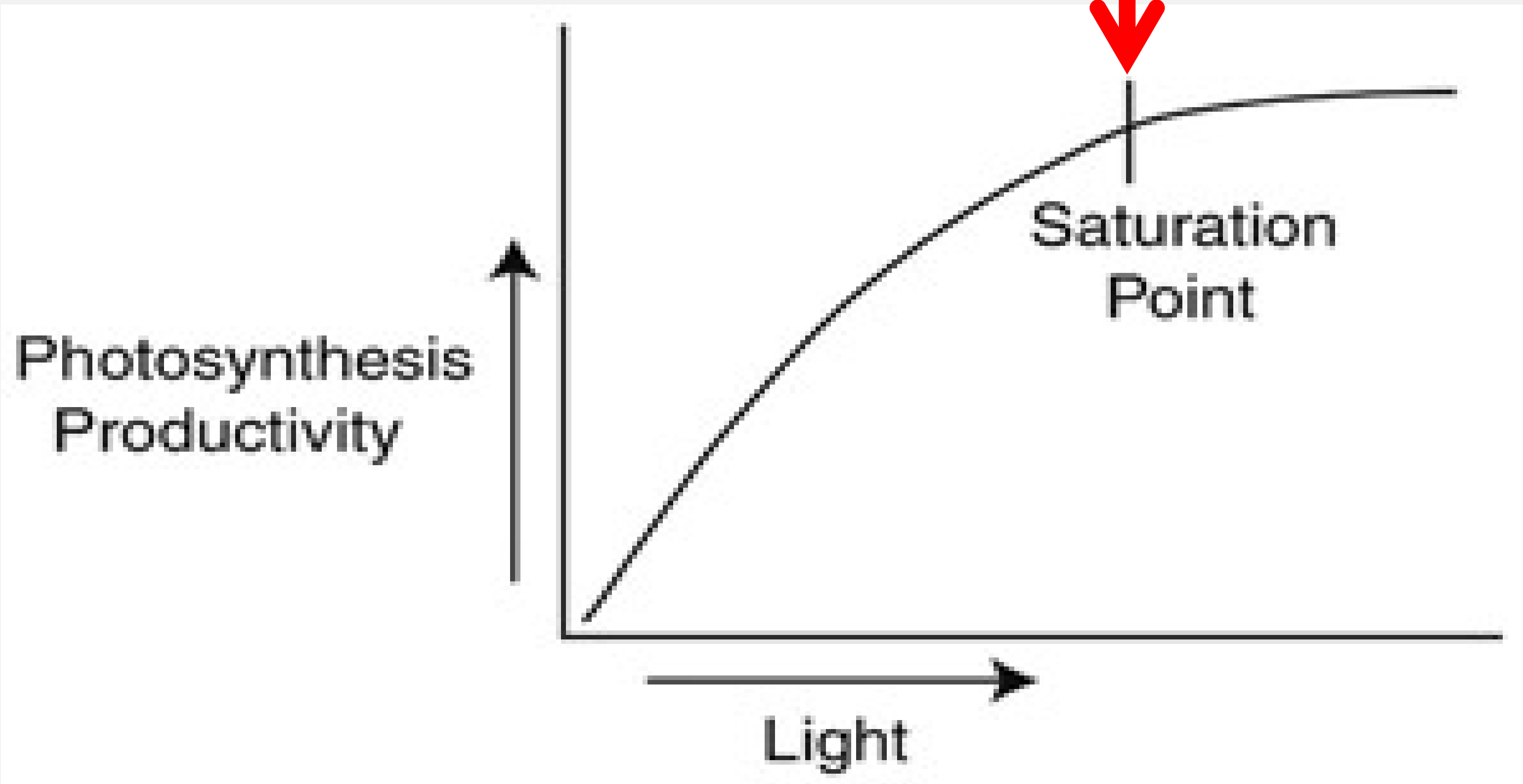


http://en.wikipedia.org/wiki/Electromagnetic_spectrum

This value determined by …

… temperature, other growing conditions

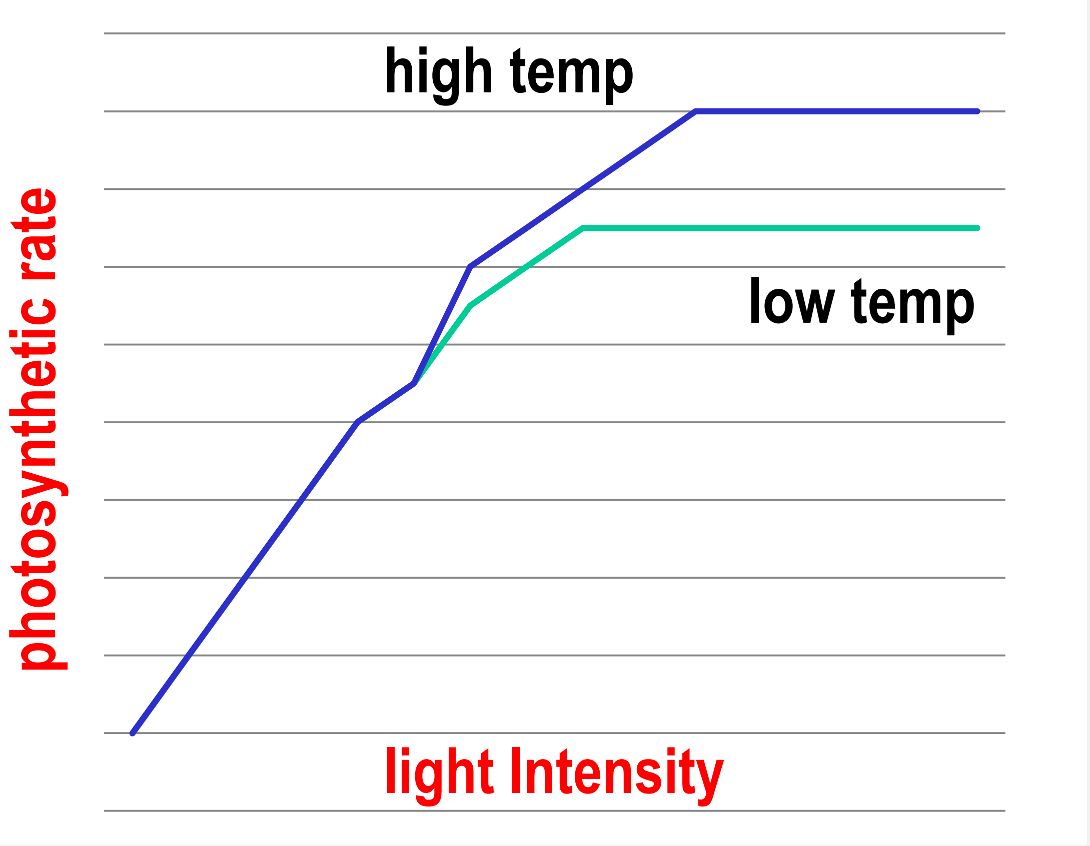
… crop species, cultivar and stage



http://www.hort.purdue.edu/newcrop/tropical/lecture_07/lec_07.html

Light and Temperature Act Together - 1

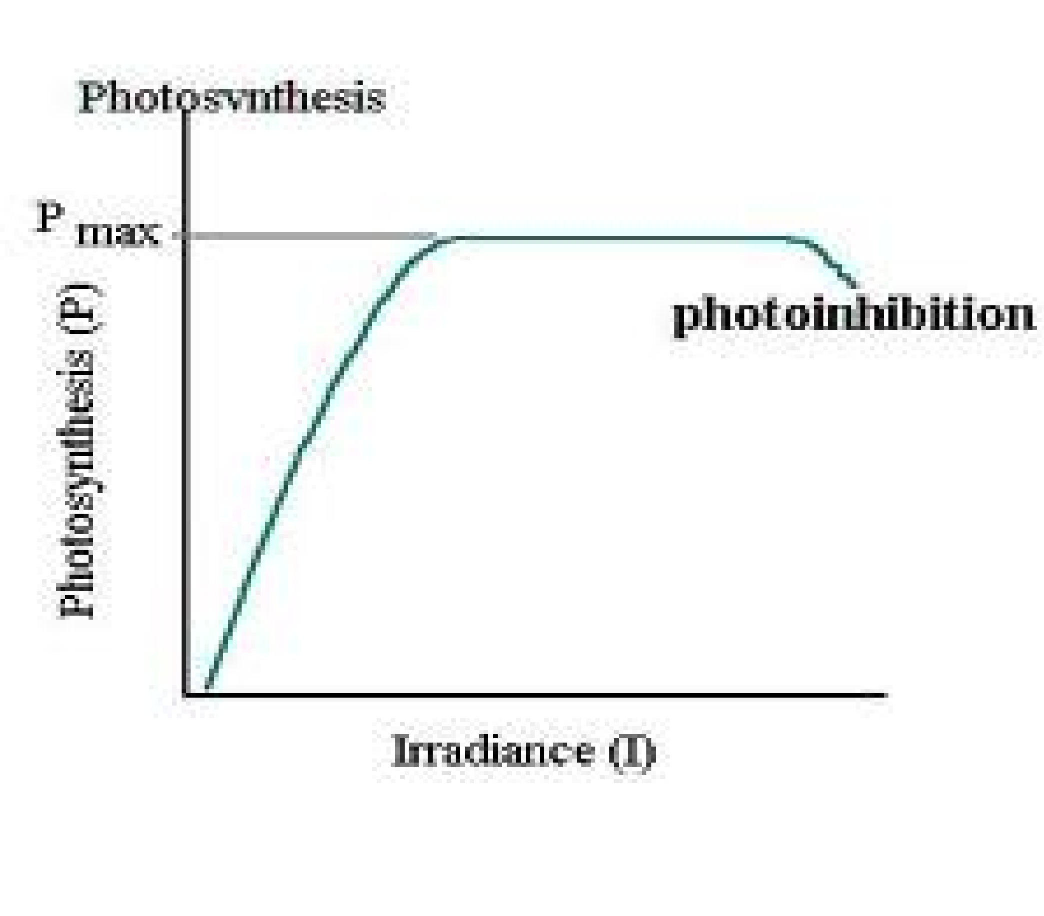
- light <u>and</u> temperature levels must be optimal for maximum plant growth
- natural variation at all time scales complicates achieving these levels



Light and Temperature Act Together - 2

- photo-inhibition … light levels higher than needed for photosynthesis that cause damage
- photo-inhibition and the related photo-oxidation occur at lower levels of light intensity as temperatures decline

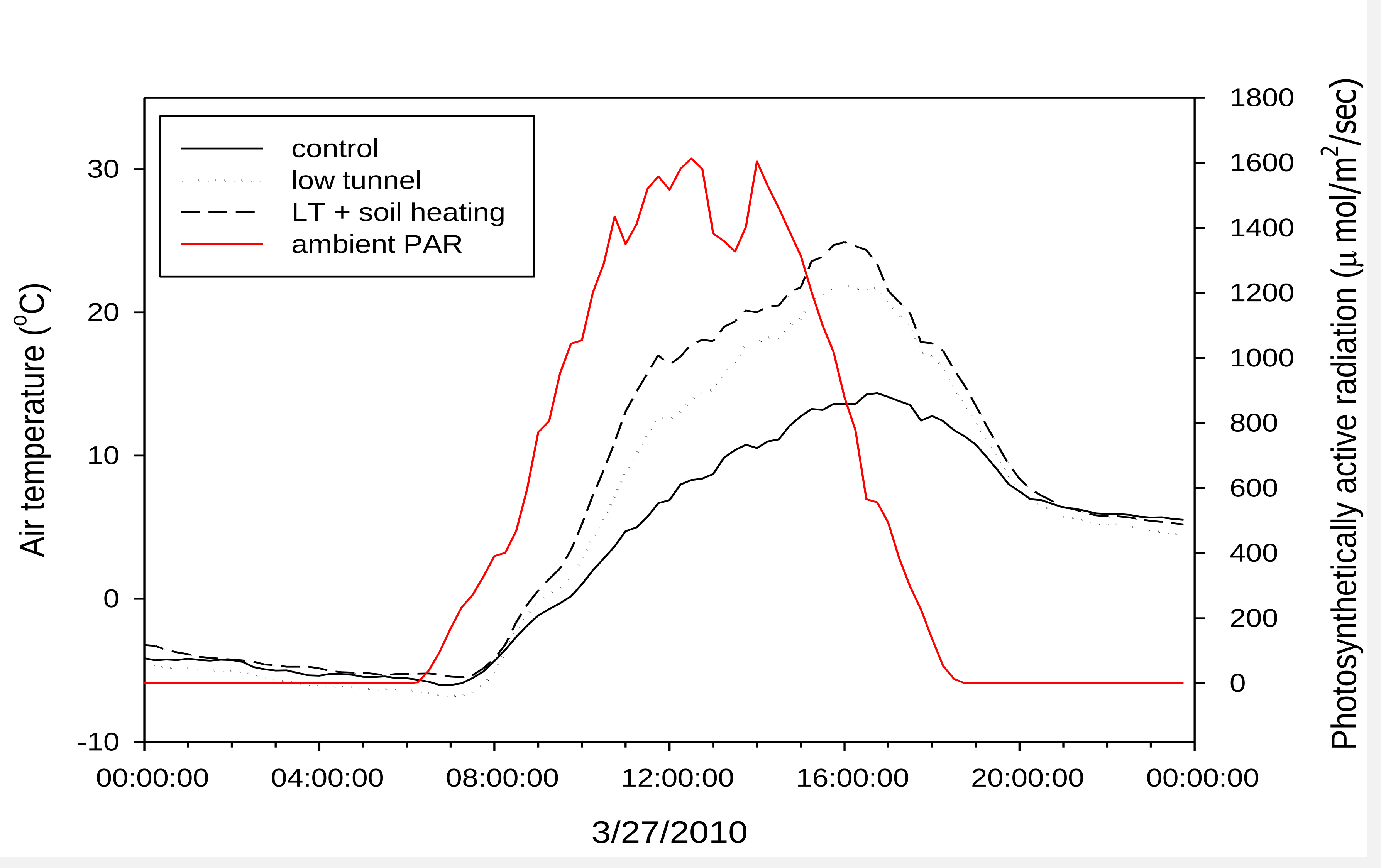
Plant species and temperature strongly influences the light level at which photo-inhibition and photo-oxidation occur.



Why Should Growers Care?

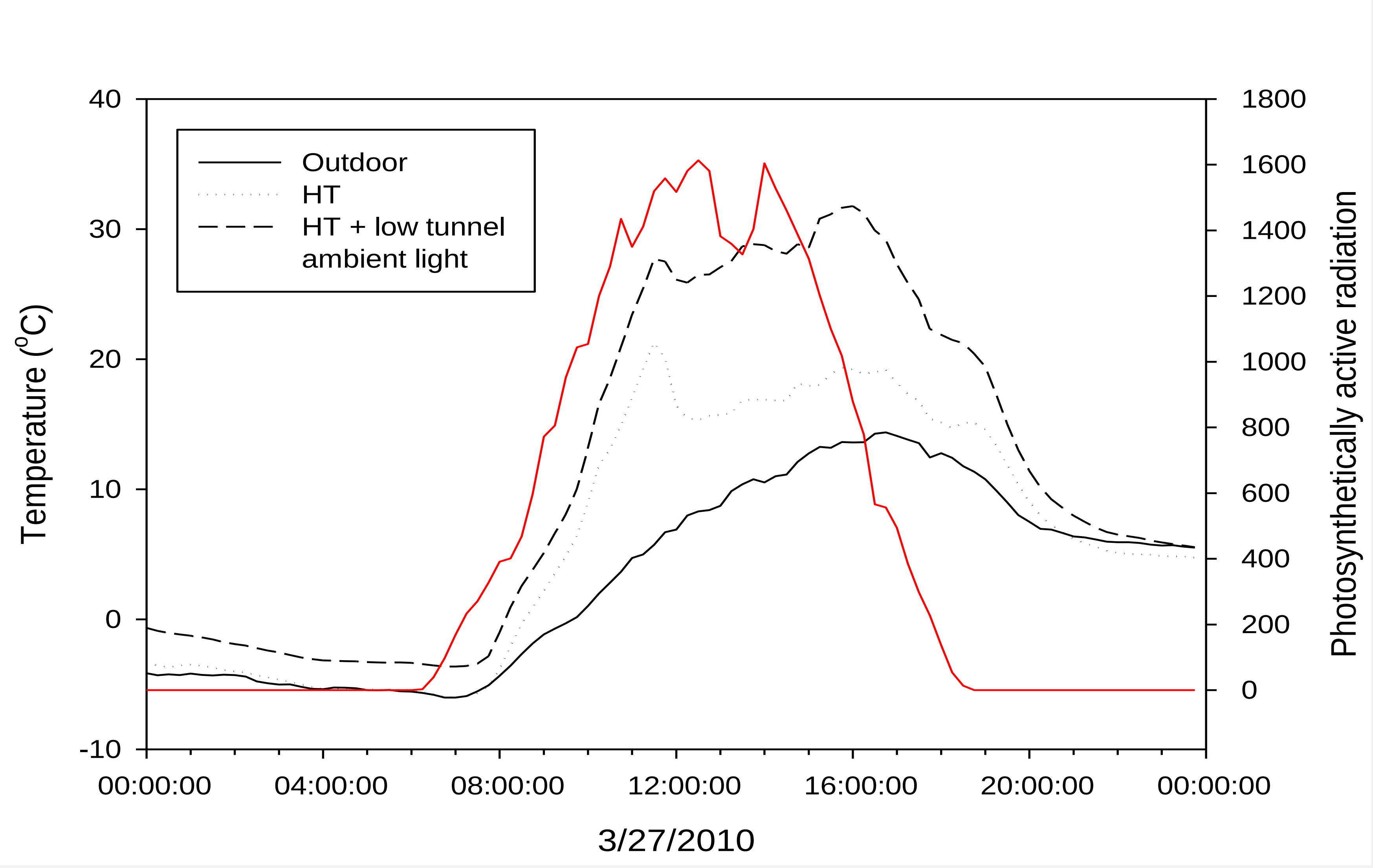
- high light-low temp conditions can reduce yield (actually, more damaging than high light alone)
- microclimate management allows us to achieve productive light-temperature levels over a larger portion of the day – especially during spring and fall

Outdoor



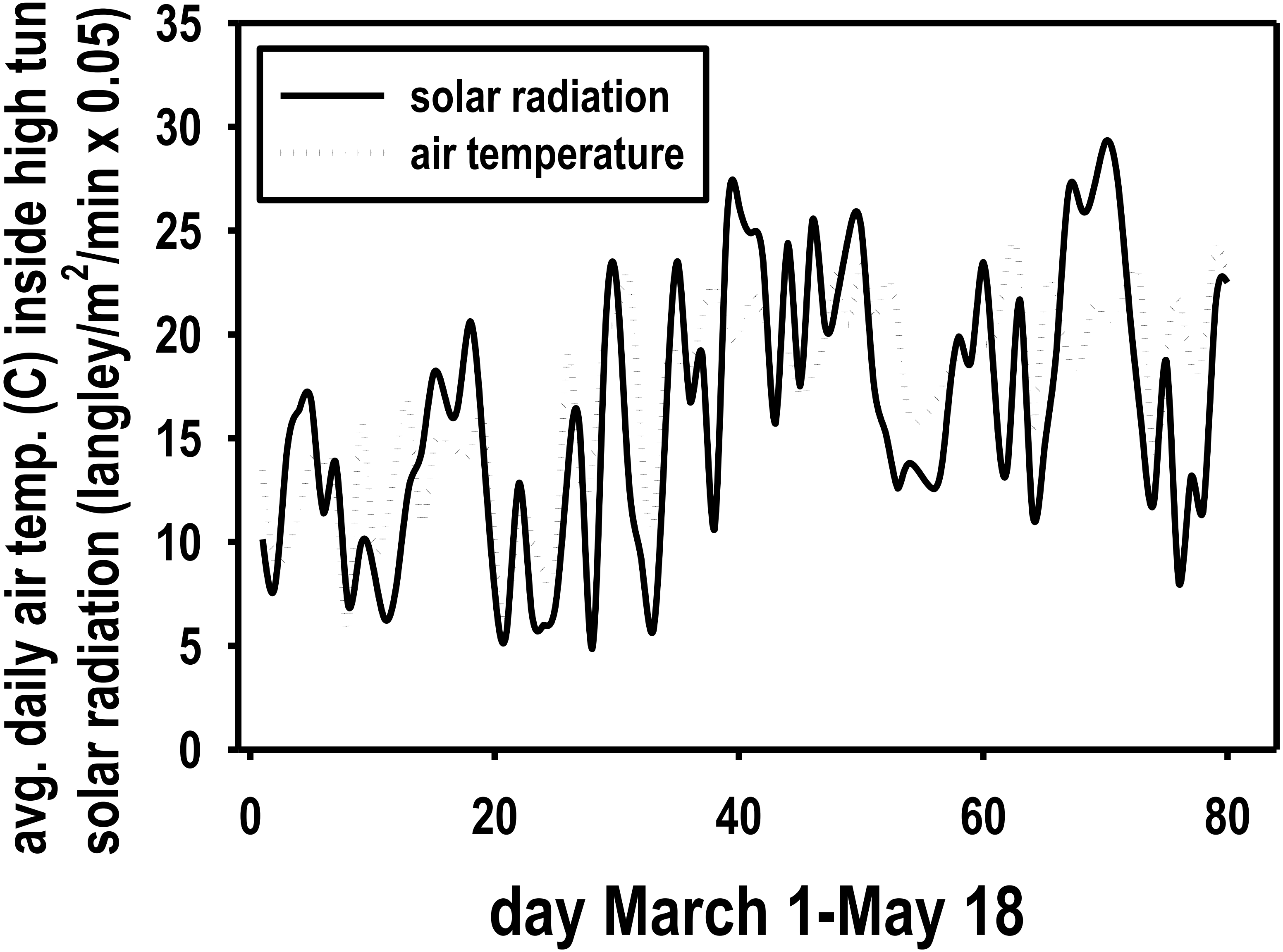
control
low tunnel
LT + soil heating
ambient PAR
Air temperature (°C)
30
20
10
0
-10
1800
1600
1400
1200
1000
800
600
400
200
0
Photosynthetically active radiation (μ mol/m2/sec)
00:00:00
04:00:00
08:00:00
12:00:00
16:00:00
20:00:00
00:00:00
3/27/2010

High Tunnel

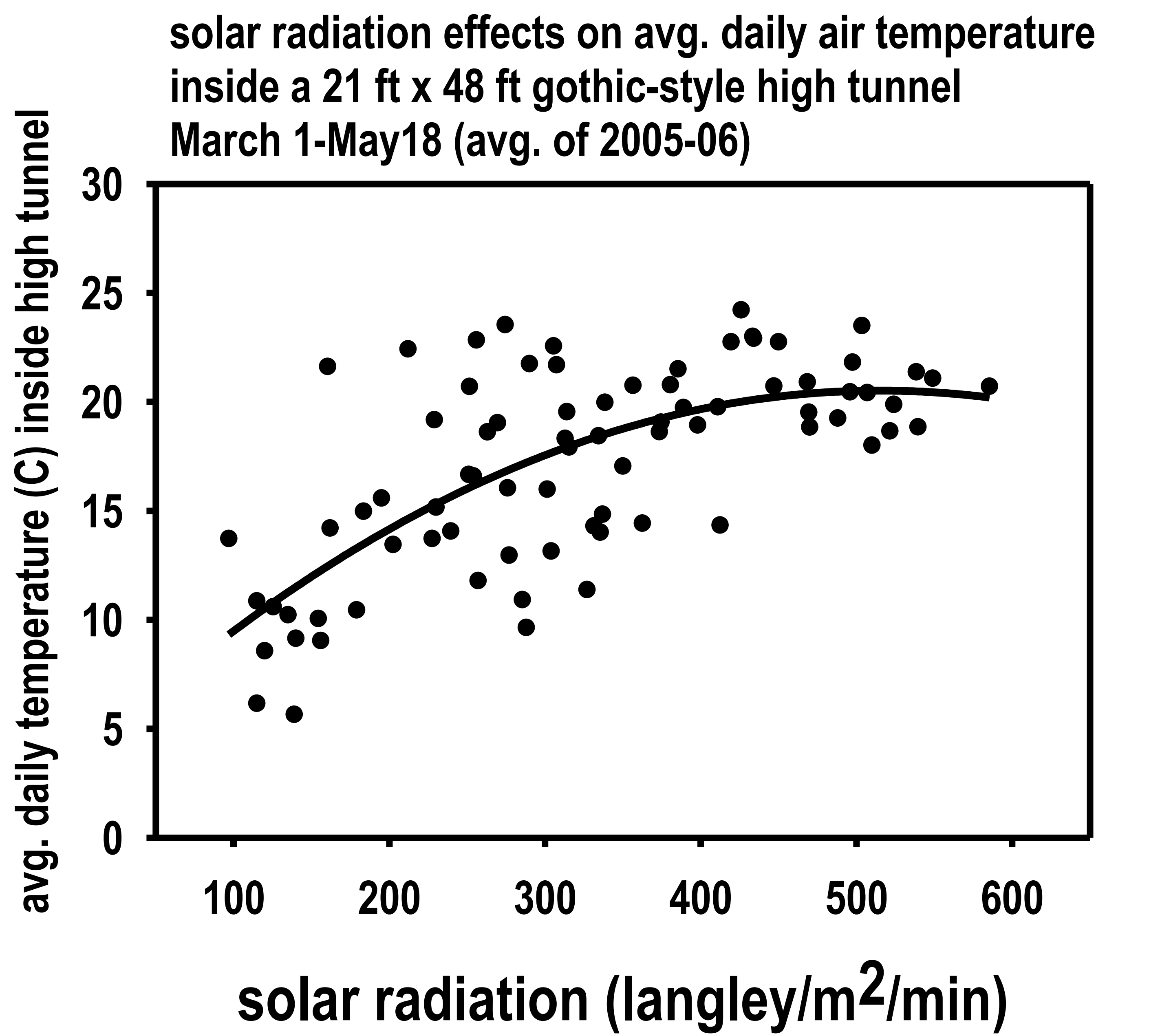


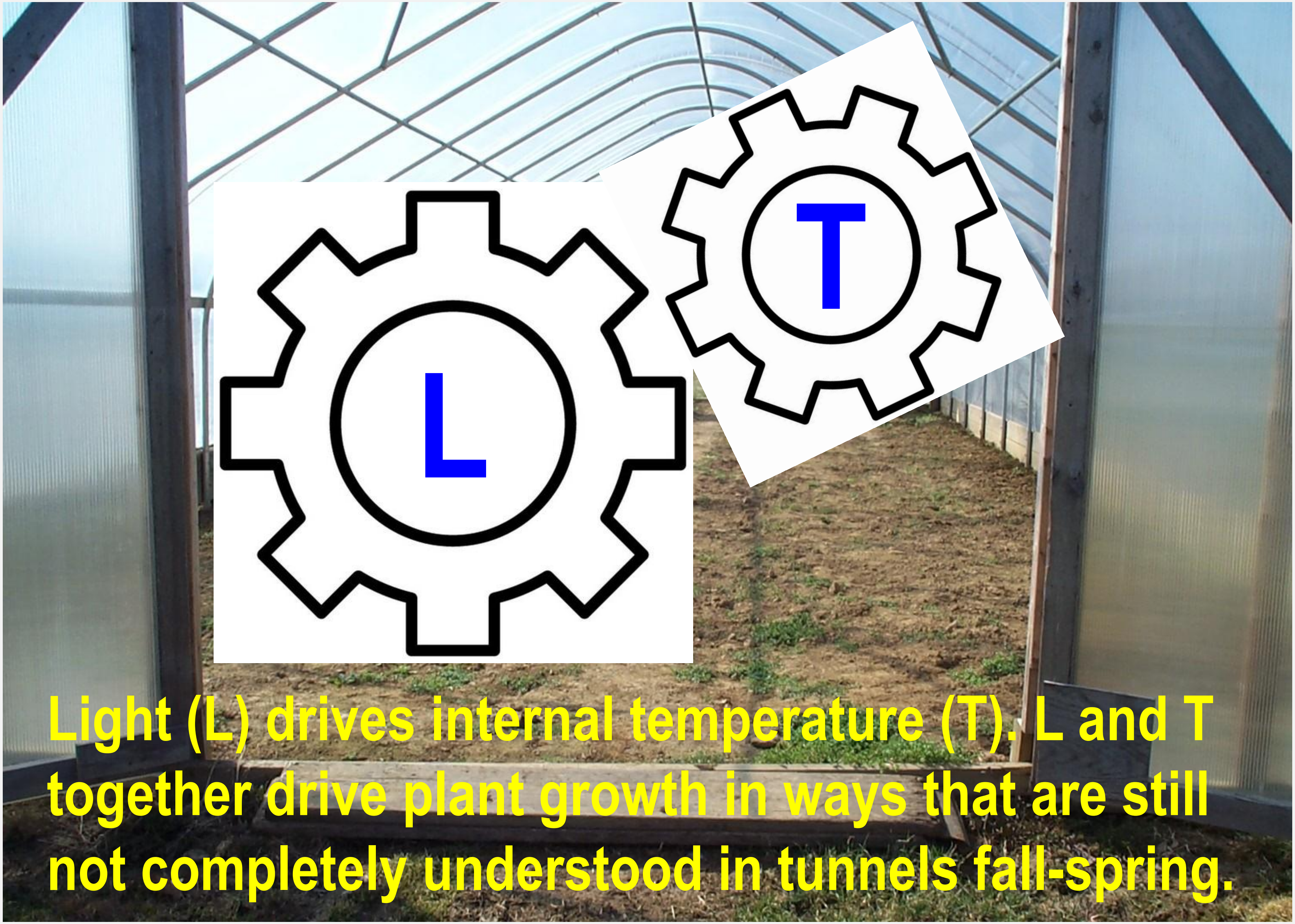
Outdoor
HT
HT + low tunnel
ambient light
Temperature (°C)
Photosynthetically active radiation
40
30
20
10
0
-10
1800
1600
1400
1200
1000
800
600
400
200
0
00:00:00
04:00:00
08:00:00
12:00:00
16:00:00
20:00:00
00:00:00
3/27/2010


Light carries heat, which
accumulates unless vented.
Plastic slows but does not
prevent heat loss.

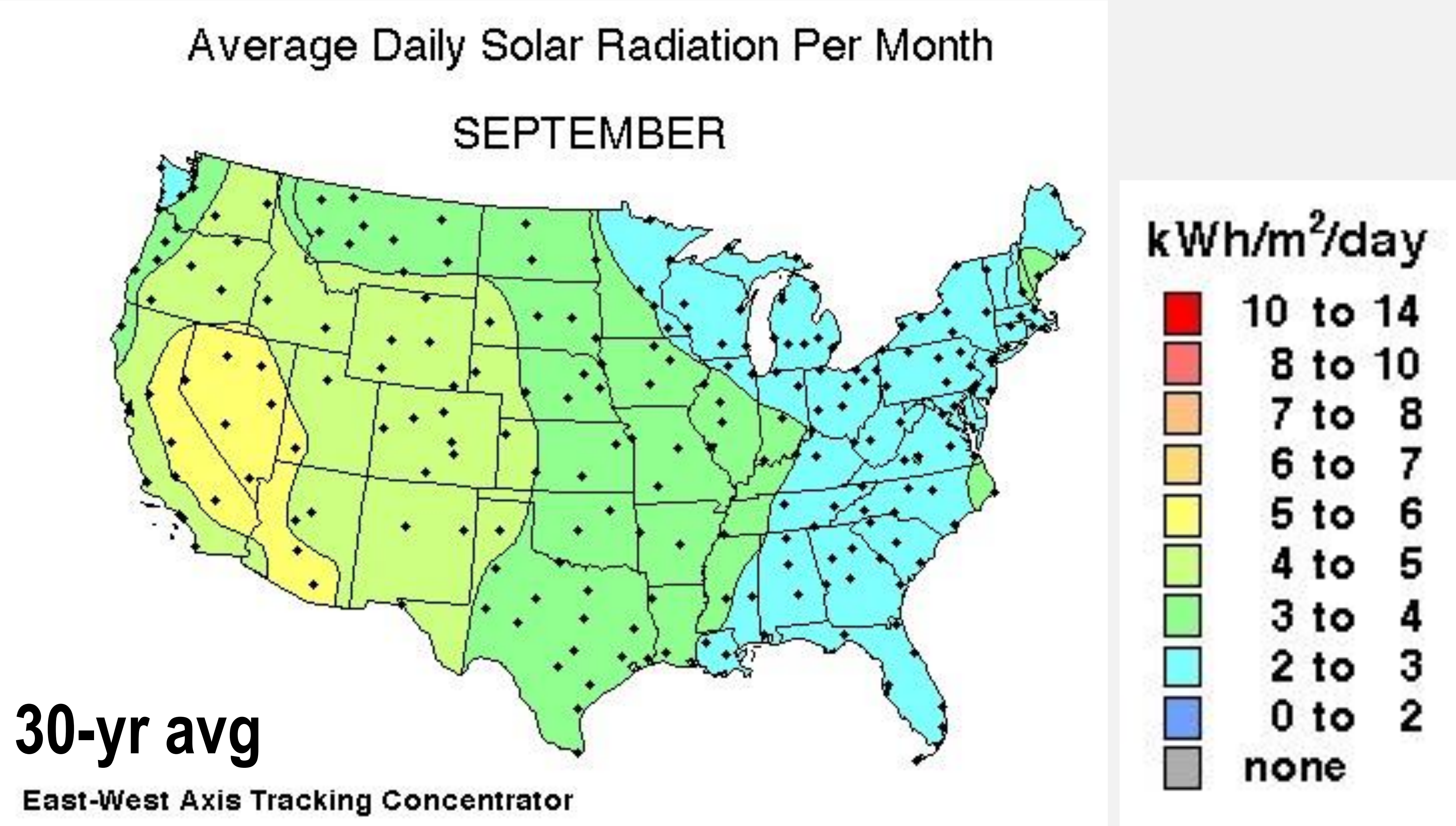


avg. daily air temp. (C) inside high tunnel,
solar radiation (langley/m2/min x 0.05)
solar radiation
air temperature
35
30
25
20
15
10
5
0
0
20
40
60
80
day March 1-May 18

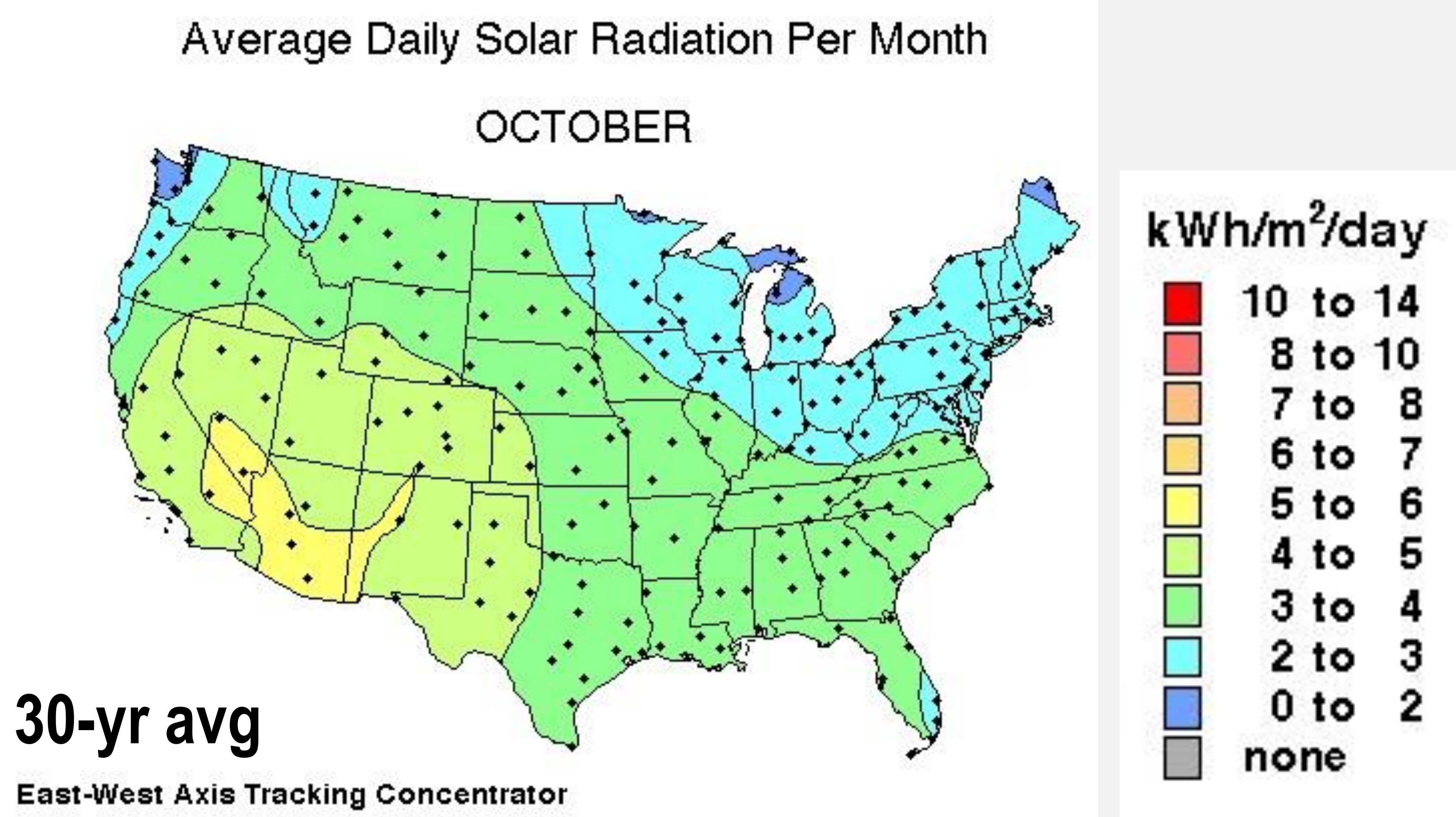

solar radiation effects on avg. daily air temperature
inside a 21 ft x 48 ft gothic-style high tunnel
March 1-May18 (avg. of 2005-06)
avg. daily temperature (C) inside high tunnel
30
25
20
15
10
5
0
100
200
300
400
500
600
solar radiation (langley/m2/min)


L
T
Light (L) drives internal temperature (T). L and T together drive plant growth in ways that are still not completely understood in tunnels fall-spring.


TAYLOR.
°F
°C
120
100
80
60
40
20
0
-20
-40
50
40
30
20
10
0
-10
-20
-30
-40
intensity
makeup
duration
angle



https://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/atlas/



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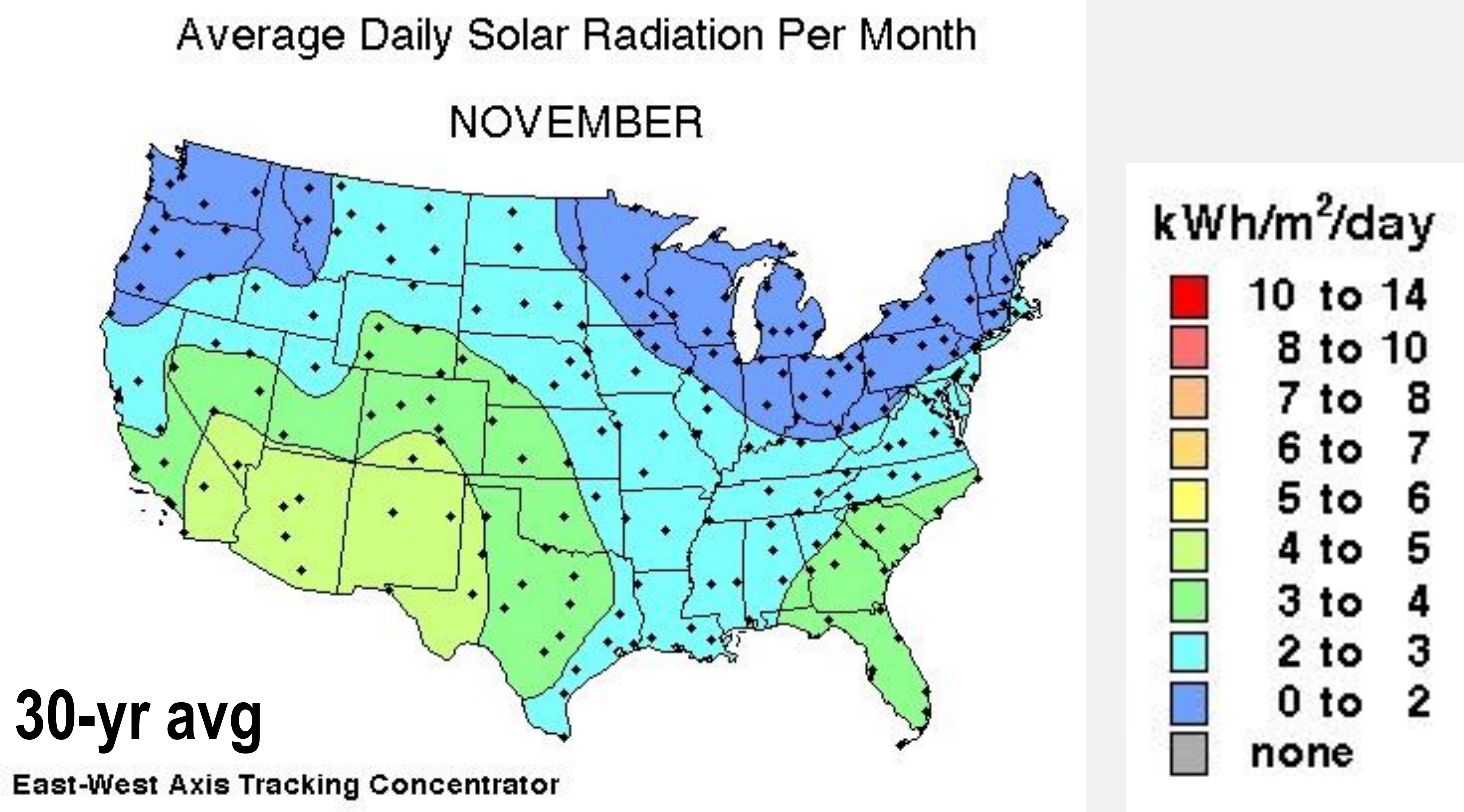

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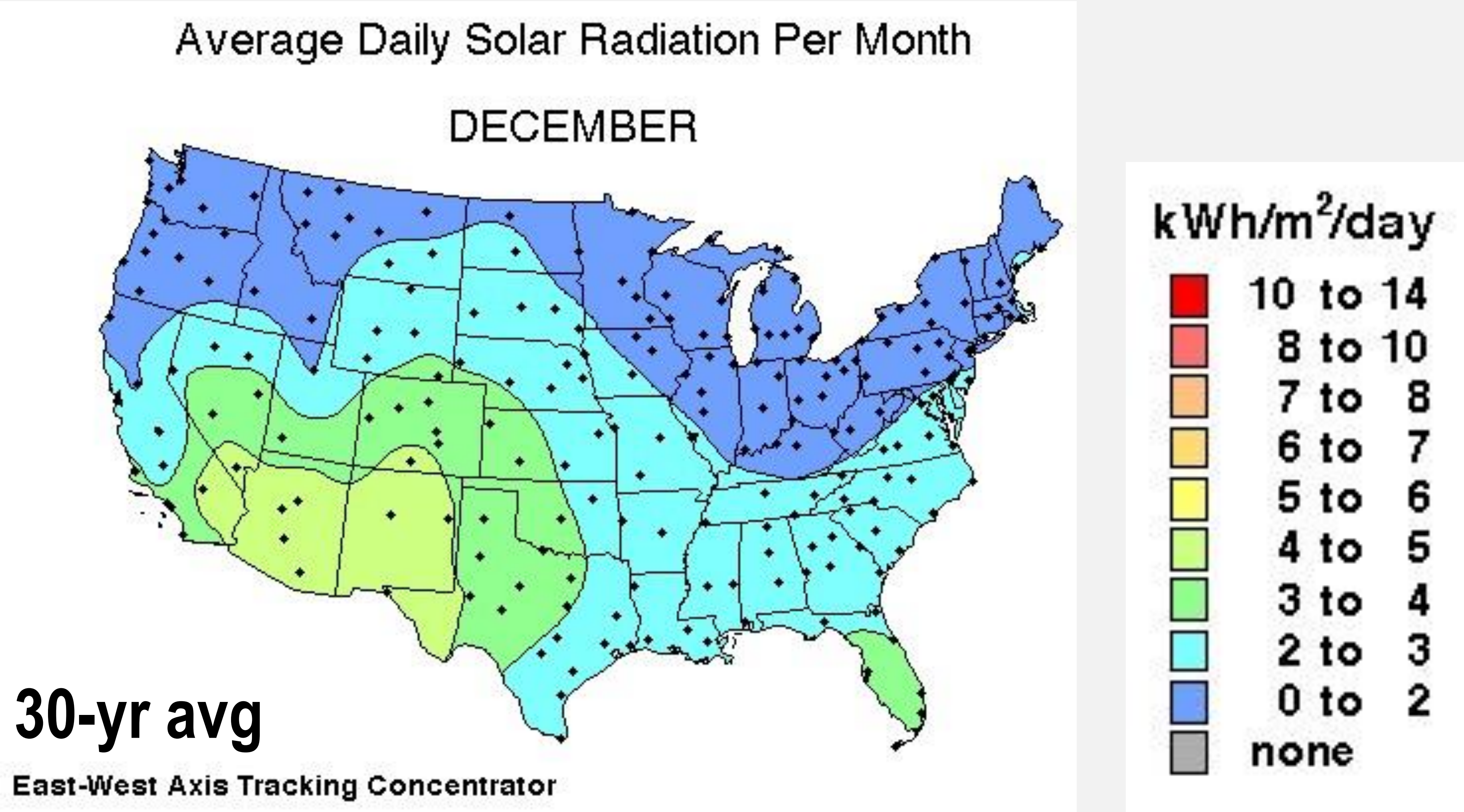

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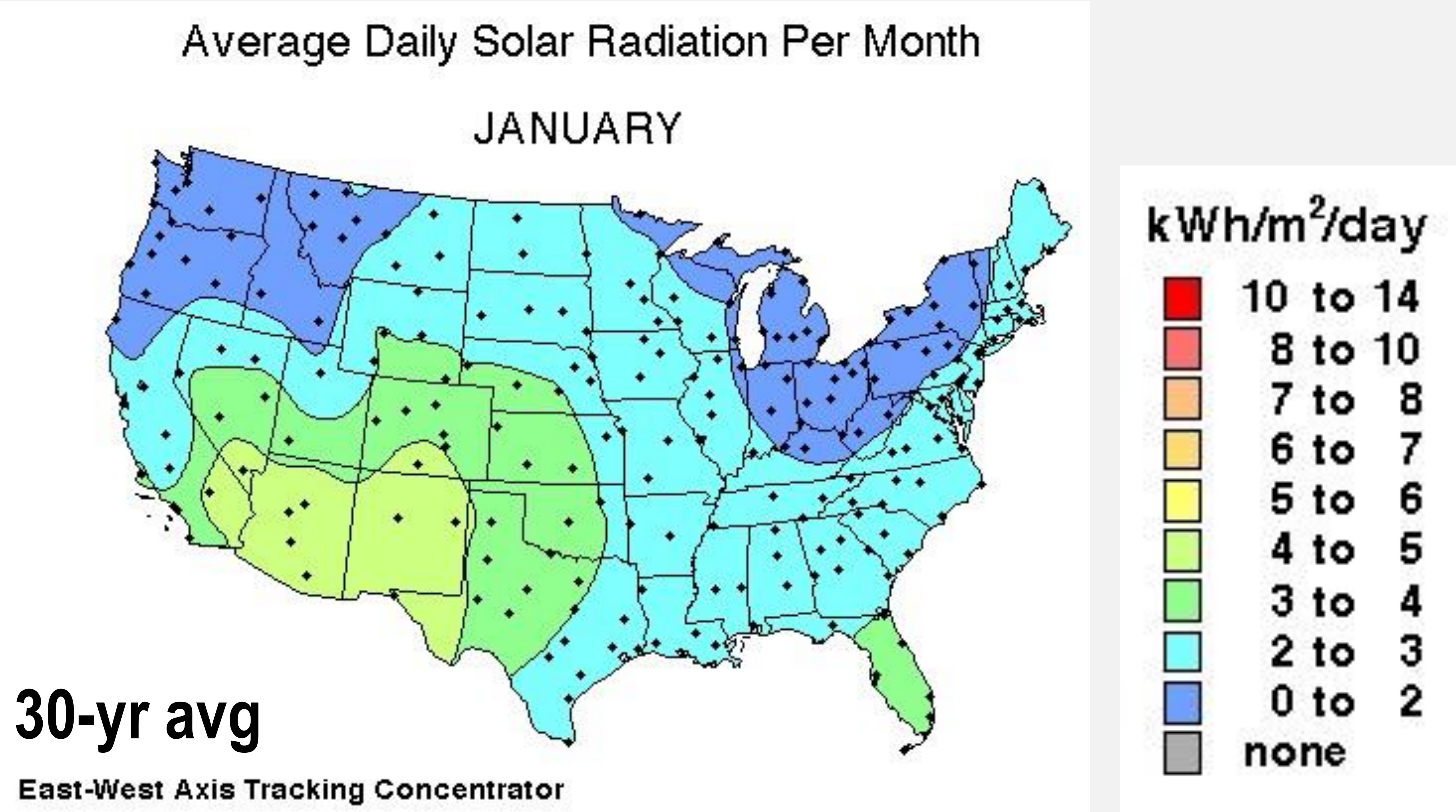
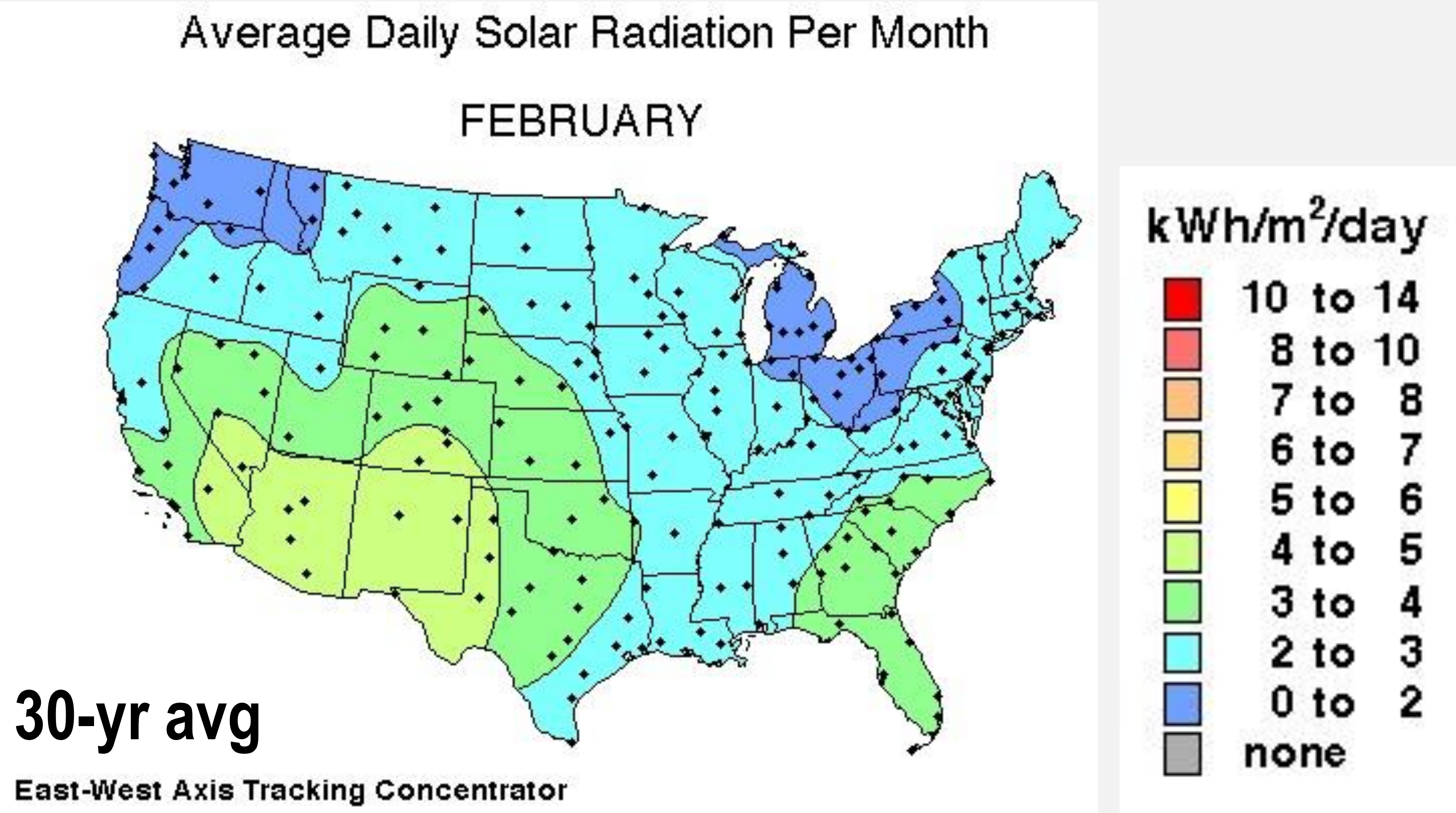


https://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/atlas/



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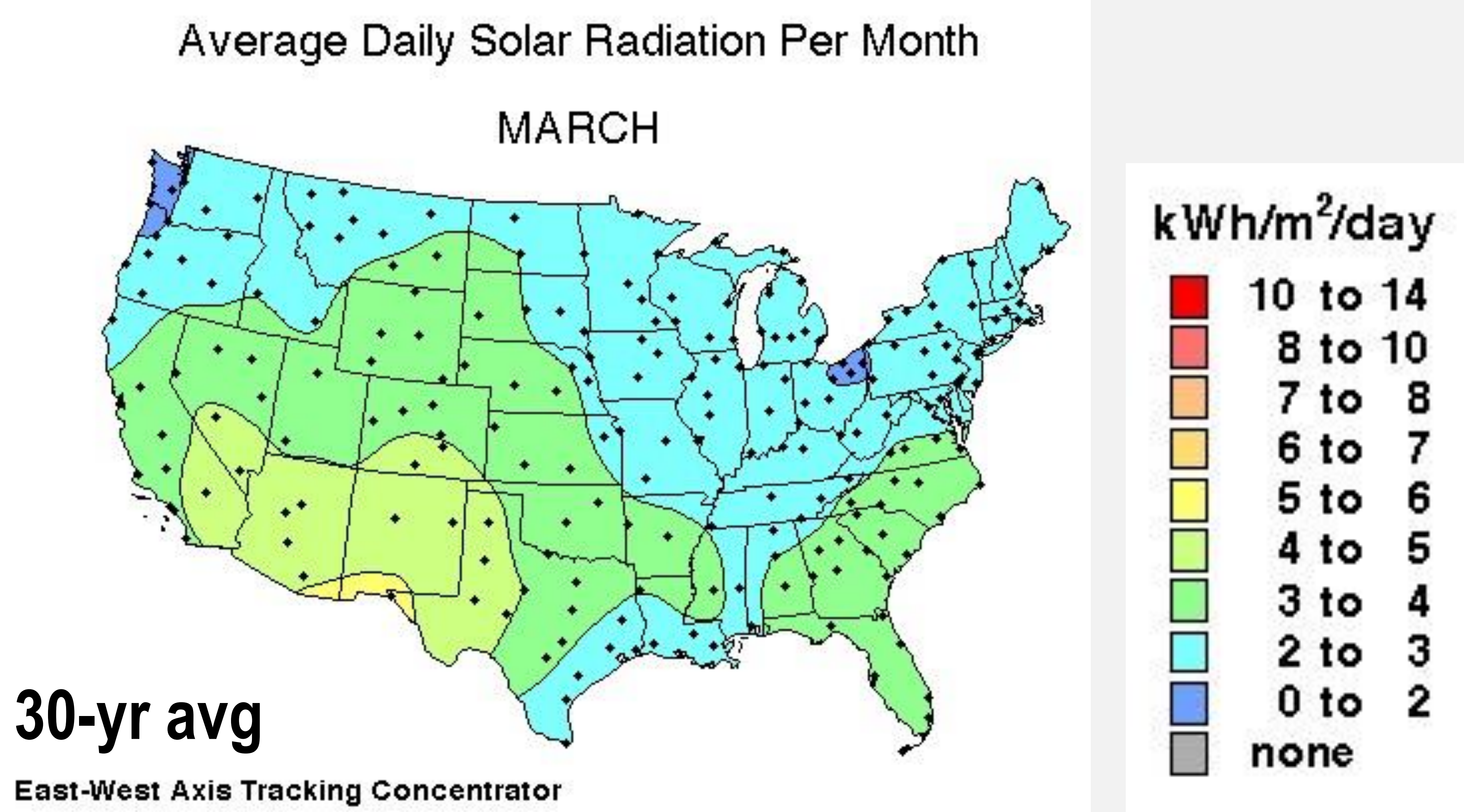

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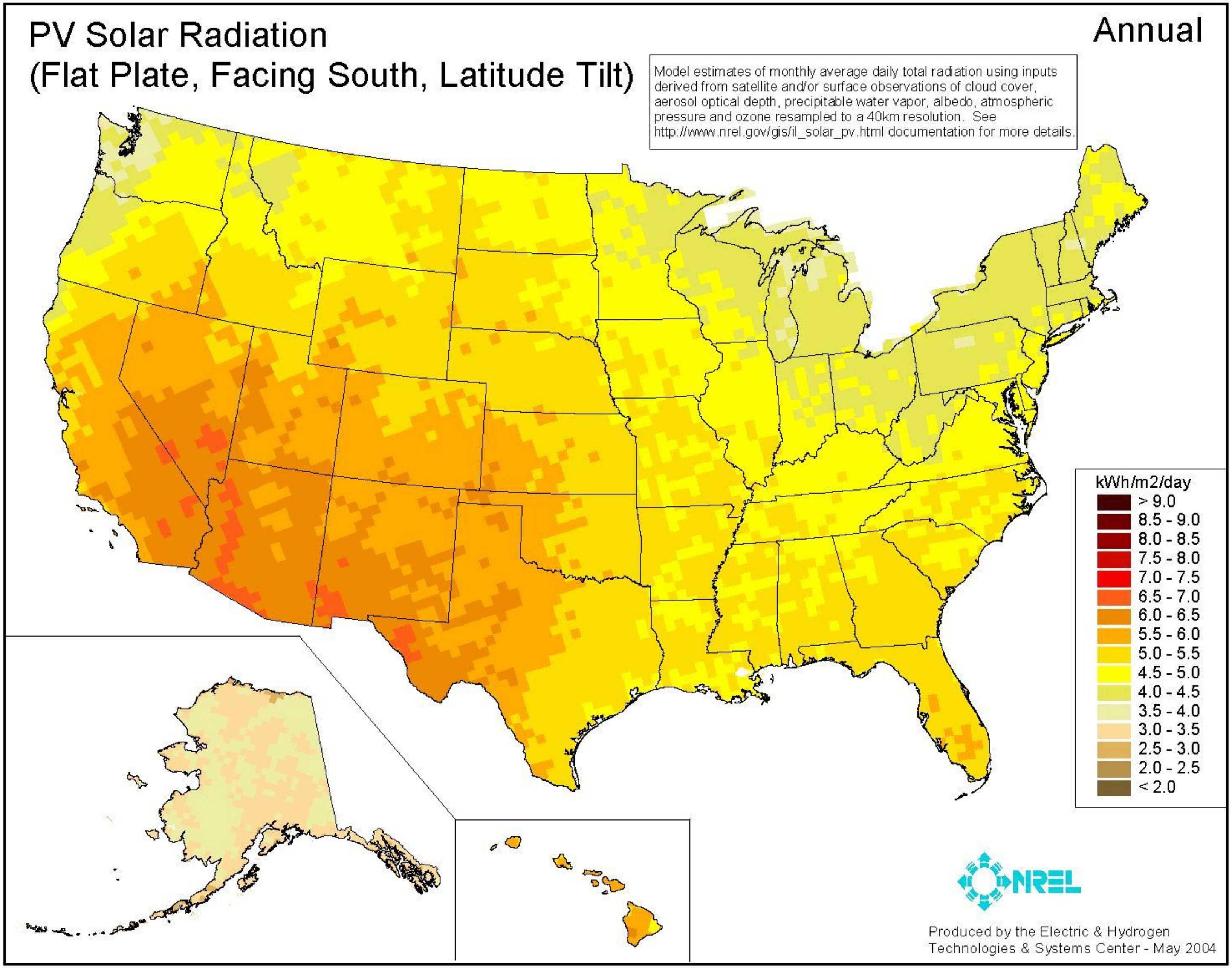
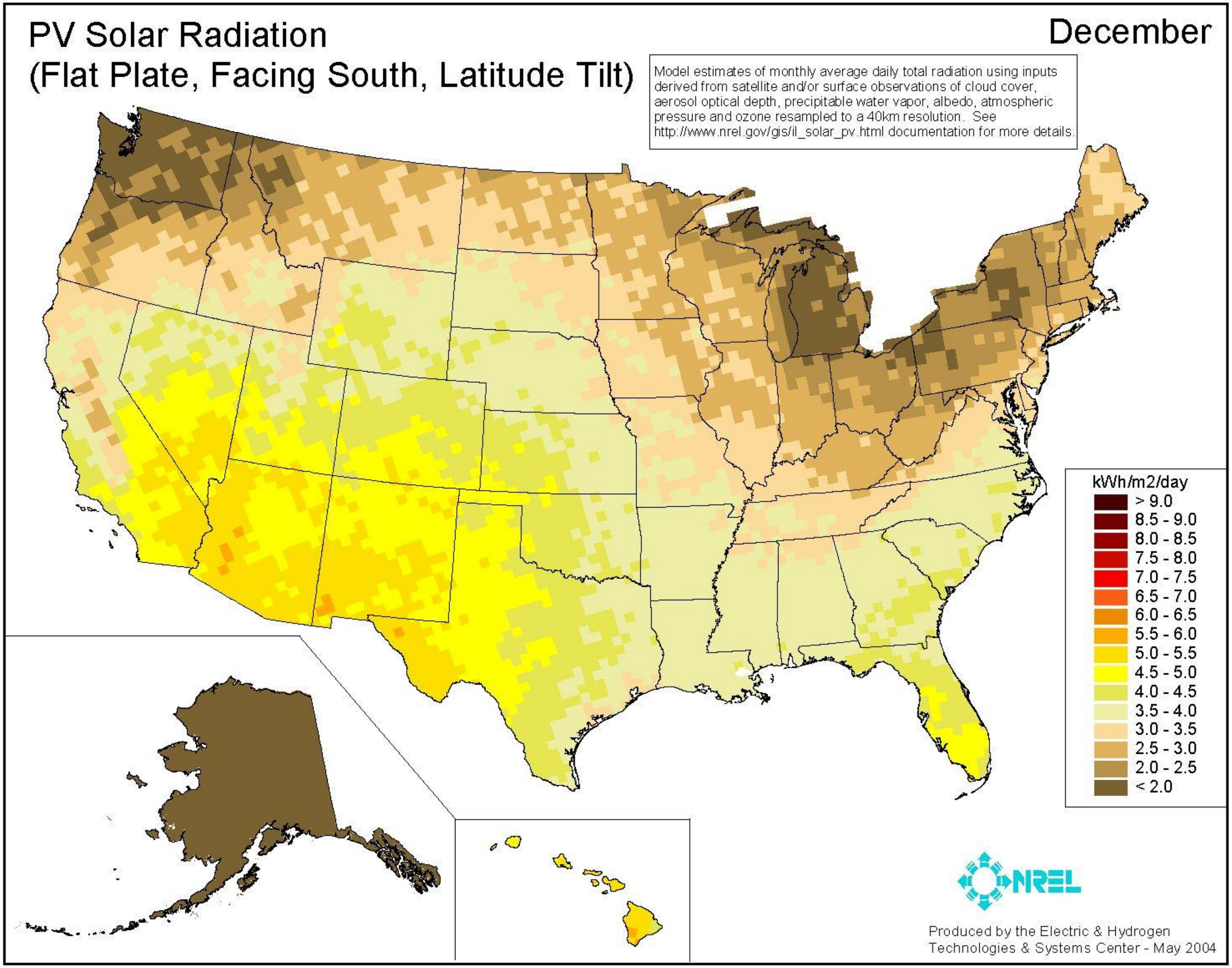
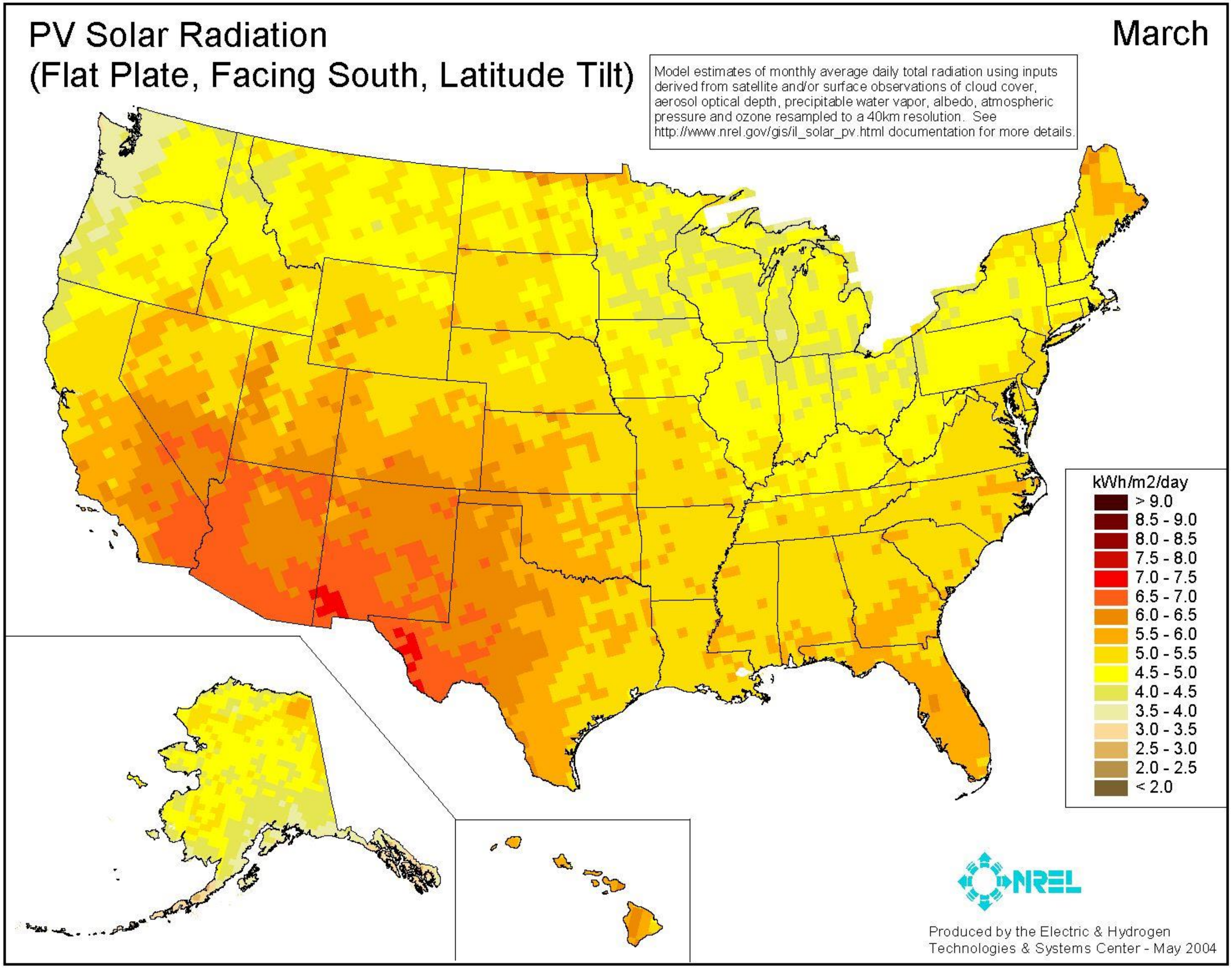
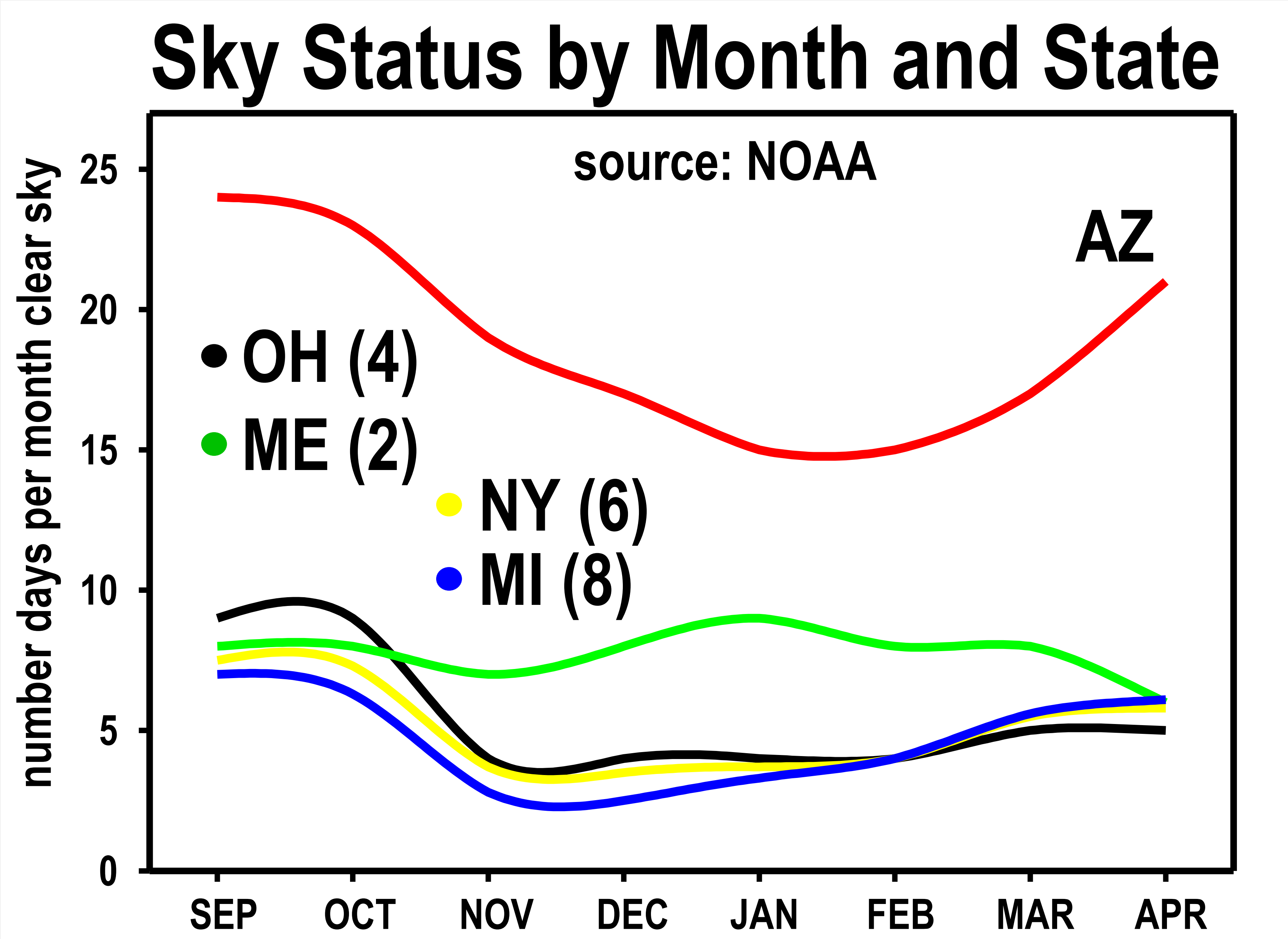


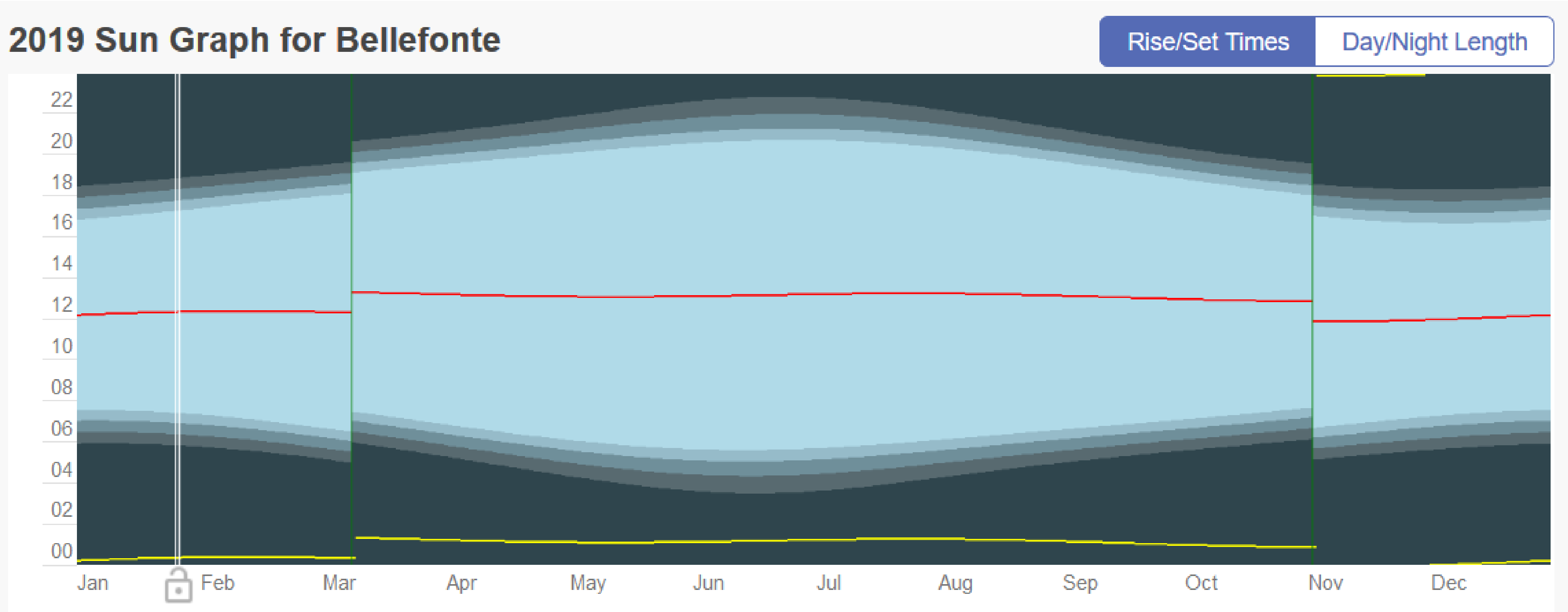
PV Solar Radiation
(Flat Plate, Facing South, Latitude Tilt)
Annual
Model estimates of monthly average daily total radiation using inputs derived from satellite and/or surface observations of cloud cover, aerosol optical depth, precipitable water vapor, albedo, atmospheric pressure and ozone resampled to a 40km resolution. See http://www.nrel.gov/gis/il_solar_pv.html documentation for more details.
kWh/m2/day
> 9.0
8.5 - 9.0
8.0 - 8.5
7.5 - 8.0
7.0 - 7.5
6.5 - 7.0
6.0 - 6.5
5.5 - 6.0
5.0 - 5.5
4.5 - 5.0
4.0 - 4.5
3.5 - 4.0
3.0 - 3.5
2.5 - 3.0
2.0 - 2.5
< 2.0
NREL
Produced by the Electric & Hydrogen Technologies & Systems Center - May 2004


PV Solar Radiation
(Flat Plate, Facing South, Latitude Tilt)
December
Model estimates of monthly average daily total radiation using inputs derived from satellite and/or surface observations of cloud cover, aerosol optical depth, precipitable water vapor, albedo, atmospheric pressure and ozone resampled to a 40km resolution. See http://www.nrel.gov/gis/il_solar_pv.html documentation for more details.
kWh/m2/day
> 9.0
8.5 - 9.0
8.0 - 8.5
7.5 - 8.0
7.0 - 7.5
6.5 - 7.0
6.0 - 6.5
5.5 - 6.0
5.0 - 5.5
4.5 - 5.0
4.0 - 4.5
3.5 - 4.0
3.0 - 3.5
2.5 - 3.0
2.0 - 2.5
< 2.0
NREL
Produced by the Electric & Hydrogen Technologies & Systems Center - May 2004



PV Solar Radiation
(Flat Plate, Facing South, Latitude Tilt)
March
Model estimates of monthly average daily total radiation using inputs derived from satellite and/or surface observations of cloud cover, aerosol optical depth, precipitable water vapor, albedo, atmospheric pressure and ozone resampled to a 40km resolution. See http://www.nrel.gov/gis/il_solar_pv.html documentation for more details.
kWh/m2/day
> 9.0
8.5 - 9.0
8.0 - 8.5
7.5 - 8.0
7.0 - 7.5
6.5 - 7.0
6.0 - 6.5
5.5 - 6.0
5.0 - 5.5
4.5 - 5.0
4.0 - 4.5
3.5 - 4.0
3.0 - 3.5
2.5 - 3.0
2.0 - 2.5
< 2.0
NREL
Produced by the Electric & Hydrogen Technologies & Systems Center - May 2004


Sky Status by Month and State
source: NOAA
AZ
OH (4)
ME (2)
NY (6)
MI (8)
number days per month clear sky
0
5
10
15
20
25
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR



approx. elevation (°) of sun at noon on 15th of each month

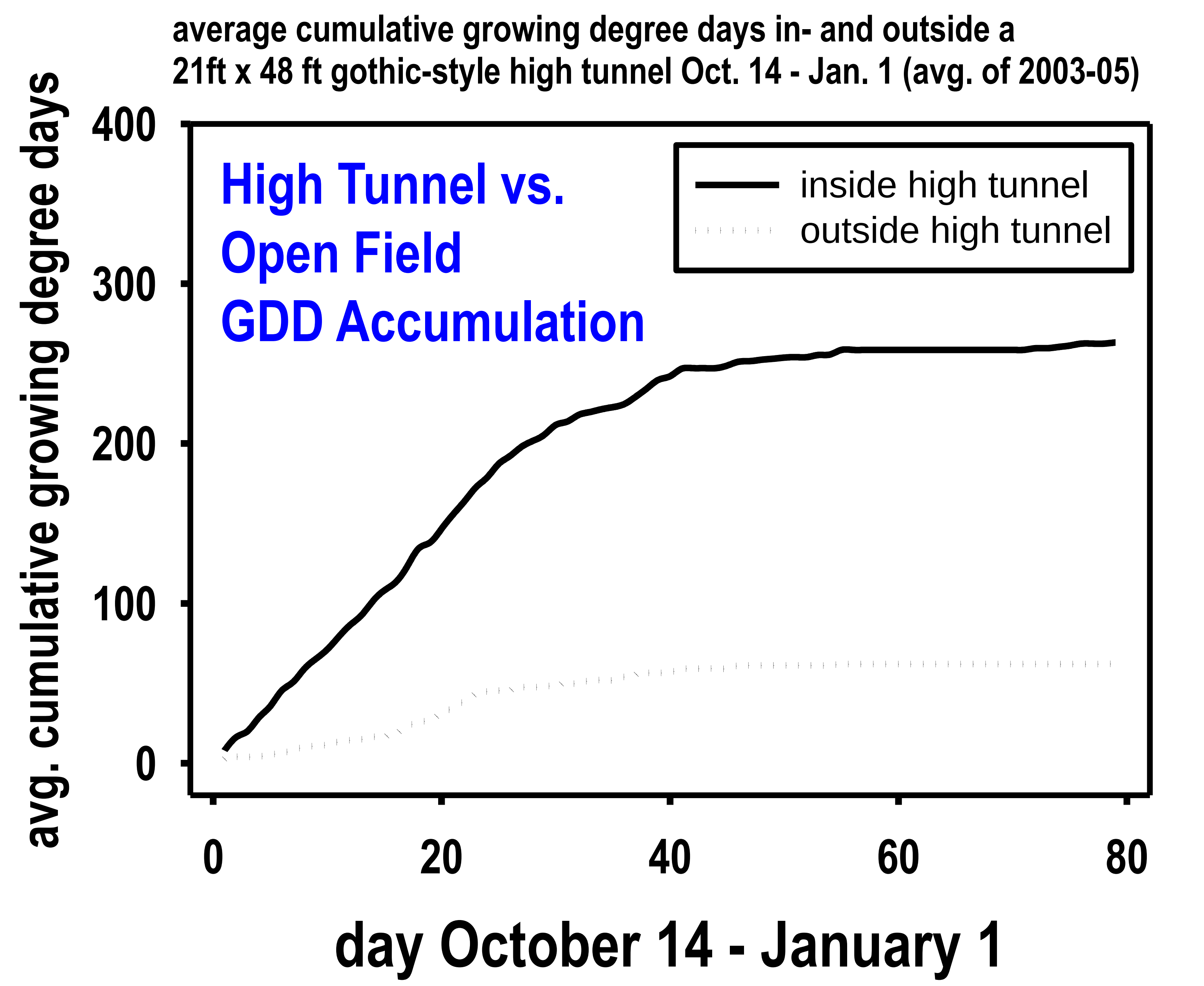
Sept	Oct	Nov	Dec	Jan	Feb	Mar
49.2	38.8	29.2	24.0	25.2	33.0	43.3

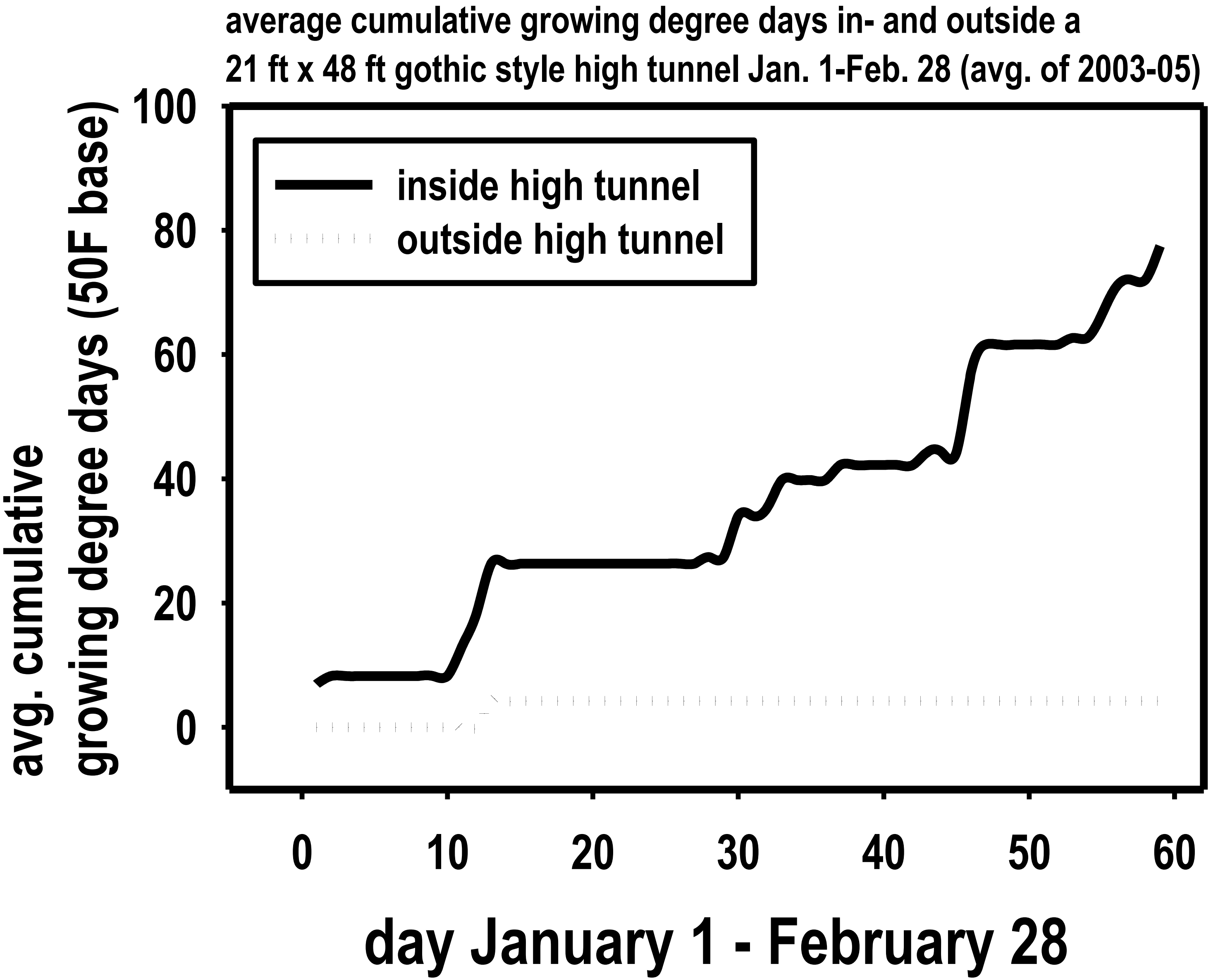
Thermal Time

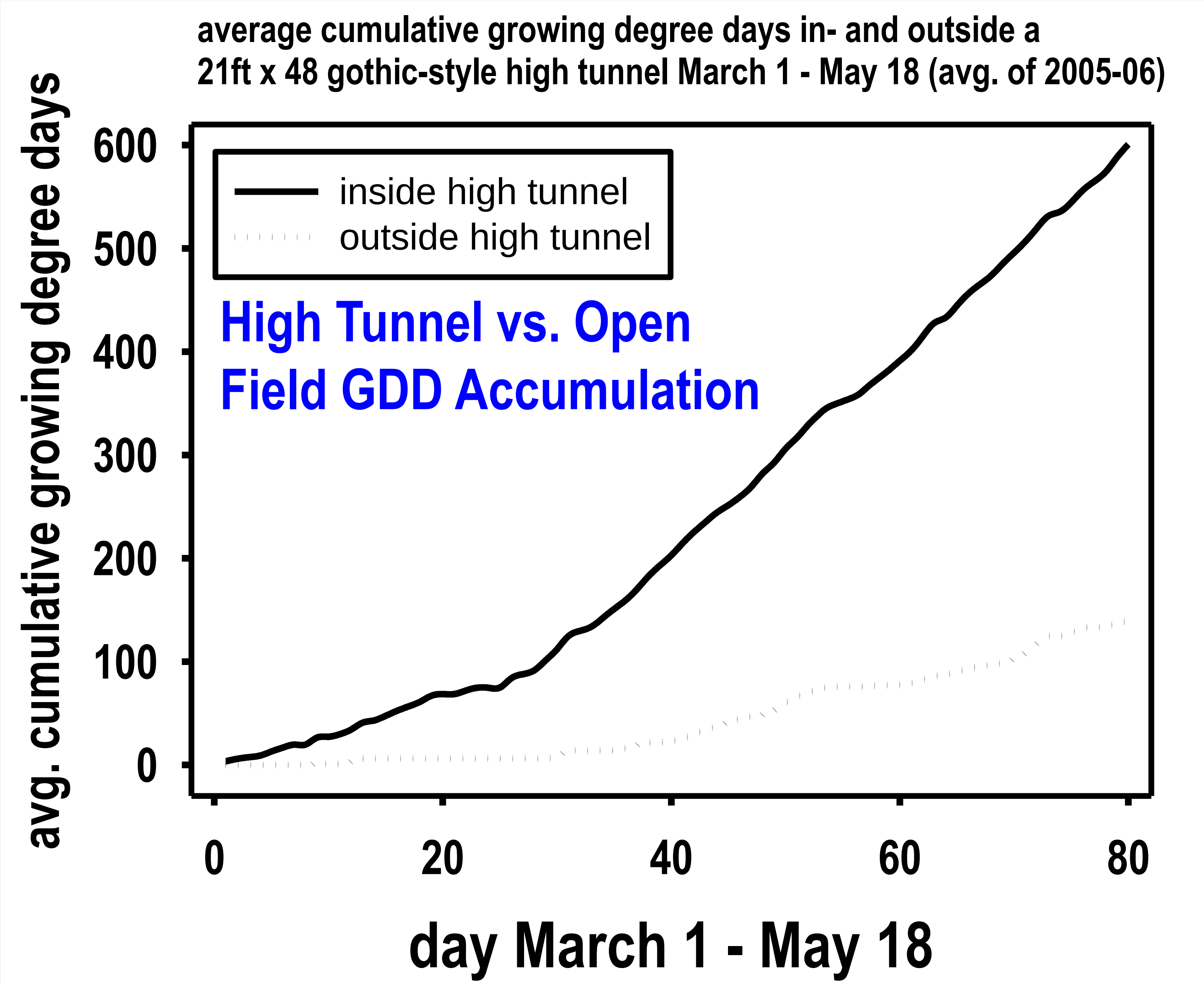
Growing Degree Days (GDD)

Heat Units

$$GDD = \frac{Tmax + Tmin}{2} - Tbase$$


average cumulative growing degree days in- and outside a
21ft x 48 ft gothic-style high tunnel Oct. 14 - Jan. 1 (avg. of 2003-05)
High Tunnel vs.
Open Field
GDD Accumulation
inside high tunnel
outside high tunnel
avg. cumulative growing degree days
400
300
200
100
0
0
20
40
60
80
day October 14 - January 1


average cumulative growing degree days in- and outside a
21 ft x 48 ft gothic style high tunnel Jan. 1-Feb. 28 (avg. of 2003-05)
avg. cumulative
growing degree days (50F base)
100
80
60
40
20
0
inside high tunnel
outside high tunnel
0
10
20
30
40
50
60
day January 1 - February 28


average cumulative growing degree days in- and outside a
21ft x 48 gothic-style high tunnel March 1 - May 18 (avg. of 2005-06)
inside high tunnel
outside high tunnel
High Tunnel vs. Open
Field GDD Accumulation
avg. cumulative growing degree days
600
500
400
300
200
100
0
0
20
40
60
80
day March 1 - May 18

GDD Air (by site)	Field	Low Tunnel	High Tunnel	HT + LT
Spring 2009	95	163 (1.72x)	195 (2.05x)	295 (3.11x)
Fall 2009	117	157 (1.34x)	164 (1.40x)	217 (1.85x)
Spring 2010	178	214 (1.20x)	206 (1.16x)	280 (1.57x)

Seasonal light, ventilation also important.

Crop Cover Effects on Light

Fall 2009 - Spr 2010	PAR (400-700 nm)	UVA (320-400 nm)	UVB (280-320 nm)
Outdoor	100%	100%	100%
LT	86%	87%	84%
HT	77%	38%	9%
HT + LT	67%	33%	7%

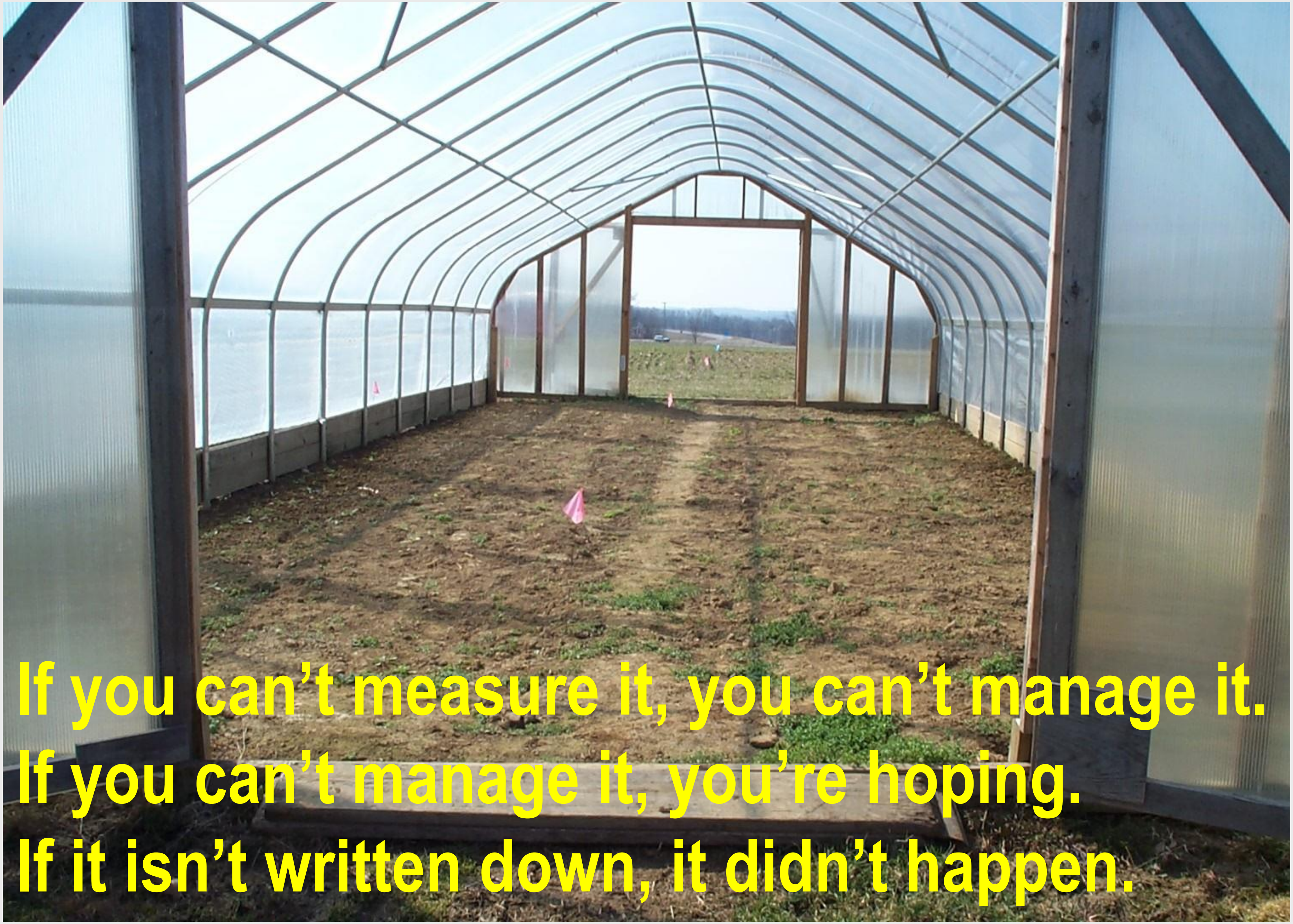
Plus other Factors

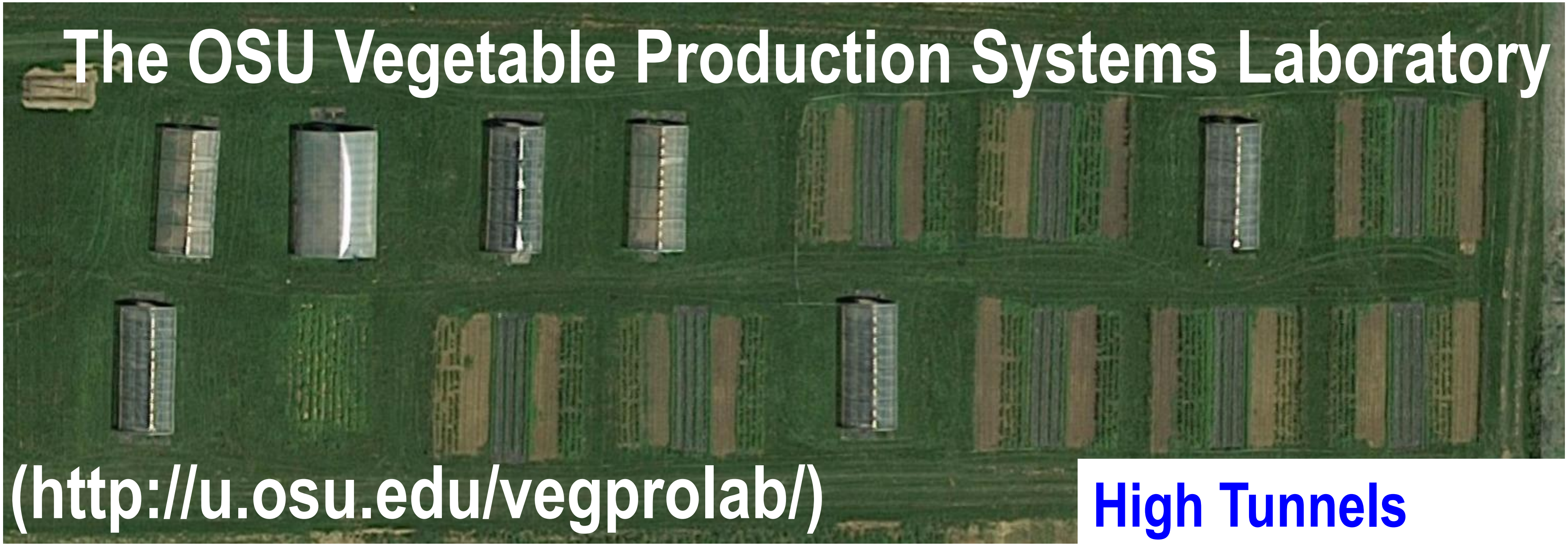
Microclimate management also affects …

- Wind
- Humidity
- Carbon dioxide concentrations
- Pest populations
- Plant /disease interactions

The temperature of groundwater is generally equal to the mean air temperature above the land surface. It usually stays within a narrow range year-round.

https://www.ngwa.org/what-is-groundwater/About-groundwater/groundwater-temperature%27s-measurement-and-significance


If you can’t measure it, you can’t manage it.
If you can’t manage it, you’re hoping.
If it isn’t written down, it didn’t happen.



High Tunnels

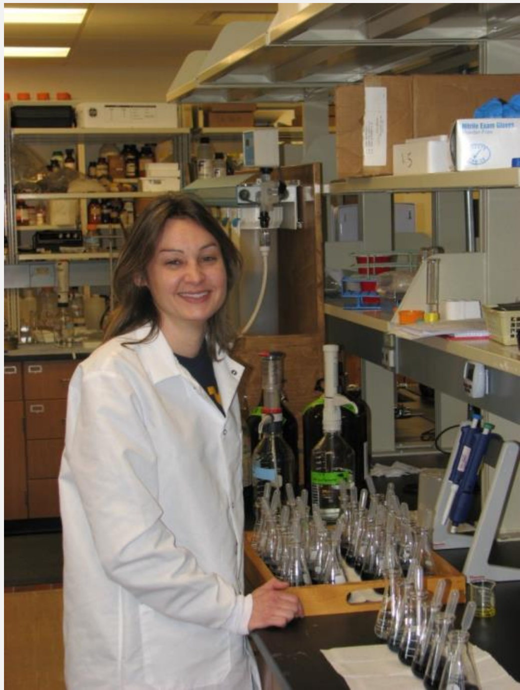
- six, 21 ft x 48 ft
- one, 30 ft x 48 ft (moveable)
- three, 30 ft x 80 ft

Mid-Tunnels

- 22, 4 ft x 30 ft

Natalie Bumgarner

University of Tennessee-Knoxville



OSU-VPSL
2008-2012

Experimental Factorial

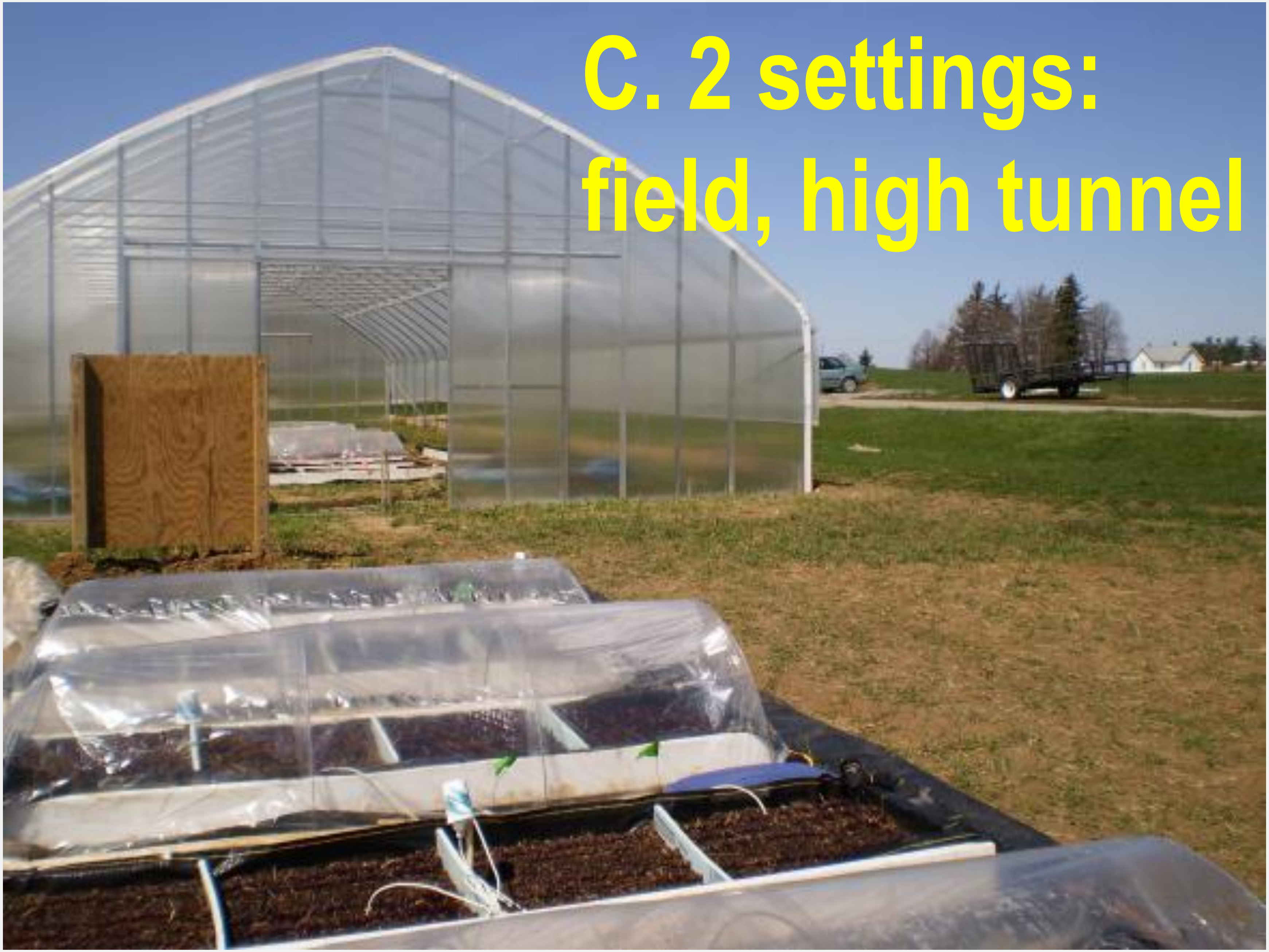
A. 2 years:

2009, 2010

B. 2 seasons:

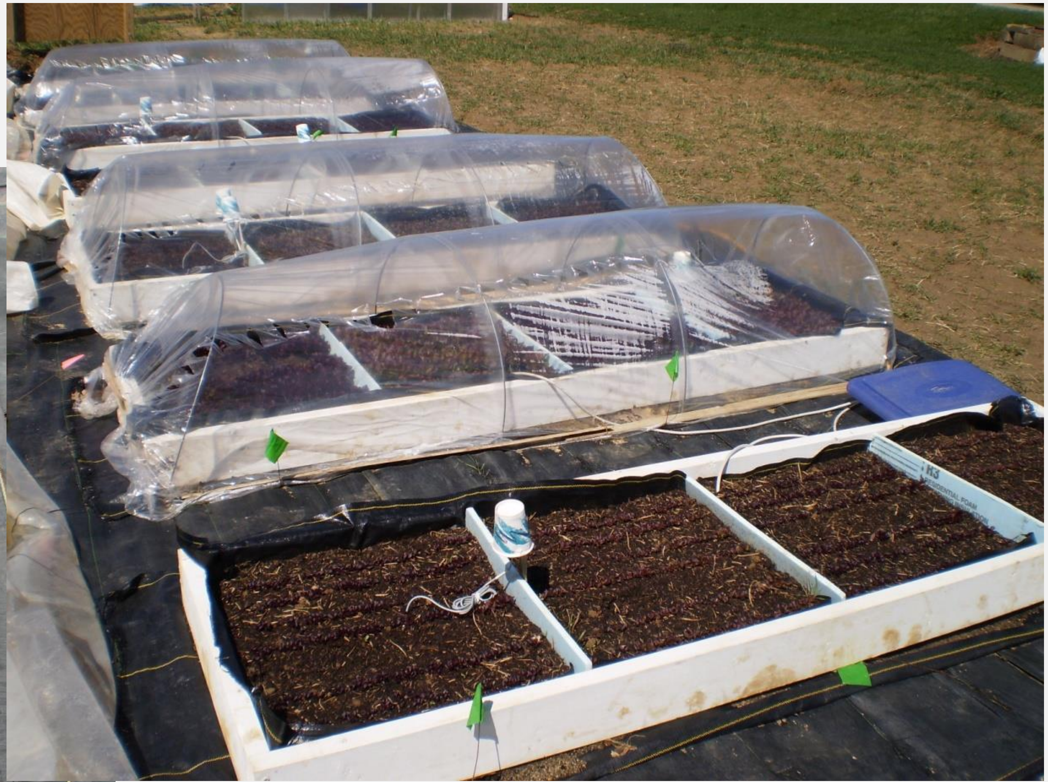
spring, fall

- **opposite trends in temperature, light**

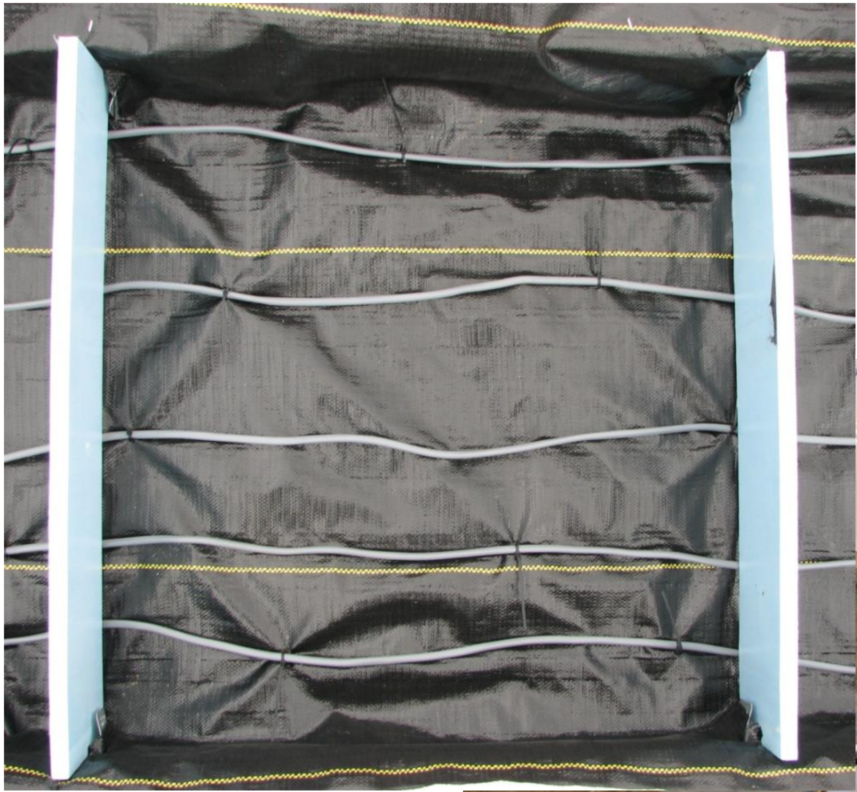

C. 2 settings:
field, high tunnel

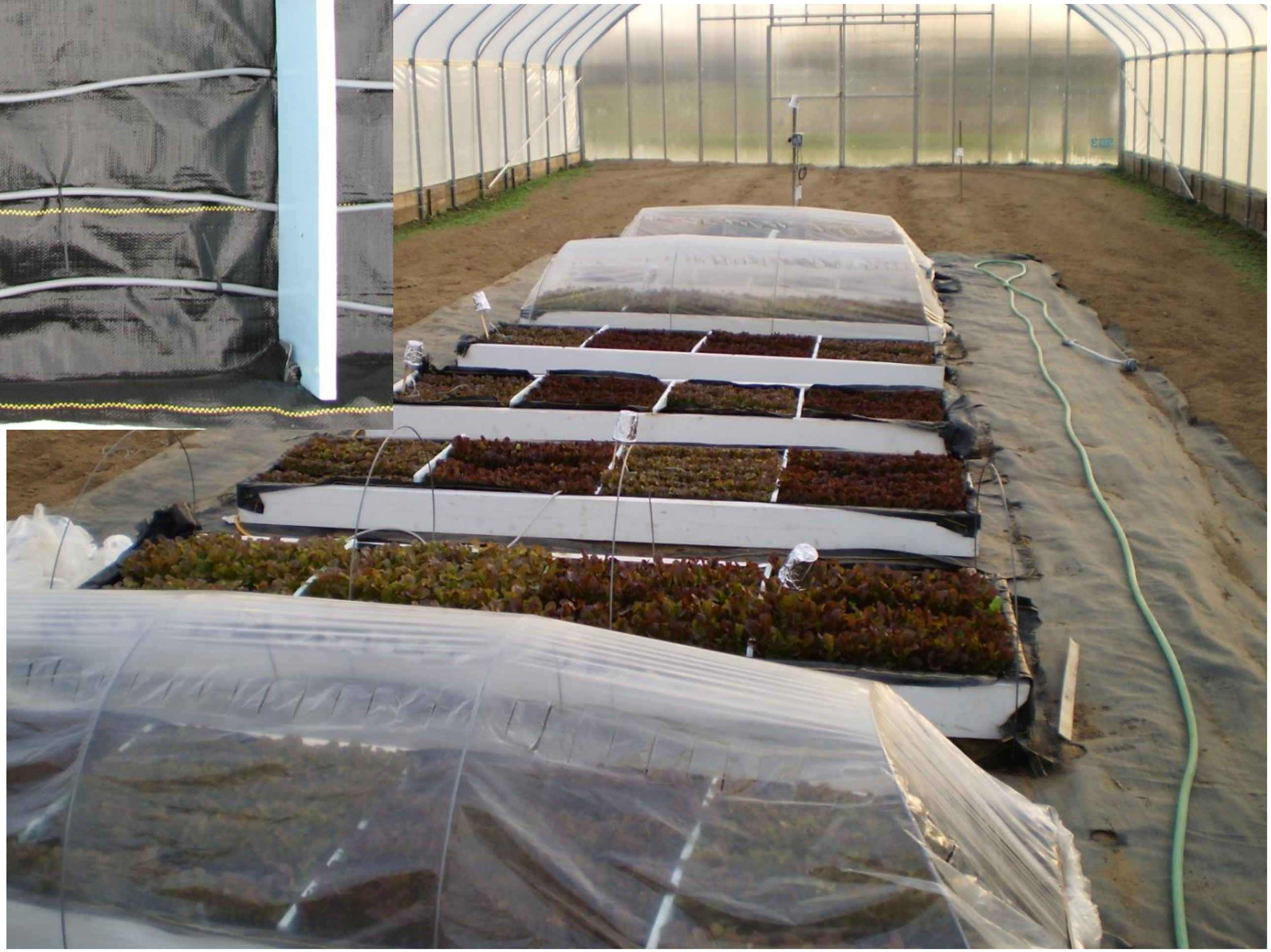
D. 4 Plot Heating Treatments

		AERIAL (passive)	
		-	+
SUBSURFACE (active)	-	none	shoot only
	+	root only	root-shoot



subsurface heating cable and slitted film (+/-) create 4 distinct microclimates

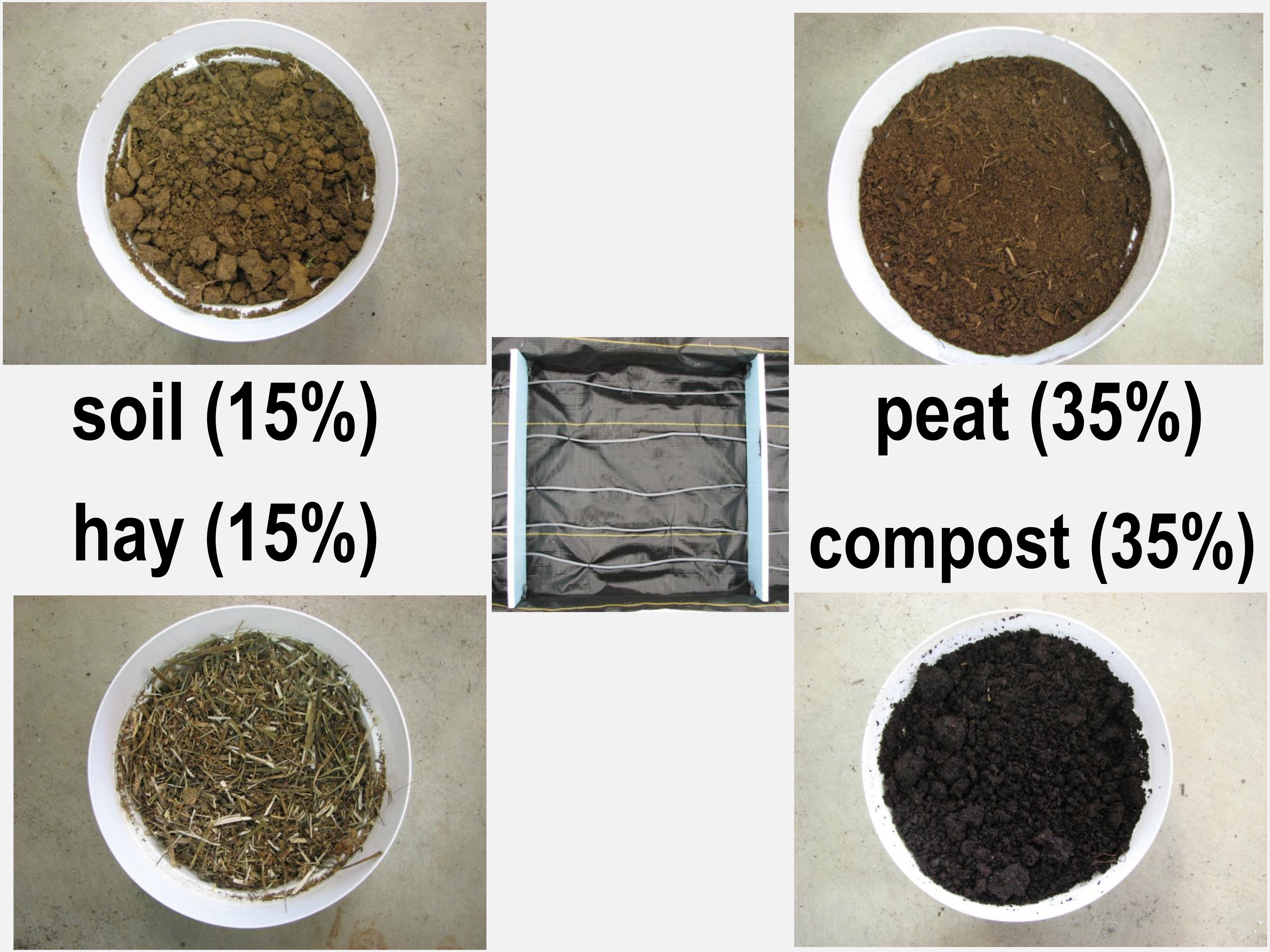




related studies completed on 4 farms

images courtesy Green Edge Gardens

with, without …
- subsurface heating
- aerial cover

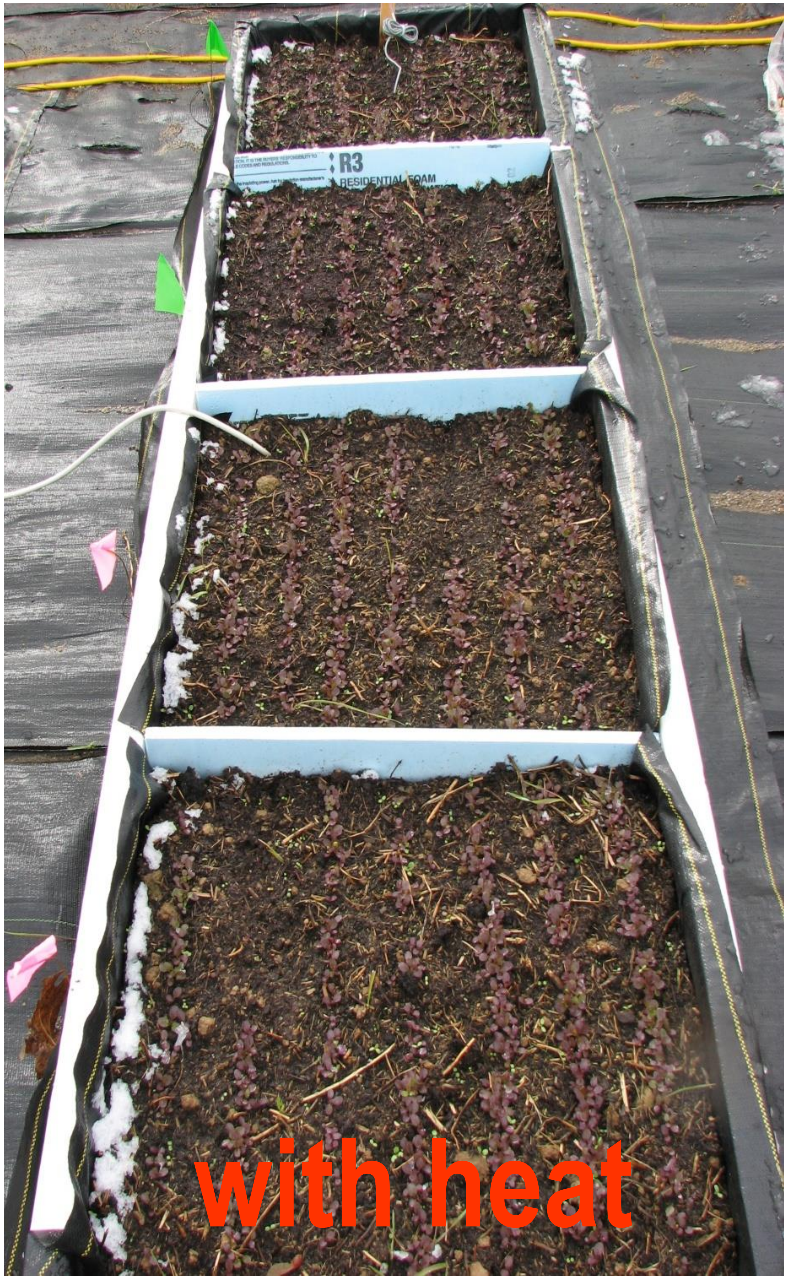

soil (15%)
hay (15%)
peat (35%)
compost (35%)

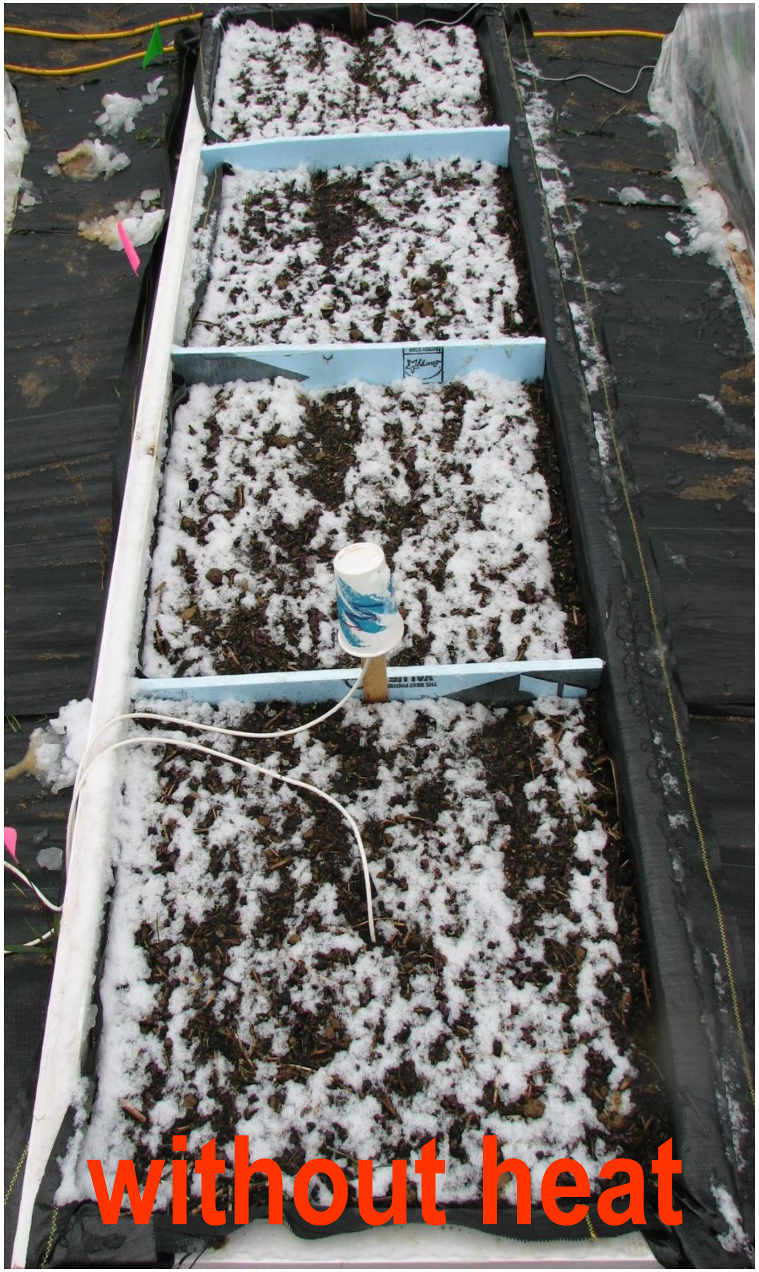

BECKMAN COULTER
DU 730
Life Science UV/Vis Spectrophotometer

shielded sensor and datalogger in each plot

temperature readings:

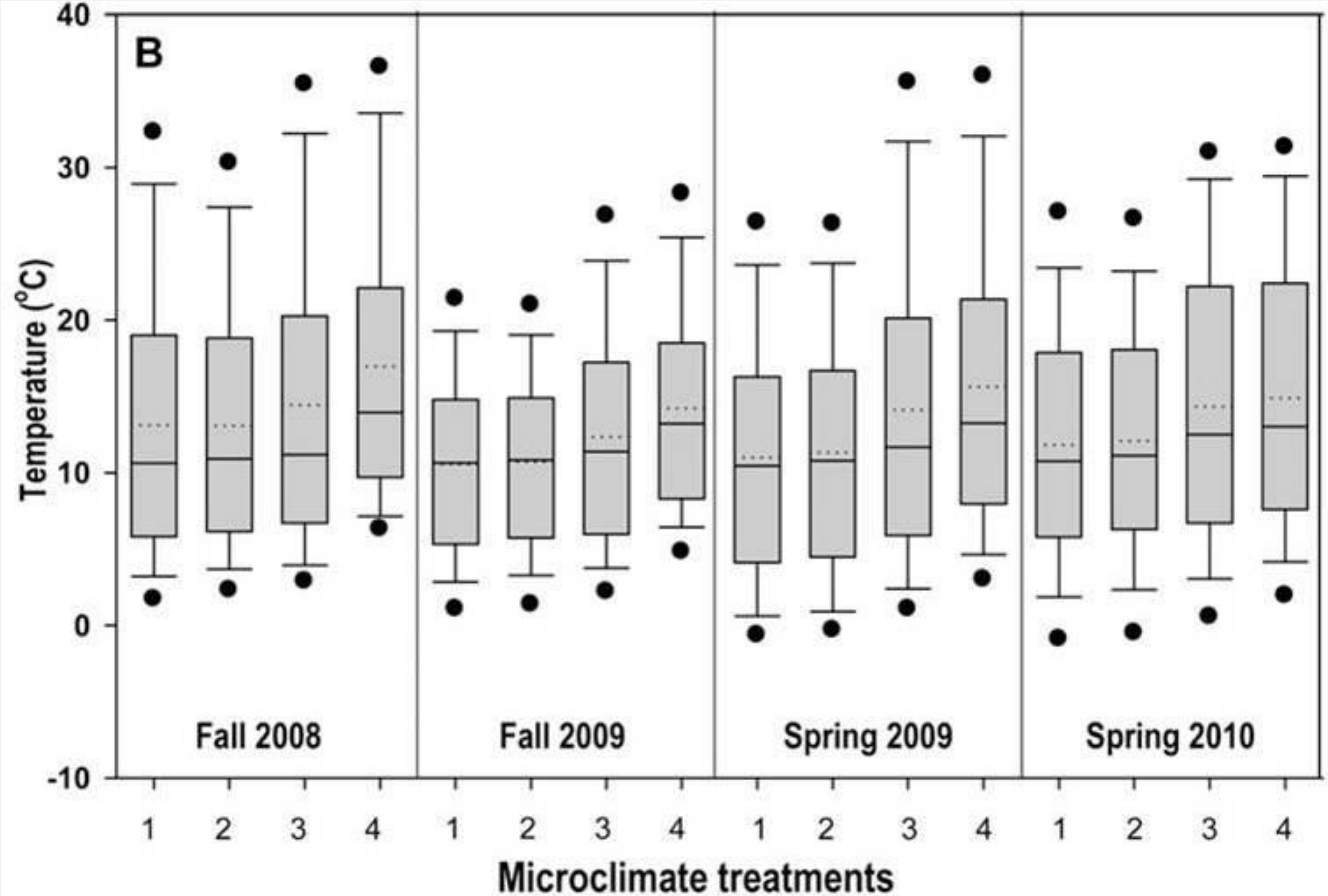
- 15- or 30-min intervals seeding-harvest
- 20 cm above, 4 cm below surface



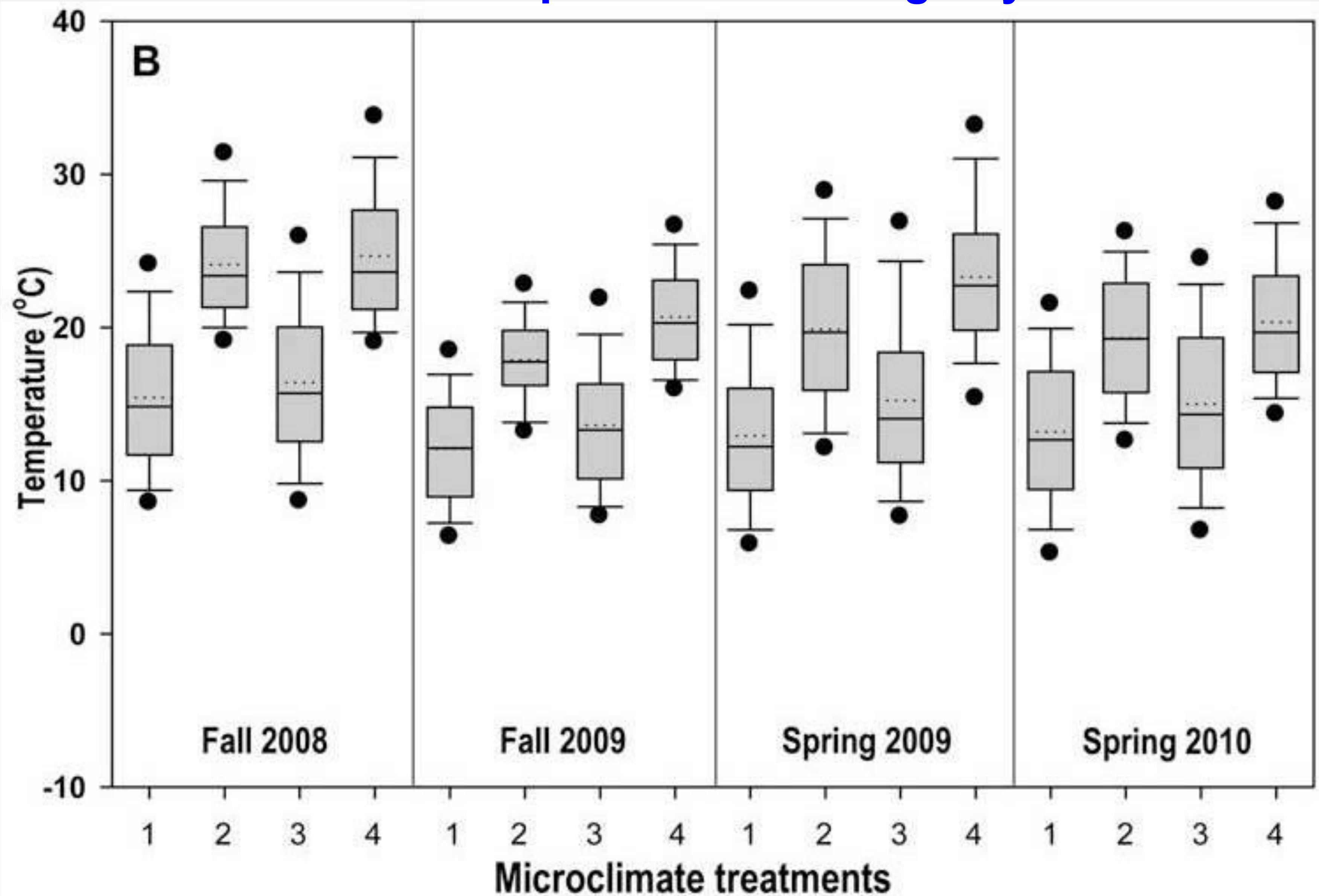


October 22, 2008

HT – Aerial Temperature Readings by Treatment



HT – Subsurface Temperature Readings by Treatment



Lettuce Yield by Experimental Microclimate

High Tunnel	yield (gram / ft^2)*
control	71.40 (1x)
heat below	95.93 (1.3x)
cover above	117.58 (1.6x)
heat + cover	136.98 (1.9x)

* average of Fall-08, Fall-09, Spring-09, Spring-10

Correlation: Yield by Average Temperature and GDD

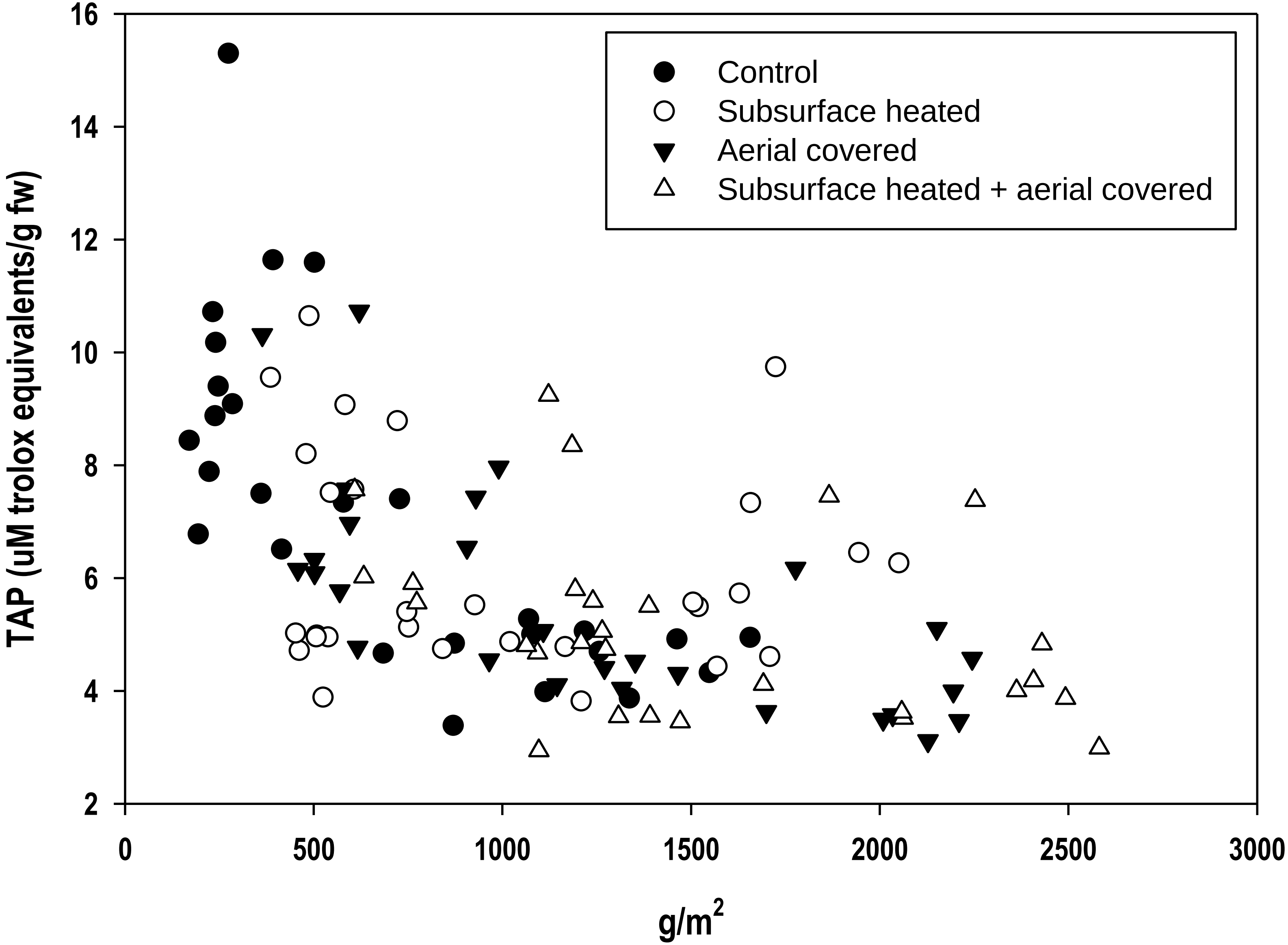
High Tunnel	r (probability value)
T above	0.60 (0.015)
T below	0.47 (0.068)
GDD above	0.68 (0.034)
GDD below	0.53 (0.033)
GDD total	0.64 (0.008)

grams lettuce harvested per aerial and subsurface GDD accumulated*

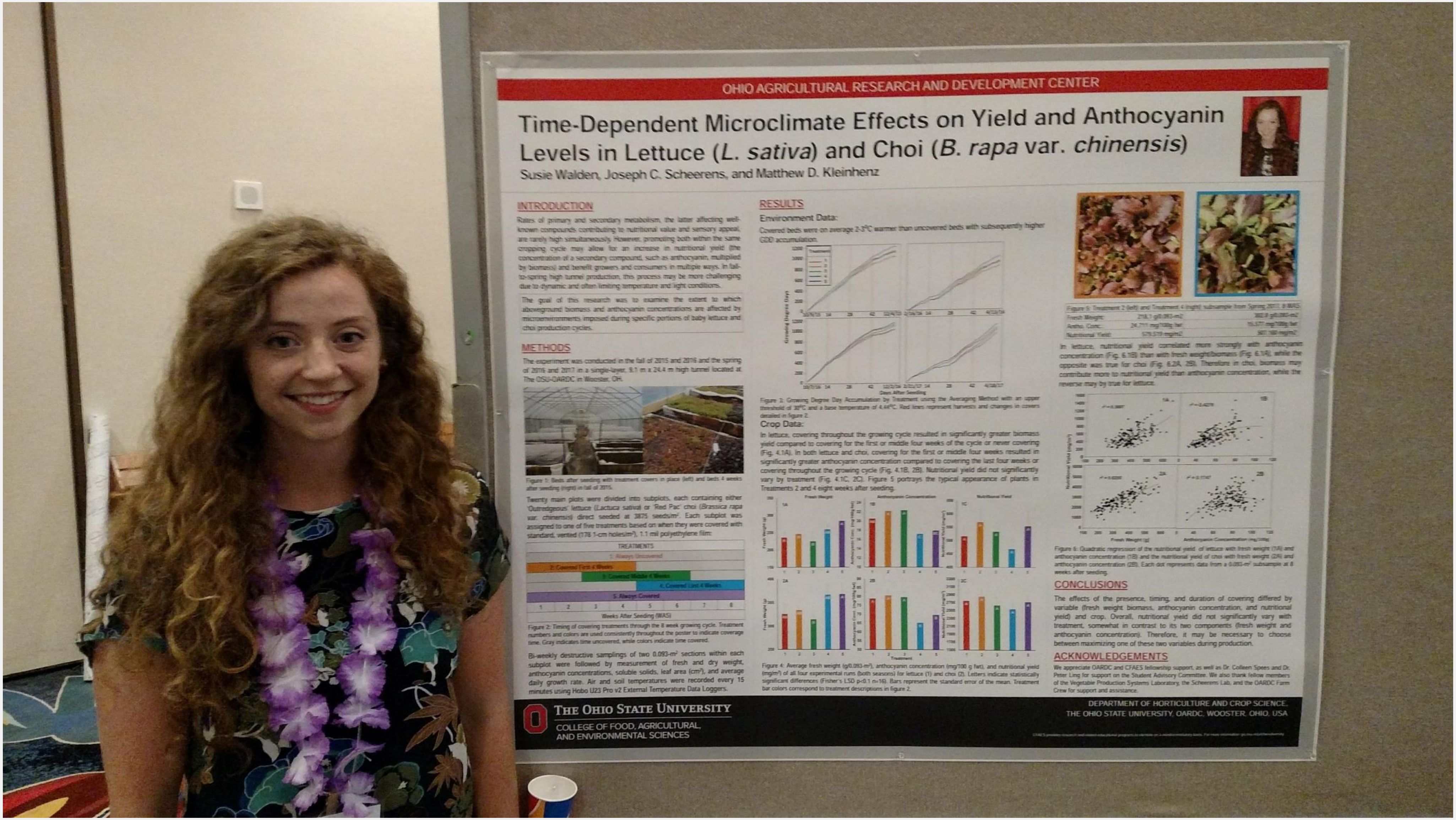
High Tunnel	above	below
control	0.34	0.26
heat below	0.46	0.20
cover above	0.42	0.37
heat + cover	0.43	0.26

* average of Fall-08, Fall-09, Spring-09, Spring-10

HT – Yield versus Antioxidant Potential

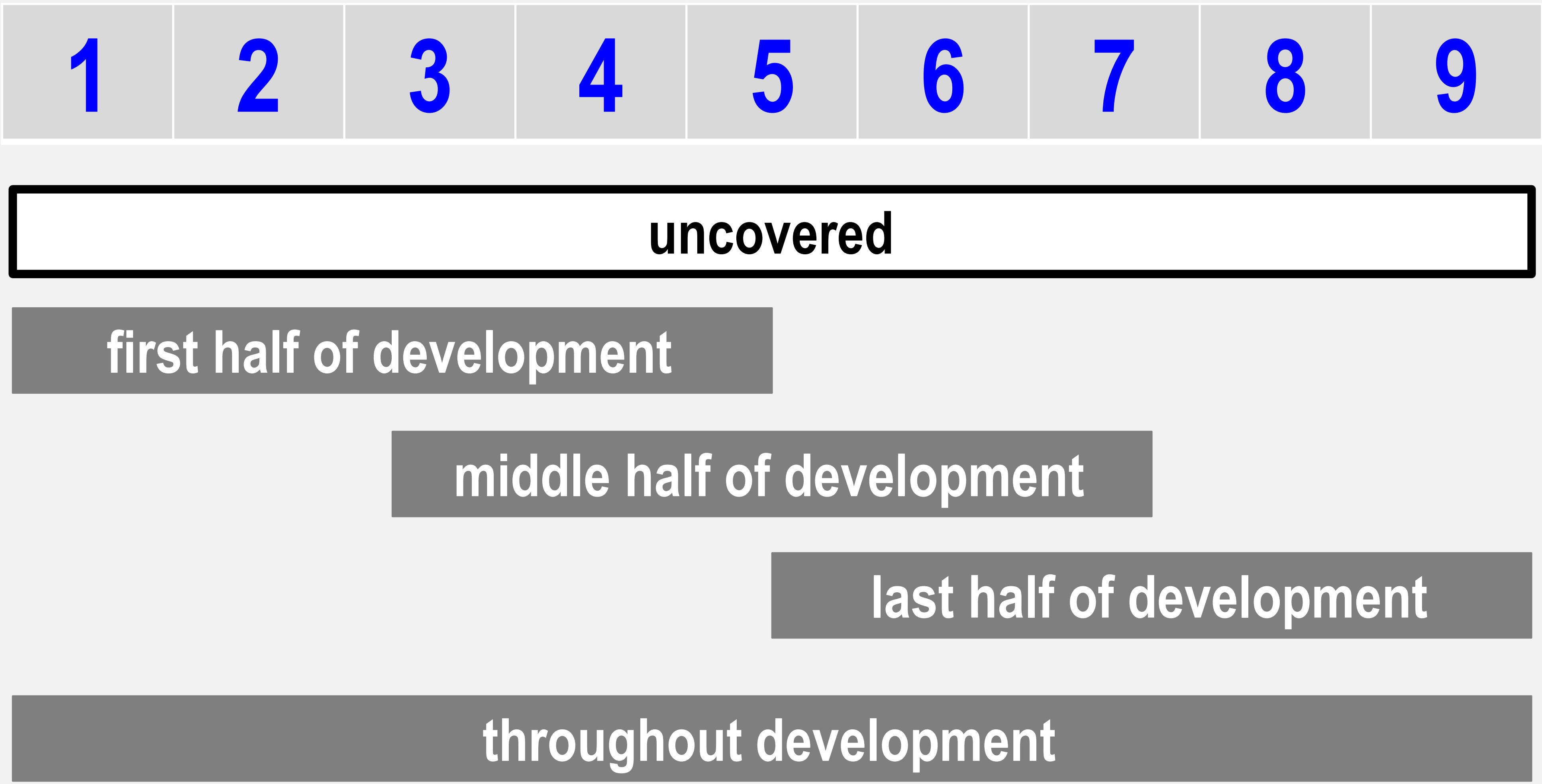


High tunnel Spring 09	Unheated + uncovered	Subsurface heated	Aerial covered	Subsurface heated + aerial covered
Yield (g/m²)	1162.5 a	1717.9 b	2093.6 b	2306.7 c
Anthocyanin mg/100g fw	14.8 ab	16.5 b	13.0 a	13.4 a



Susie Walden, M.S.

OSU-VPSL 2015-2017

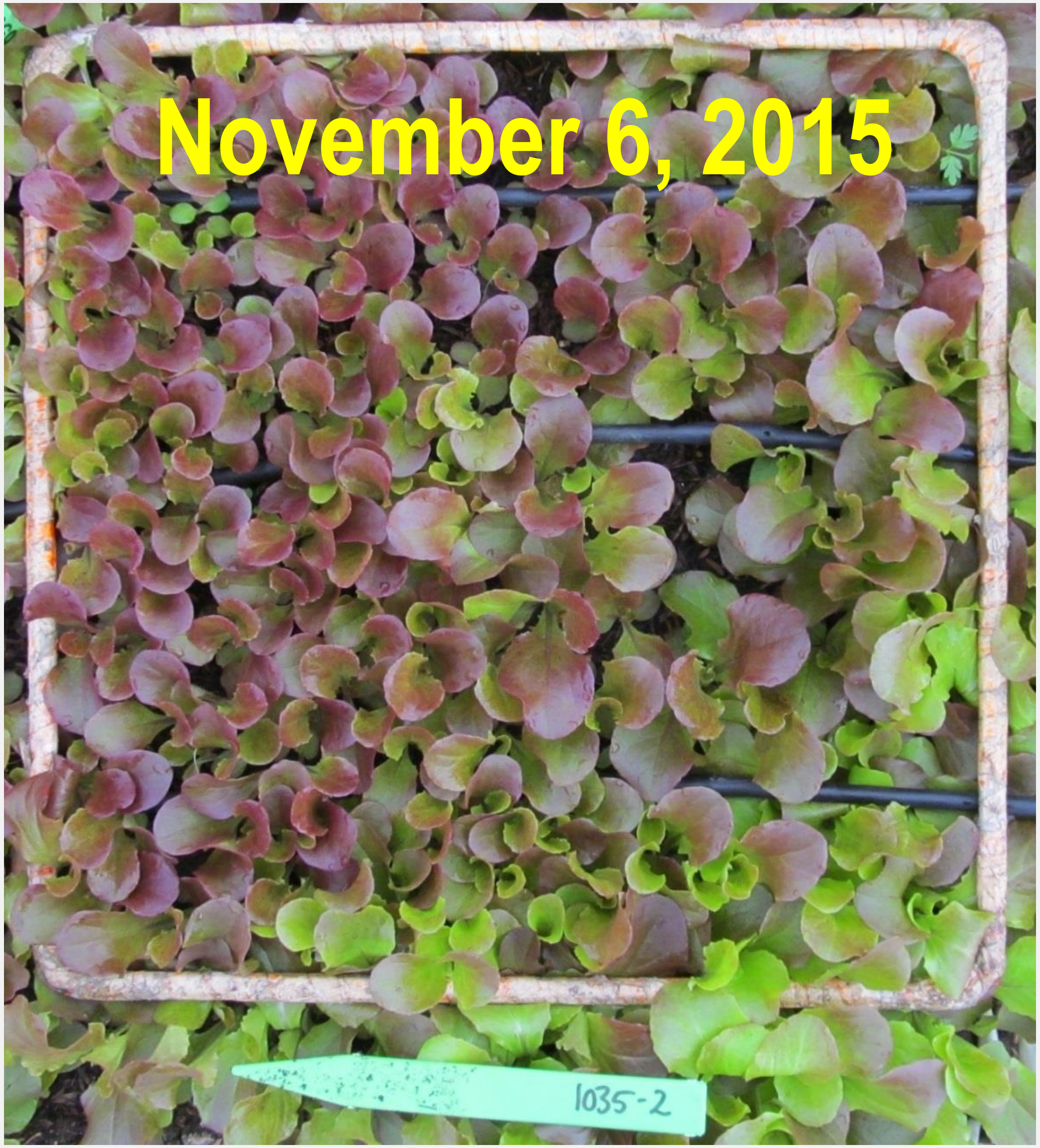


red lettuce and choi grown in a high tunnel with or without a low tunnel (vented) during portions of development over 9 weeks.

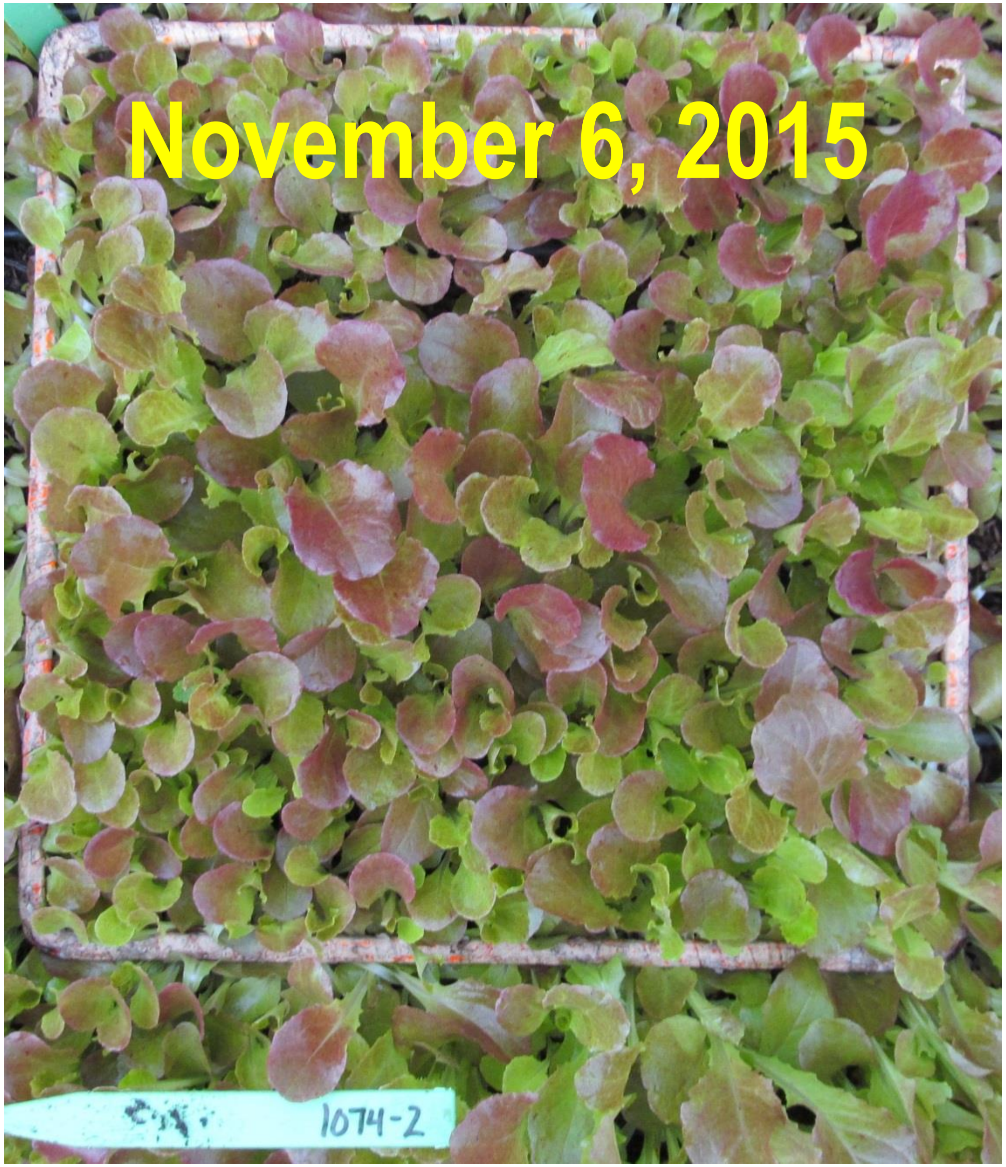
red lettuce and choi grown in a high tunnel with or without a low tunnel (vented) during portions of development over 9 wks.

Relative effects on crop yield and quality, including aspects of sensory appeal and nutritional value?


November 6, 2015



low tunnel	no	first half of development



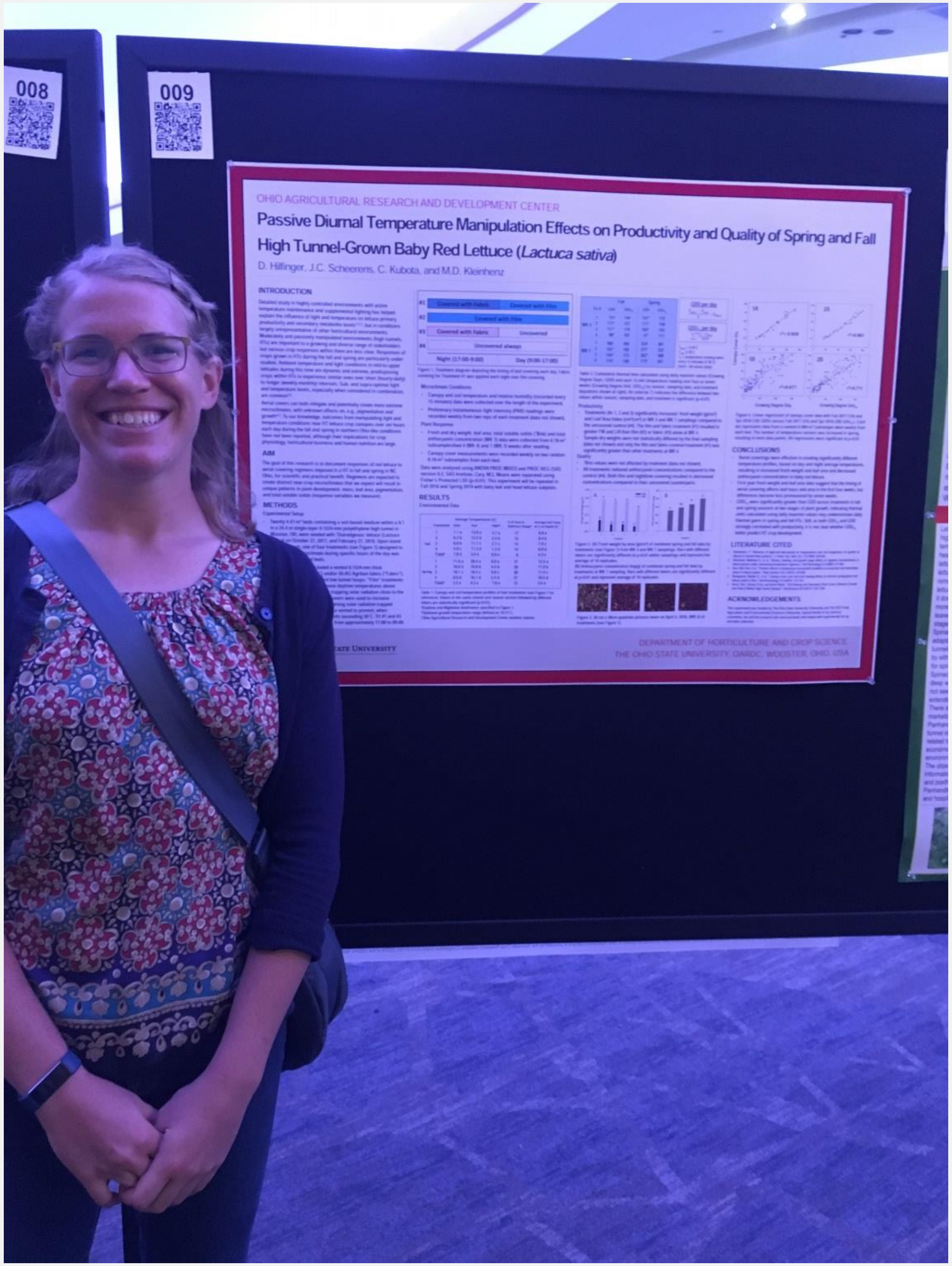
low tunnel	middle half of dev.	throughout development

low tunnel	no	first half of development

low tunnel	middle half of dev.	throughout development

Diurnal Temperature Differences: Do they Influence Lettuce Yield and/or Peoples' Opinions and Ratings of the Product?

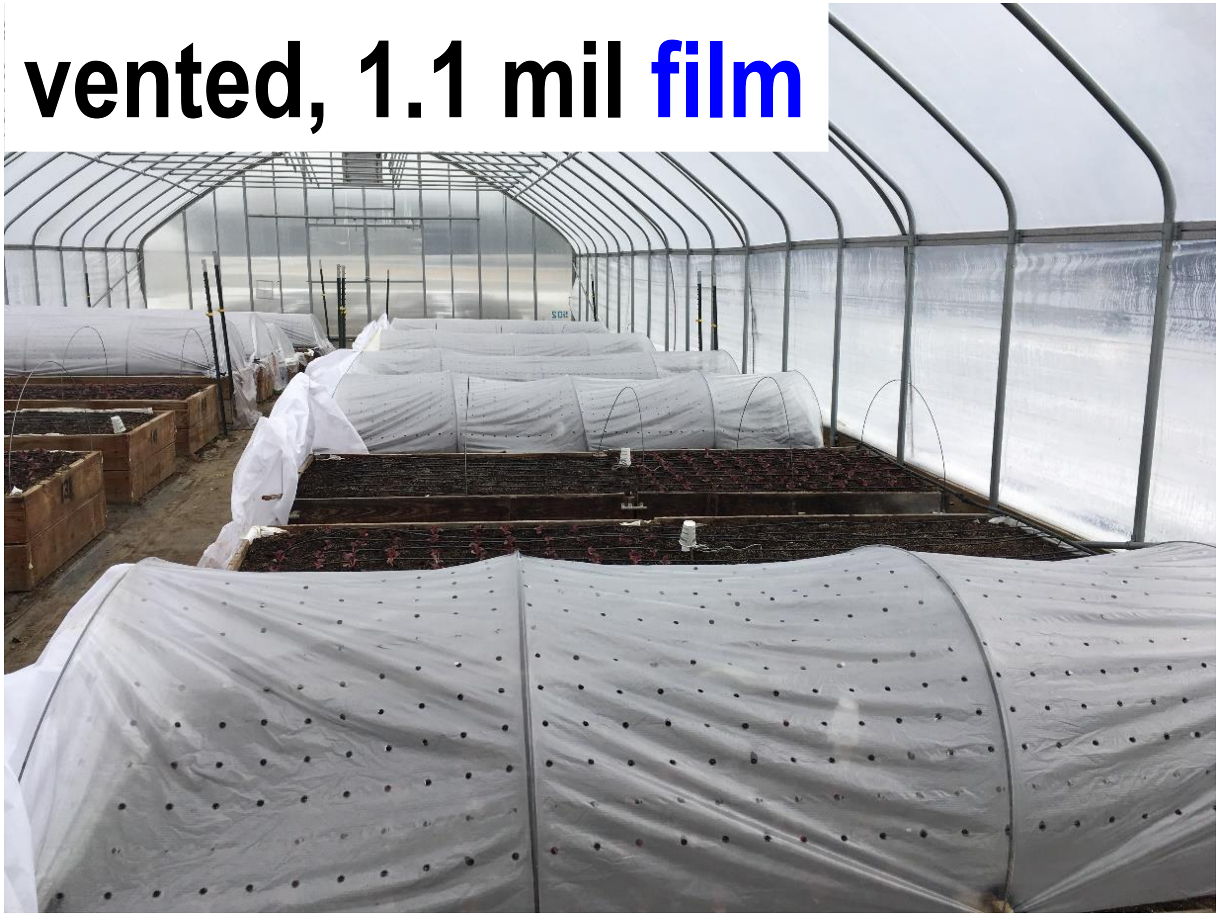
OSU-VPSL
2017-present



Dana Hilfinger
M.S. student and Program Coordinator, Initiative for Food and AgriCultural Transformation (InFACT)

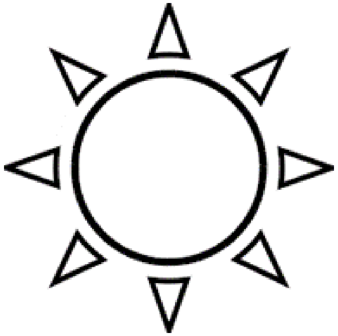
red lettuce grown seven weeks in a high tunnel each fall and spring was left uncovered or covered with film, fabric, or both on specific day- and nighttime schedule.

- crop yield and quality, including sensory appeal, color and antioxidant content?



Nov 12, 2017

For select plots, fabric installed around 4 pm each afternoon was removed by 10 am the next day every day for seven weeks.

period	material	- treatment -			
		1	2	3	4
	film	N	Y	N	Y
	fabric	N	N	N	N
	film	N	Y	N	Y
	fabric	N	N	Y	Y

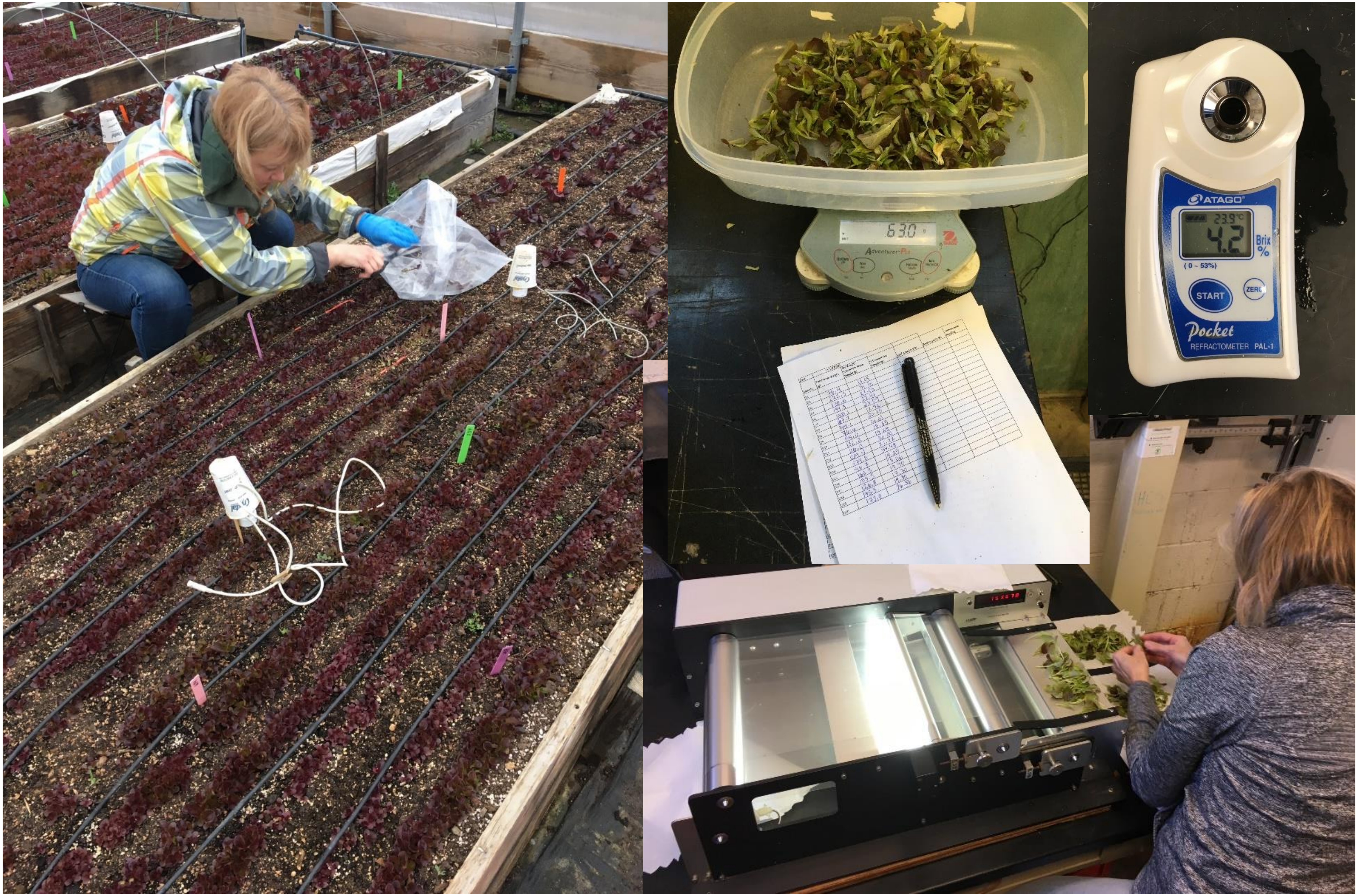
treatments initiated ~7 days after seeding and/or transplanting

Data:

1. round-the-clock temperature
2. weekly canopy cover ratings, pictures

Data:

3. sampling 4 and 7 weeks after start
   - fresh, dry wt
   - leaf area
   - °Brix
   - pigmentation


63.0 g
ATAGO
23.9°C
4.2
Brix %
(0 ~ 53%)
START
ZERO
Pocket
REFRACTOMETER PAL-1


VPLAB
VICTOR
VPSL

Data:

4. sensory evaluation

(untrained panelists)

- discrimination
- color (intensity, distribution)
- preference

Lettuce Visual Evaluation

Members of the Horticulture and Crop Science Department at OSU are engaged in research to improve the quality of red leaf lettuce. We would like you to assist us in our efforts by evaluating color differences among various lettuce samples. There are three parts to this test.

Part 1:

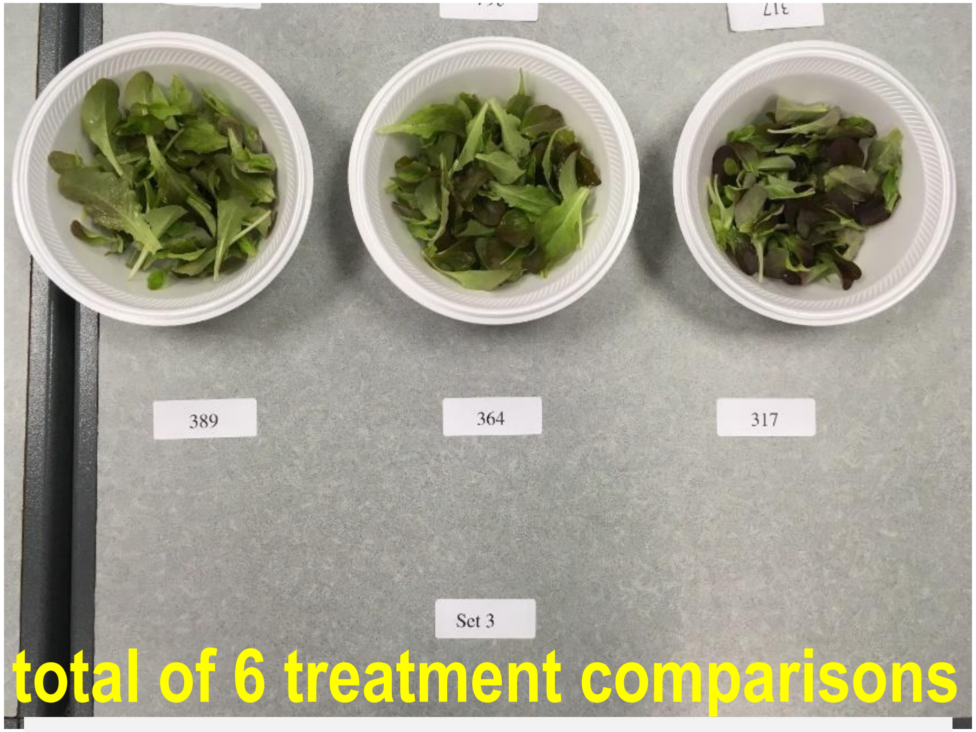
In this part of the test, you will be asked to evaluate six sets of lettuce samples (labeled **Sets 1-6**) arrayed on the tables in front of you. Each set is composed of three samples that have been coded with three-digit numbers. Two of the samples in each set are similar and the third is different. Please attempt to determine which samples is "different," and then indicate it by circling or marking its code number on the ballot for Part 1 below. As you evaluate each sample within the set, please consider differences based only on the color, intensity of color or distribution of color on the leaf. Ignore differences in leaf shape or size.

Set 1 Sample Codes		
134	176	102

Once you are finished with the first set of samples, please move to the next set (Set 2). Subsequently, after finishing your assessment of Set 2, move to Set 3 and so forth. Evaluate each successive set as you did the first set.

Set 2 Sample Codes		
242	291	272

Set 3 Sample Codes		
389	364	317



discrimination (‘triangle’) test asks panelists to identify which sample is “different” based ONLY on color, color intensity, and/or color distribution.

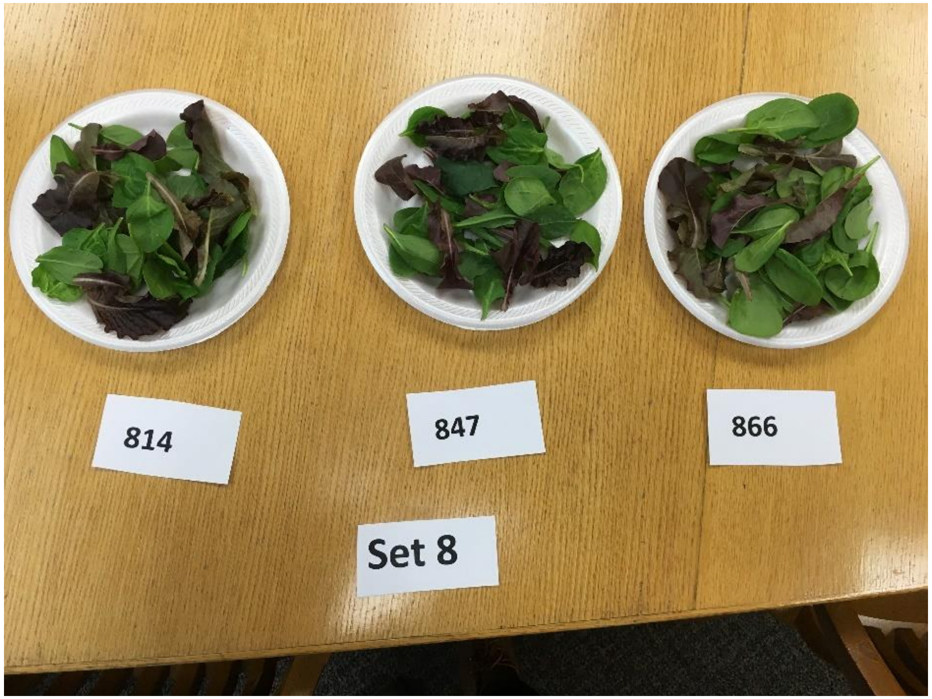
Part 4:

In this part of the test, you will be asked to evaluate one set of salad mixes containing lettuce samples (labeled Set 8) arrayed on one of the tables in front of you. This set is composed of four samples that have been coded with three-digit numbers. 814, 847, 866, 891

For Part 4, we would like you to indicate how much you like the complexity (the relative diversity in the components of the mixture), color vibrancy, shininess and overall appearance using the following tables. Indicate the statement that best fits how you feel about each of the samples for the characteristic in question by placing a ✓ or an ✗ in the corresponding box. It is acceptable to rate two or more samples similarly by using the same statement. However, you will need to indicate which statement best fits your viewpoint for each of the four samples.

Complexity	**814**	**847**	**866**	**891**
I **like** the complexity of this sample **extremely**				
I **like** the complexity of this sample **very much**				
I like the complexity of this sample **moderately**				
I like the complexity of this sample **slightly**				
I neither **like nor dislike** the complexity of this sample				
I **dislike** the complexity of this sample **slightly**				
I **dislike** the complexity of this sample **moderately**				
I **dislike** the complexity of this sample **very much**				
I **dislike** the complexity of this sample **extremely**				

Color vibrancy	**814**	**847**	**866**	**891**
I like the color of this sample **extremely**				
I **like** the color of this sample **very much**				
I like the color of this sample **moderately**				
I like the color of this sample **slightly**				
I neither **like nor dislike** the color of this sample				
I **dislike** the color of this sample **slightly**				
I **dislike** the color of this sample **moderately**				
I **dislike** the color of this sample **very much**				
I **dislike** the color of this sample **extremely**				



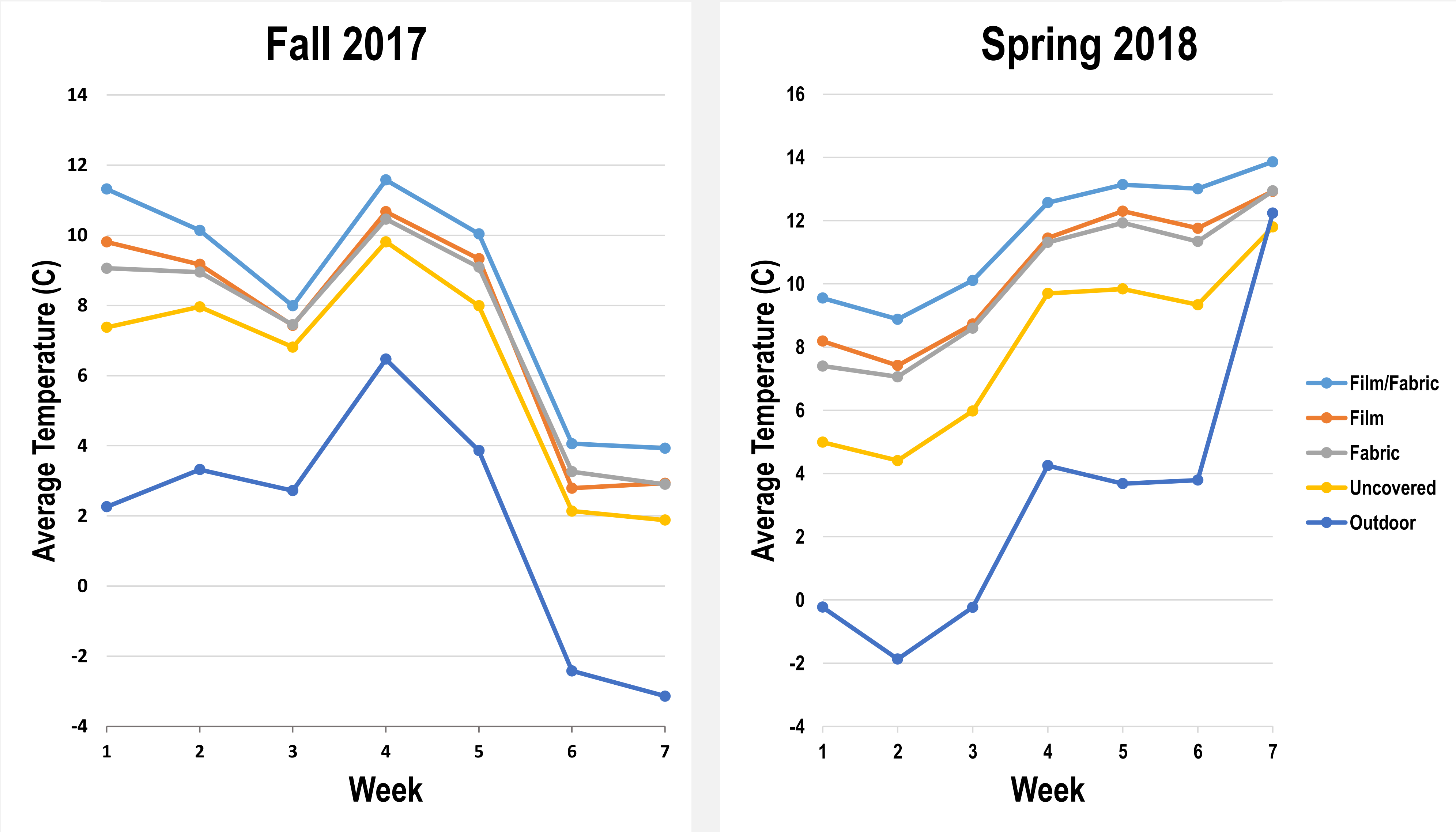
preference test asks panelists to indicate their level of liking of samples when included in a mix (spinach as common 'matrix'). Panelists asked to focus on complexity, color vibrancy.


Kottman Hall at OSU, Dec-2018

Diurnal Temperature Differences: Do they Influence Lettuce Yield and/or Peoples' Opinions and Ratings of the Product?

Selected Results to Date

Treatment Temperature Profiles



DLI and GDU plots/data

none -- **D** -- none

none -- **N** -- fabric

seeded: 10/27/17

pics taken: 12/6/17

$p = 0.0077$

film ----- **D** -- film

fabric -- **N** -- film

none -- D -- none
none -- N -- fabric

seeded: 2/20/18
pics taken: 4/9/18

NS, $p = 0.43$

film ----- D -- film
fabric -- N -- film

none -- **D** -- none

none -- **N** -- fabric

seeded: 10/16/18

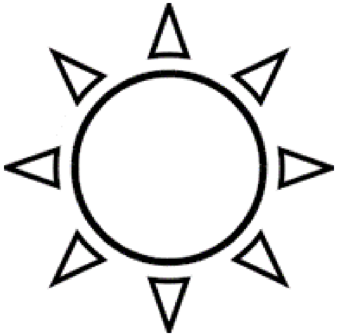
pics taken: 12/9/18

$p = 0.0014$

film ----- **D** -- film

fabric -- **N** -- film

treatment	Fall-2017		SPR-2018		Fall-2018	
	Leaf area index (cm2/cm2)	˚Brix	Leaf area index (cm2/cm2)	˚Brix	Leaf area index (cm2/cm2)	˚Brix
1 – no cover	2.04c	4.53	6.19	3.76	1.42b	4.56
2 - film (D/N)	2.83b	4.82	8.42	3.46	1.64b	4.77
3 - fabric (N)	3.09ab	4.89	7.60	3.76	2.73a	4.30
4 - film (D)/fabric (N)	3.79ab	3.89	7.95	3.40	3.37a	3.46
Significance	** p=0.0016	NS p=0.14	NS p=0.358	NS p=0.63	*** p=0.0005	NS p=0.058

period	material	- treatment -			
		1	2	3	4
	film	N	Y	N	Y
	fabric	N	N	N	N
	film	N	Y	N	Y
	fabric	N	N	Y	Y

treatments initiated ~7 days after seeding and/or transplanting

Panelist Evaluations

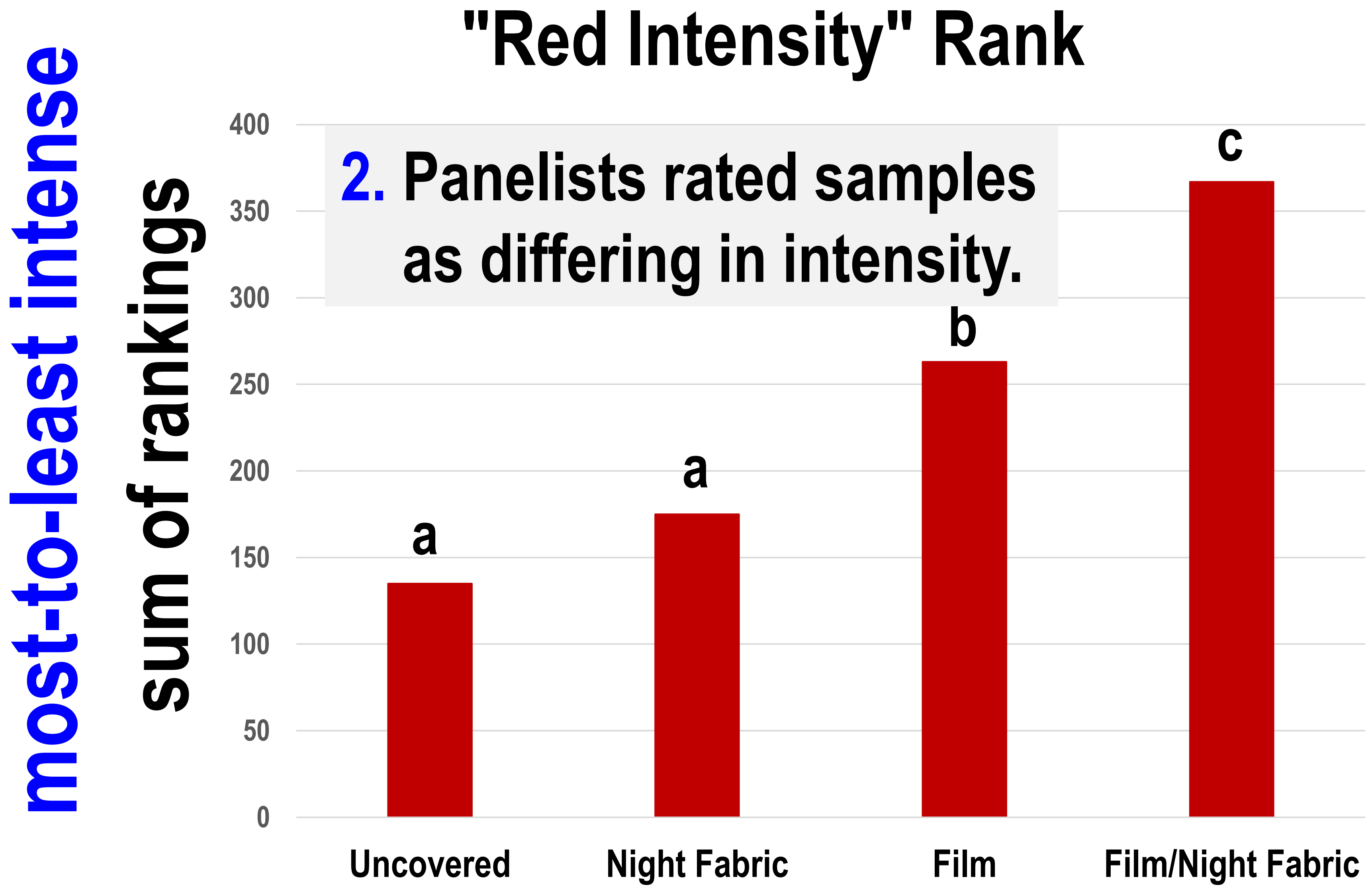
1. Panelists correctly identified 'different' sample in 4 of 6 treatment comparisons.

Did not discriminate samples taken from:

film vs. uncovered (T2 vs. T1)

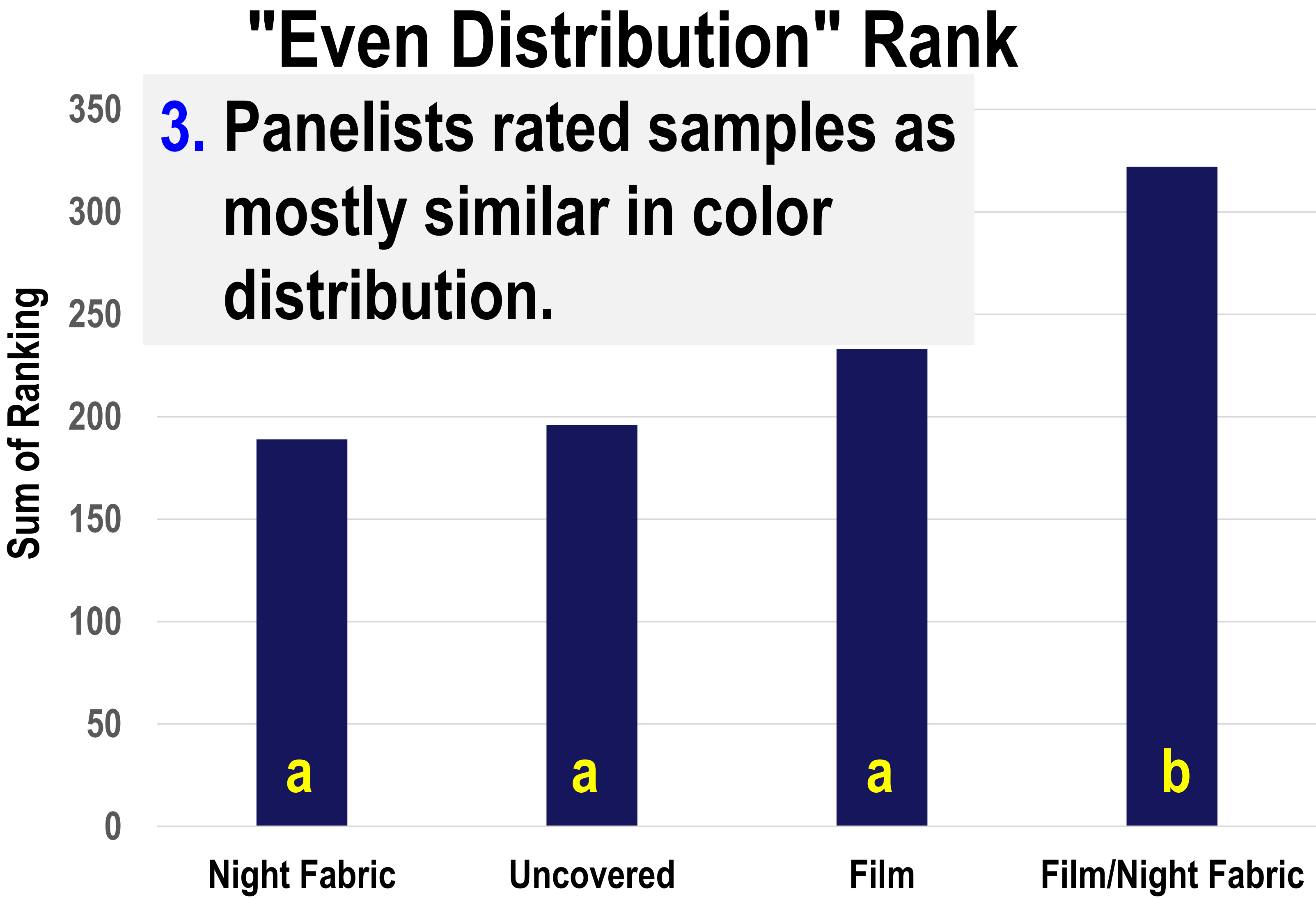
film vs. film/fabric (T2 vs. T4)

Panelist Evaluations



Panelist Evaluations

most-to-least even



3. Panelists rated samples as mostly similar in color distribution.

Panelist Evaluations

4. Panelists indicated a similar liking for all samples when included in a mesclun-like mix (spinach base).

	film	uncovered	film/fabric (N)	fabric (N)
Overall appearance	814	847	866	891
I like the appearance of this sample extremely				
I like the appearance of this sample very much				
I like the appearance of this sample moderately				★
I like the appearance of this sample slightly	★	★	★	
I neither like nor dislike the appearance of this sample				
I dislike the appearance of this sample slightly				
I dislike the appearance of this sample moderately				
I dislike the appearance of this sample very much				
I dislike the appearance of this sample extremely				

Sonia Walker, B.S.

OSU-VPSL
2003-present

1	mid-tunnel*	
2		+ low tunnel with fabric
3		+ low tunnel with vented film

* No mid-tunnels used in Sept 2016 transplanting

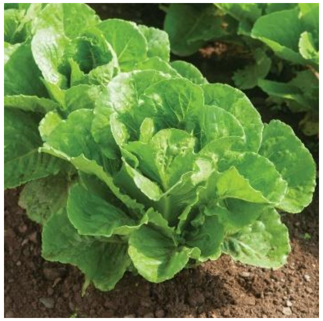
Relative effects on crop yield and quality, including aspects of sensory appeal and nutritional value?

Transplanting Dates:

Fall … 10/30/15, 9/21/16, 12/7/16 (plants froze out)

Spring … 2/23/16, 2/21/17

2 varieties of romaine lettuce transplanted into six 4'x30'x12" raised beds



Picture Courtesy of Johnny's Selected Seeds

'Parris Island' 'Outredgeous'

Picture Courtesy of Territorial Seed Co.

April 19, 2017

2 seasons

Spring

Feb. 2016
Feb. 2017

Fall

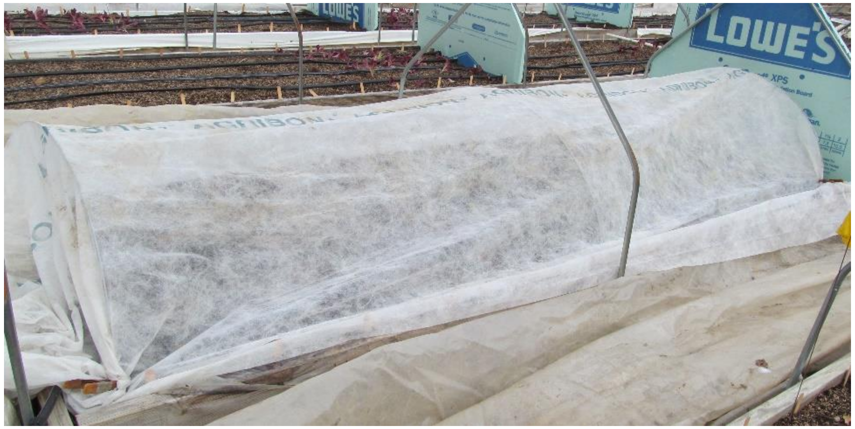
Oct. 2015
Sept. 2016
Dec. 2016 (plants froze)

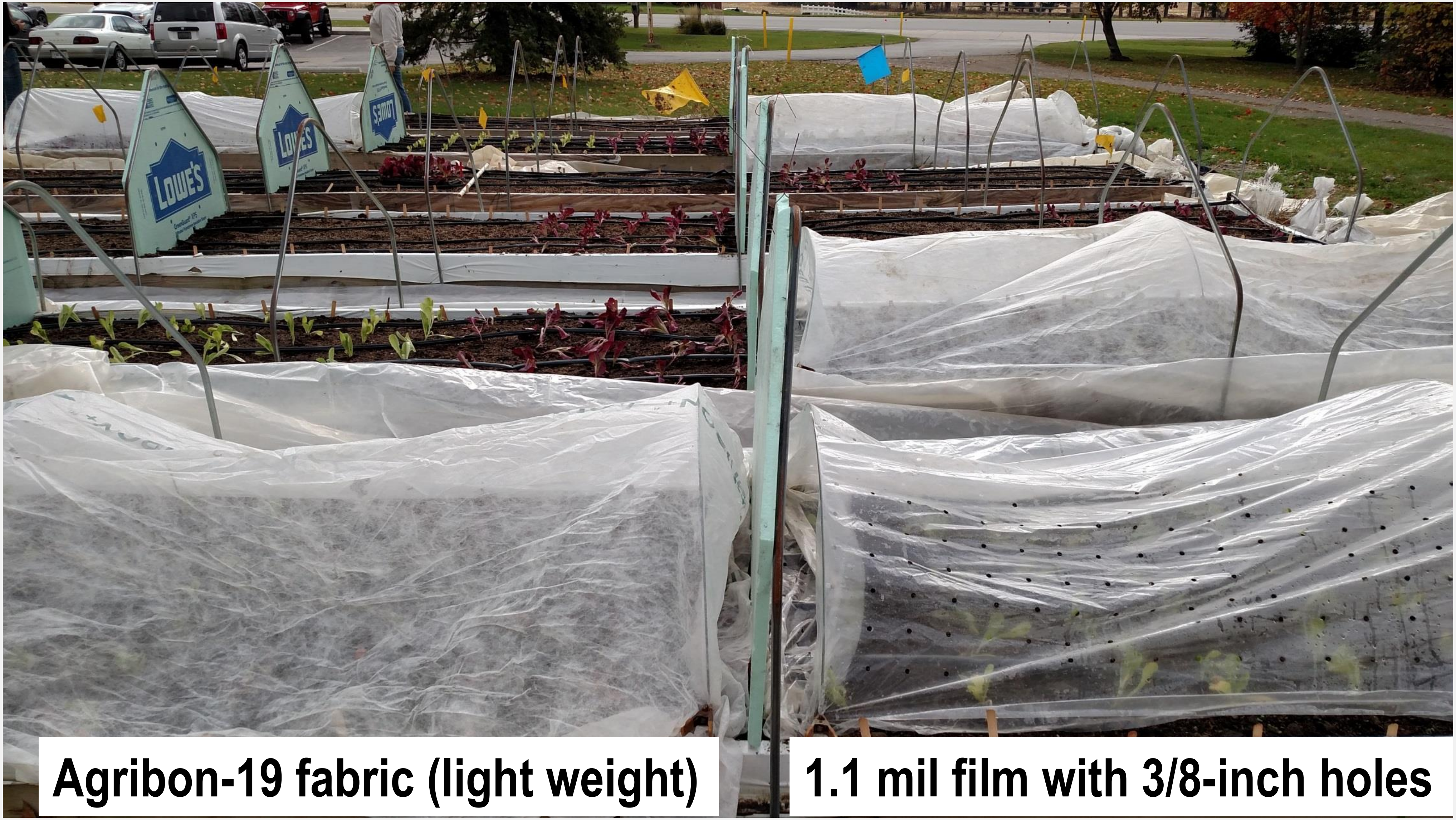
3 diurnal temperature profiles

no covering

low tunnel with perforated film

low tunnel with lightweight floating row cover (Agribon-19)





October 30, 2015

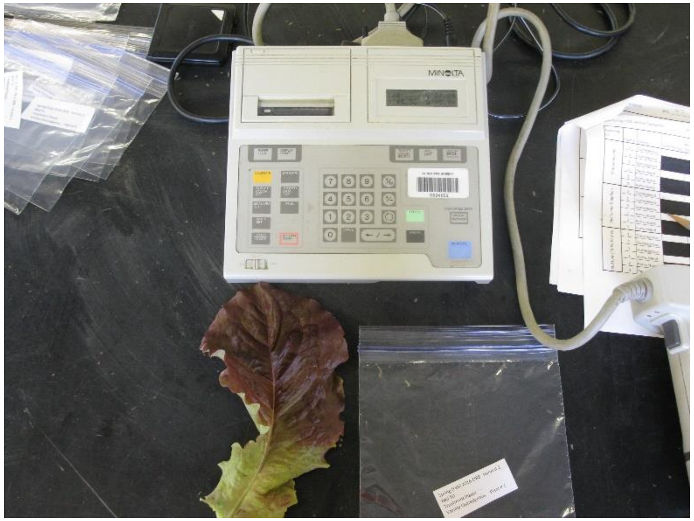
Beds covered with mid tunnels of 6-mil film in 4 of 5 plantings

Insulated dividers placed between temperature profiles

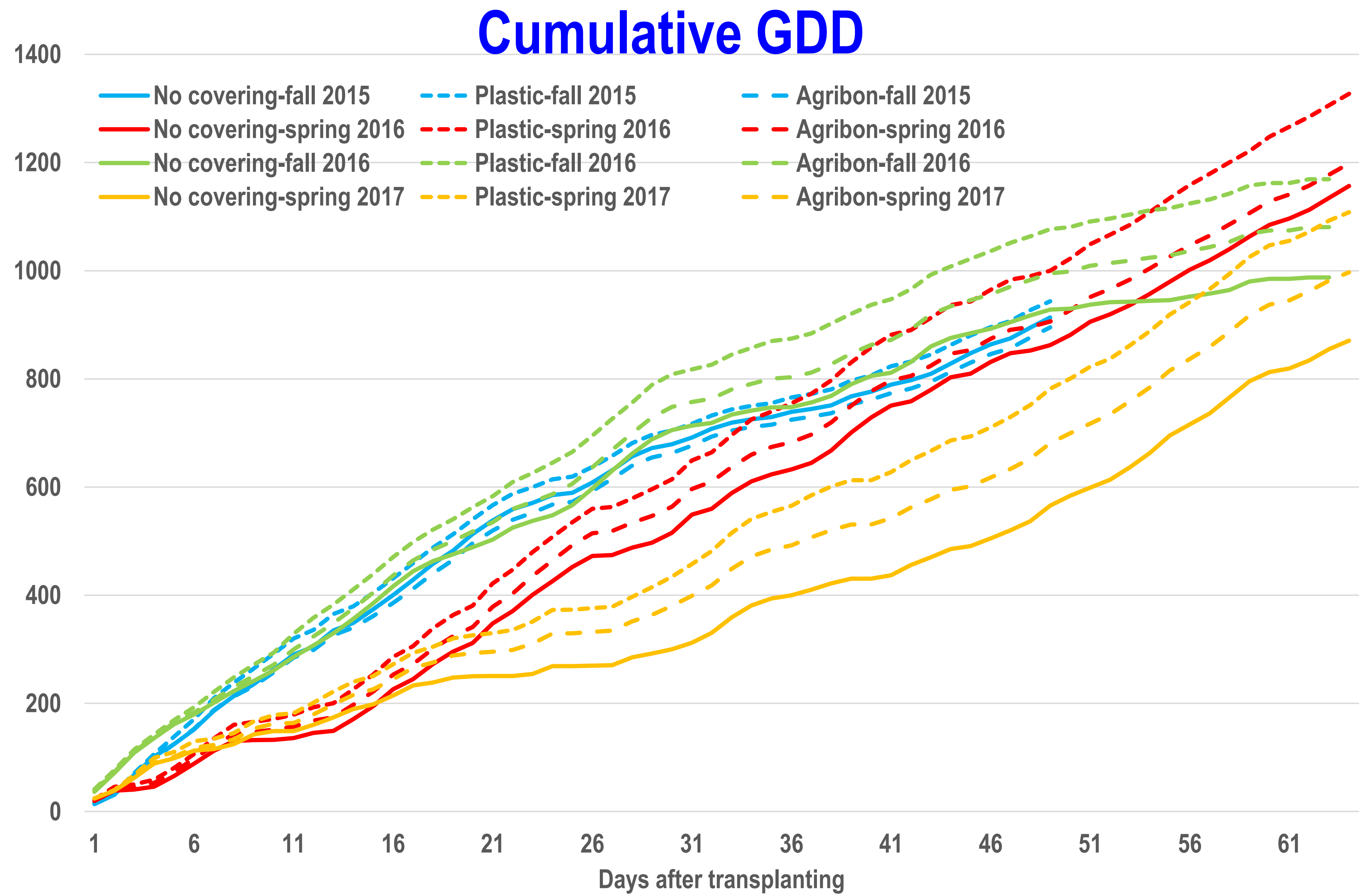
Temperatures recorded at 15 minute intervals under each temperature profile

Harvested and evaluated 1-2X for each planting

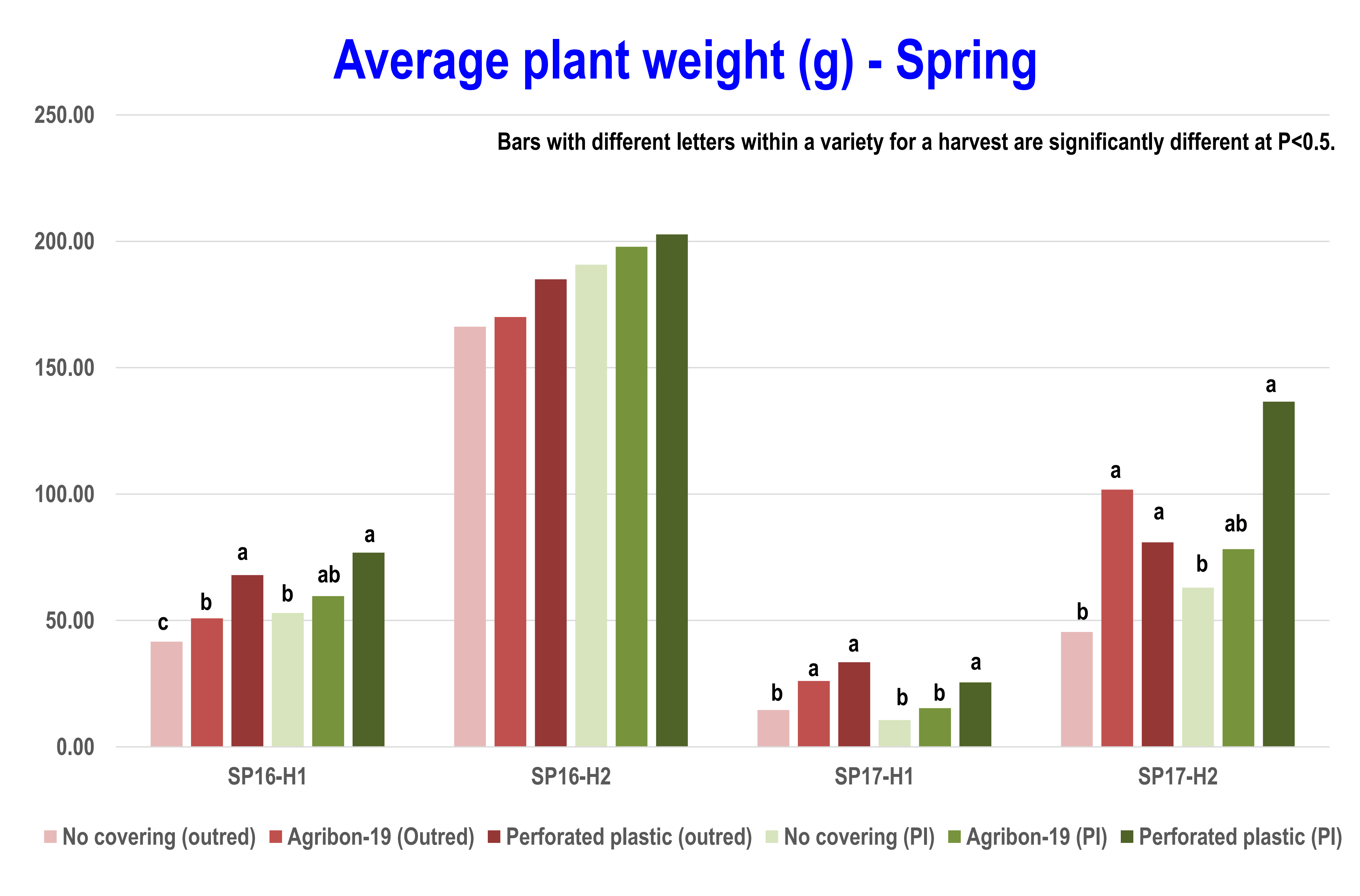
44-48 days & 62-63 days after transplanting



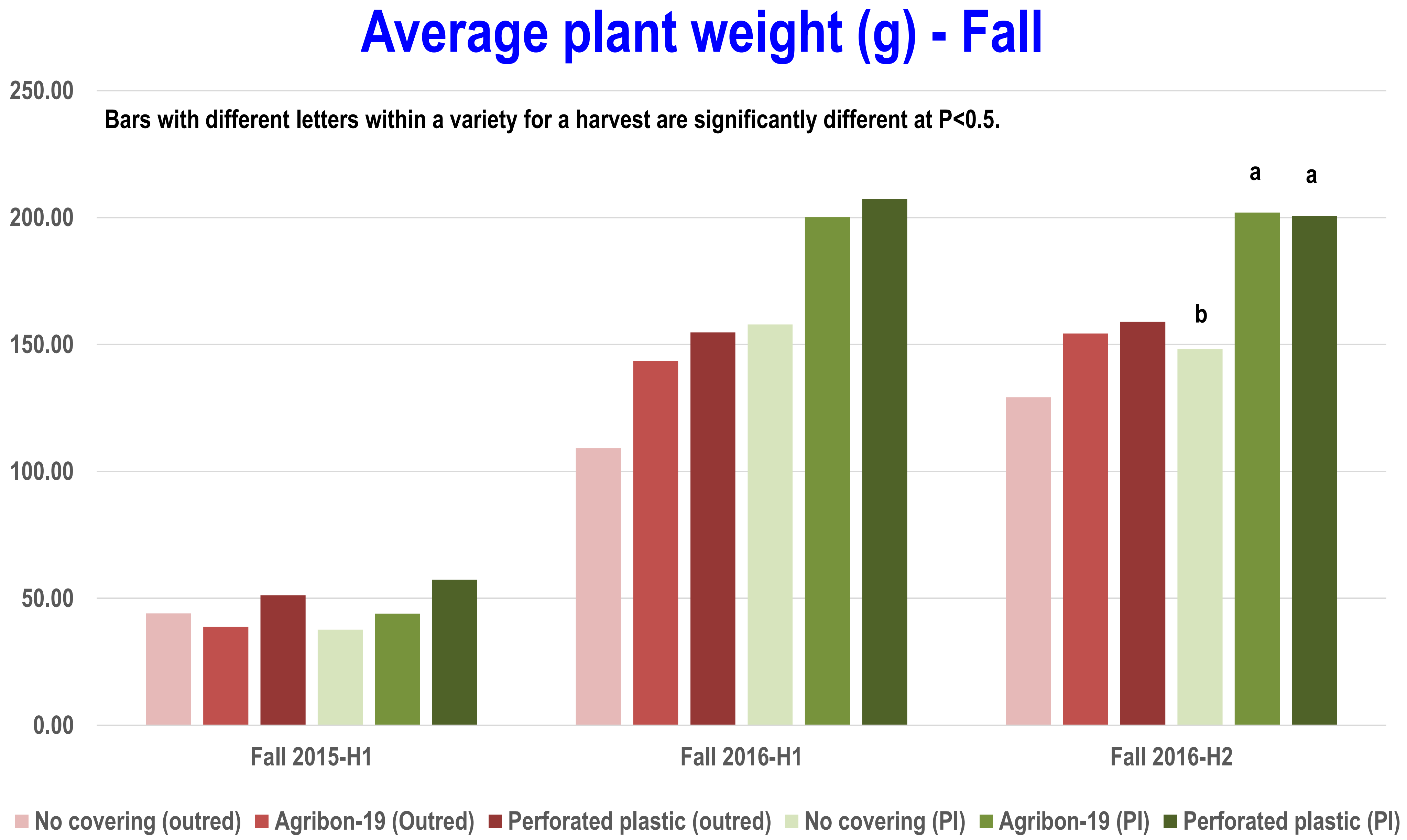

Harvest on Dec 17, 2015.



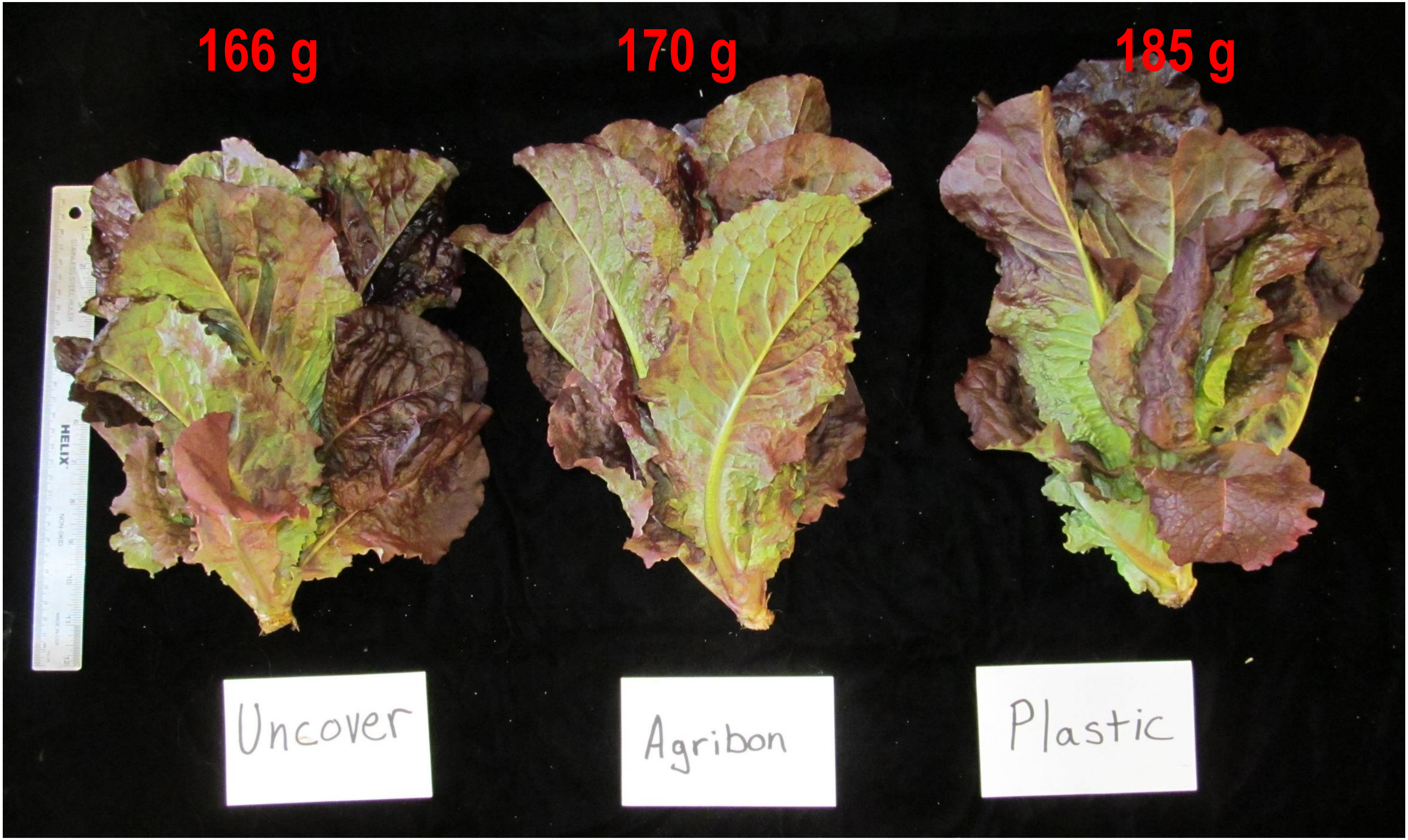
Cumulative GDD
1400
1200
1000
800
600
400
200
0
No covering-fall 2015
Plastic-fall 2015
Agribon-fall 2015
No covering-spring 2016
Plastic-spring 2016
Agribon-spring 2016
No covering-fall 2016
Plastic-fall 2016
Agribon-fall 2016
No covering-spring 2017
Plastic-spring 2017
Agribon-spring 2017
1
6
11
16
21
26
31
36
41
46
51
56
61
Days after transplanting



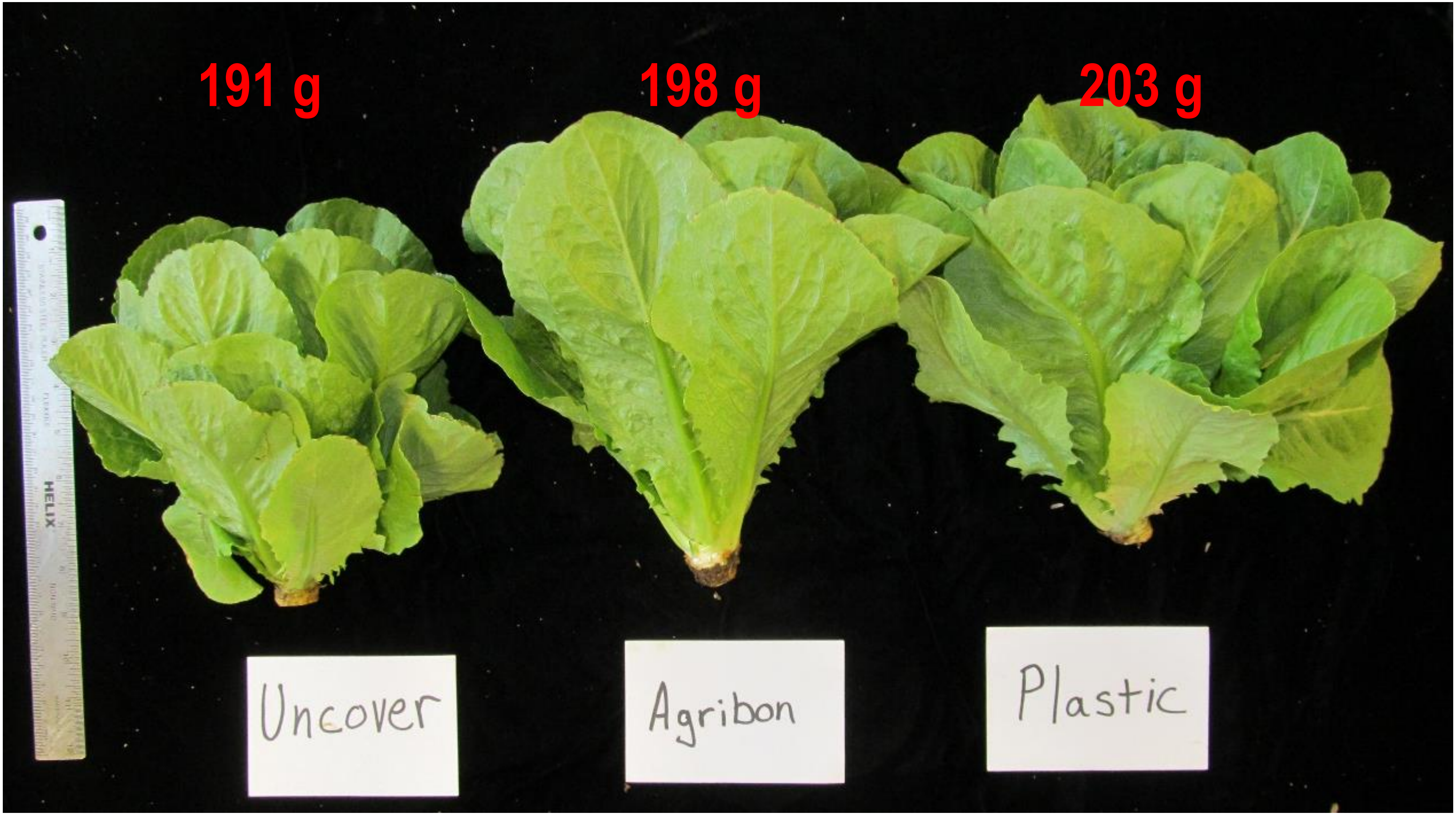
Average plant weight (g) - Spring
Bars with different letters within a variety for a harvest are significantly different at P<0.5.
250.00
200.00
150.00
100.00
50.00
0.00
c
b
a
b
ab
a
b
a
a
b
b
a
b
a
a
b
ab
a
SP16-H1
SP16-H2
SP17-H1
SP17-H2
No covering (outred)
Agribon-19 (Outred)
Perforated plastic (outred)
No covering (PI)
Agribon-19 (PI)
Perforated plastic (PI)



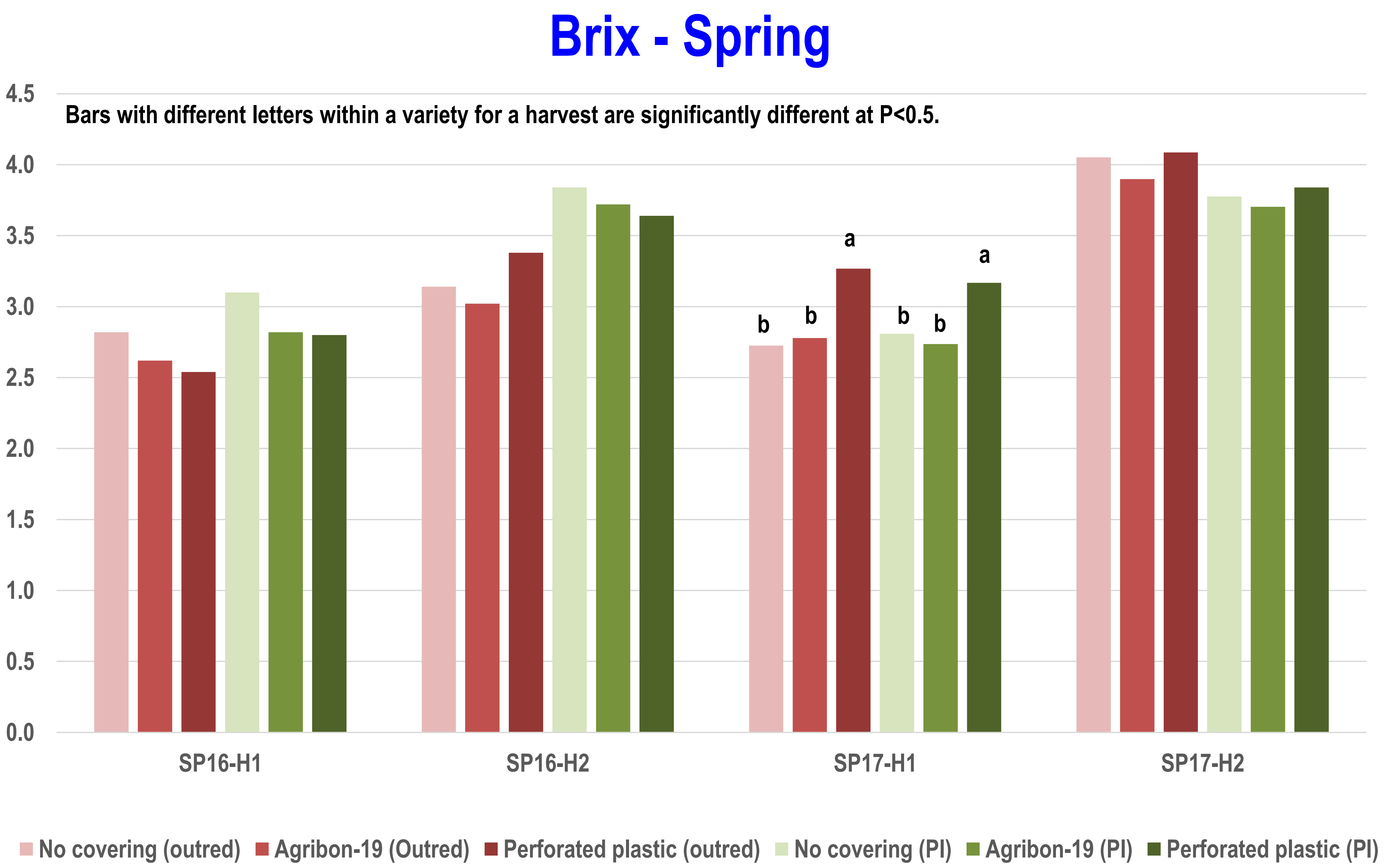
Average plant weight (g) - Fall
Bars with different letters within a variety for a harvest are significantly different at P<0.5.
250.00
200.00
150.00
100.00
50.00
0.00
a
a
b
Fall 2015-H1
Fall 2016-H1
Fall 2016-H2
No covering (outred)
Agribon-19 (Outred)
Perforated plastic (outred)
No covering (PI)
Agribon-19 (PI)
Perforated plastic (PI)

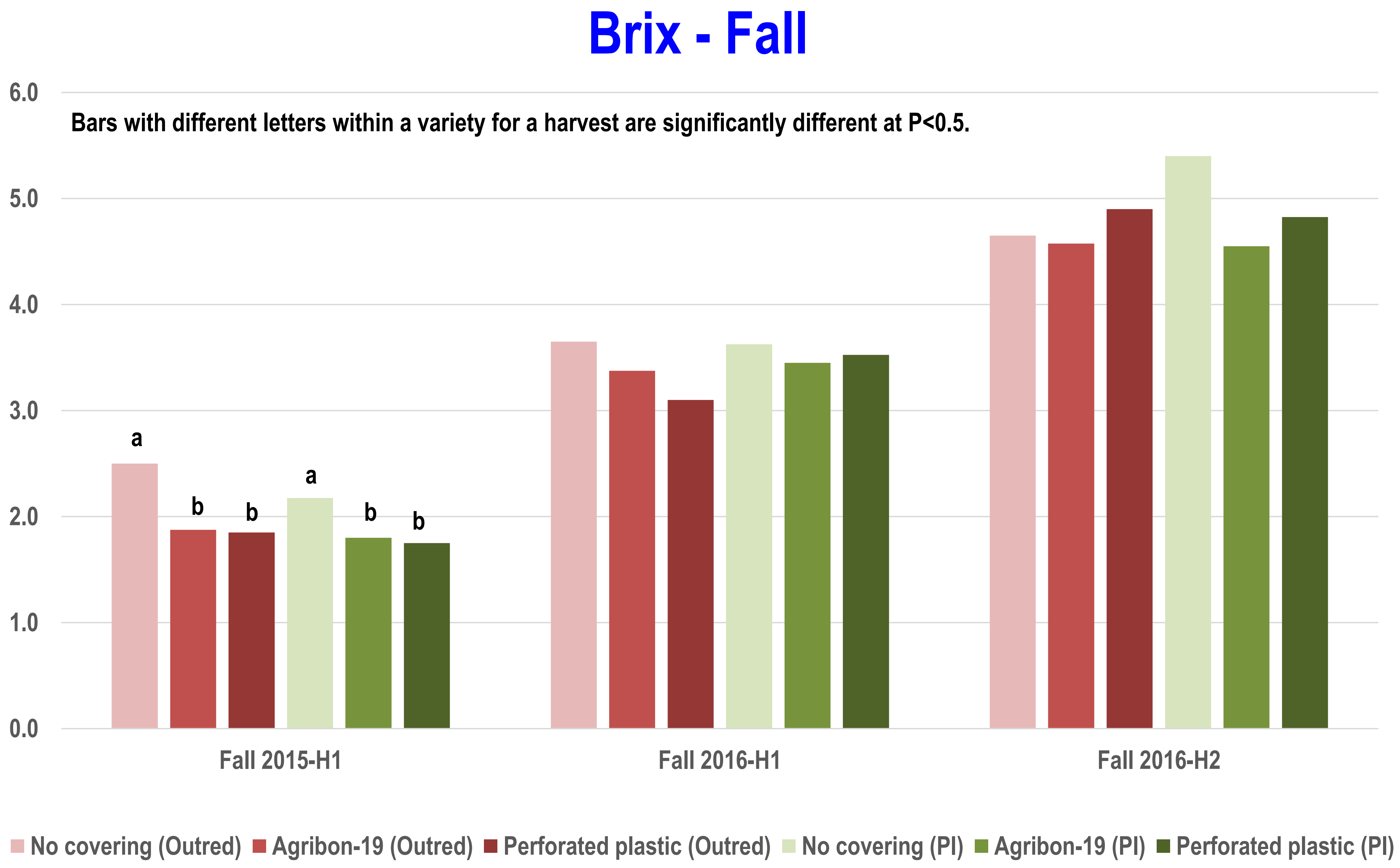


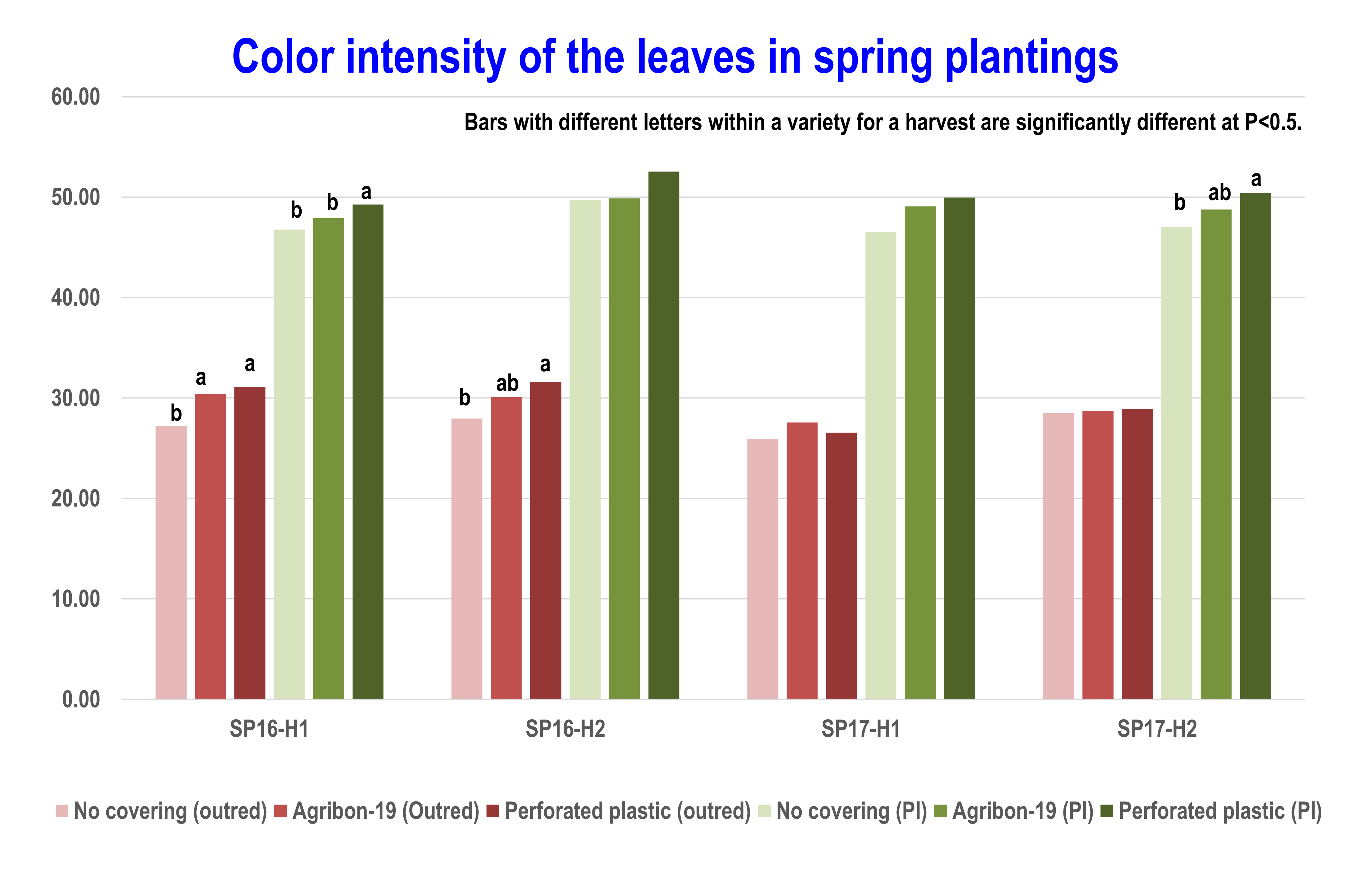
Outredgeous - April 27, 2016

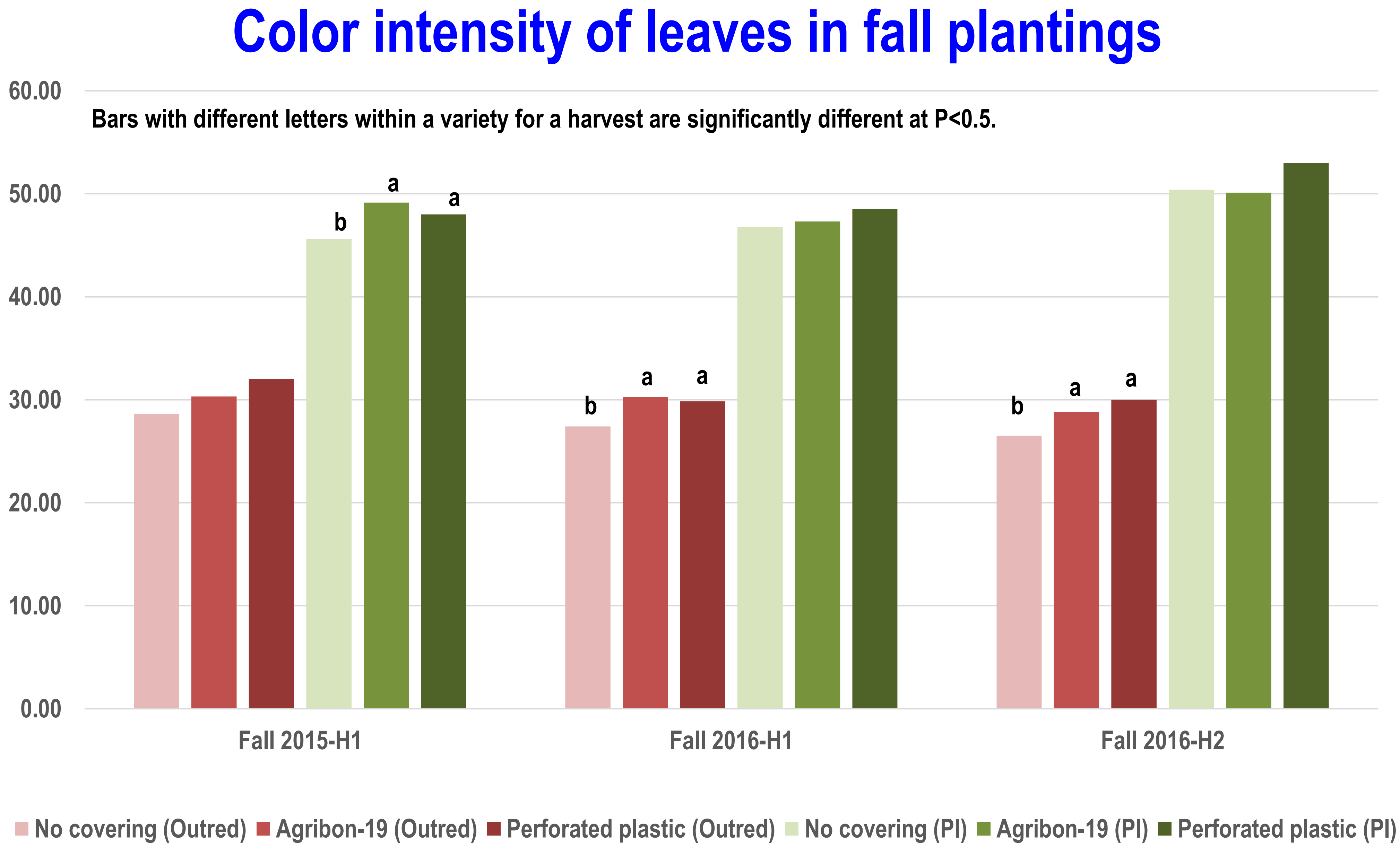


Parris Island - April 27, 2016

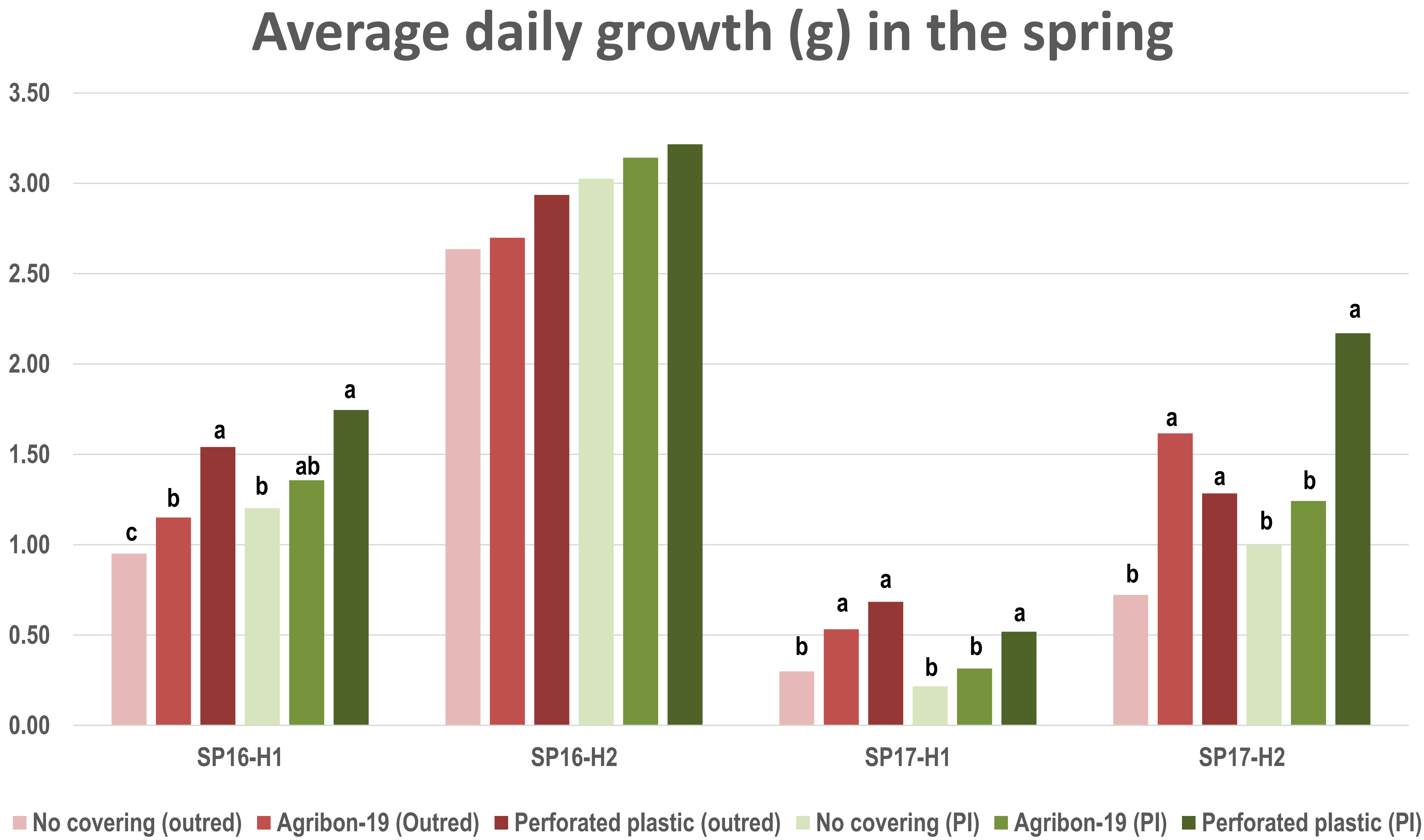

Brix - Spring
Bars with different letters within a variety for a harvest are significantly different at P<0.5.
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
b
b
a
b
b
a
SP16-H1
SP16-H2
SP17-H1
SP17-H2
No covering (outred)
Agribon-19 (Outred)
Perforated plastic (outred)
No covering (PI)
Agribon-19 (PI)
Perforated plastic (PI)


Brix - Fall
Bars with different letters within a variety for a harvest are significantly different at P<0.5.
6.0
5.0
4.0
3.0
2.0
1.0
0.0
a
b
b
a
b
b
Fall 2015-H1
Fall 2016-H1
Fall 2016-H2
No covering (Outred)
Agribon-19 (Outred)
Perforated plastic (Outred)
No covering (PI)
Agribon-19 (PI)
Perforated plastic (PI)

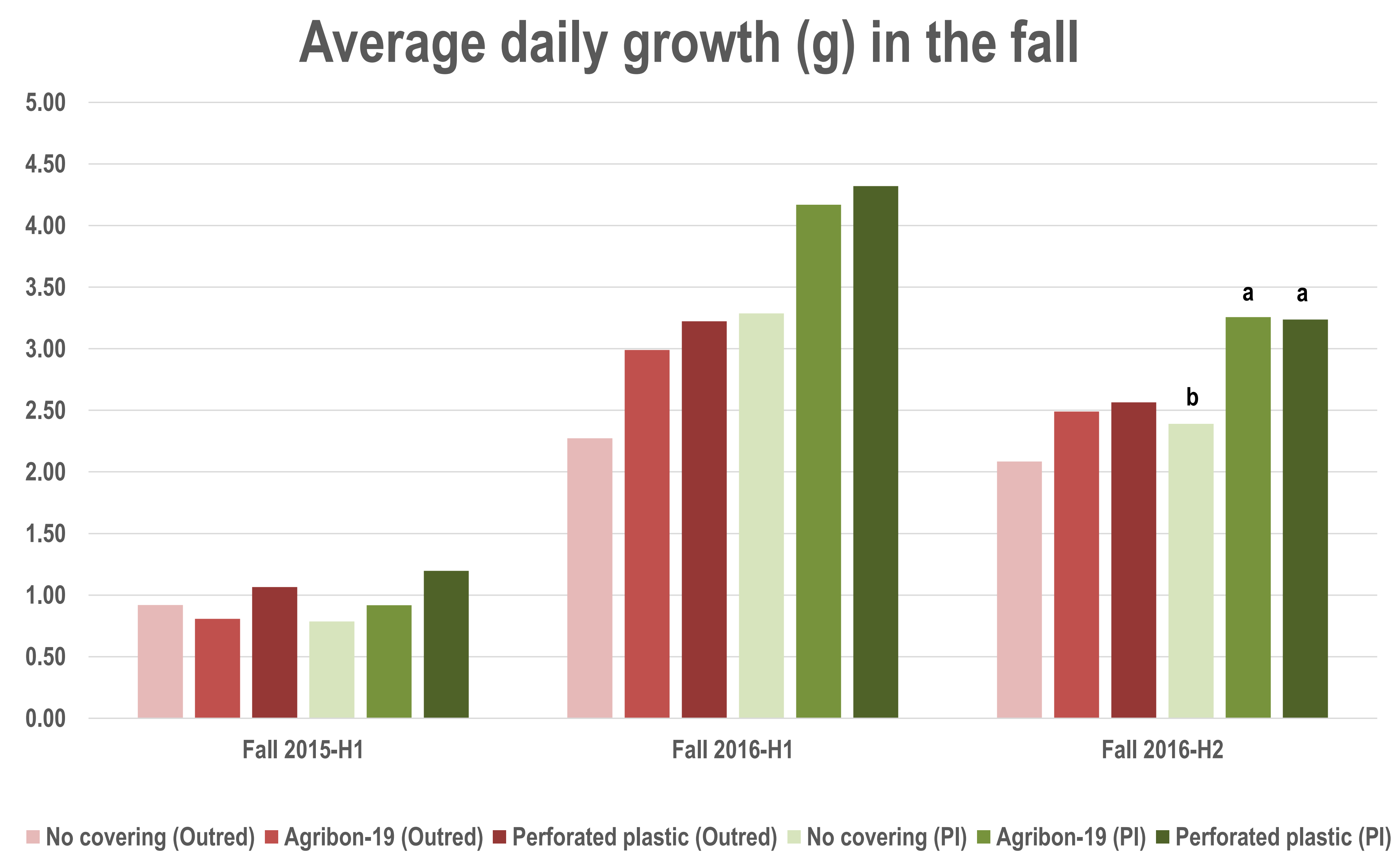

Color intensity of the leaves in spring plantings
Bars with different letters within a variety for a harvest are significantly different at P<0.5.
60.00
50.00
40.00
30.00
20.00
10.00
0.00
b
a
a
b
b
a
b
ab
a
b
ab
a
SP16-H1
SP16-H2
SP17-H1
SP17-H2
No covering (outred)
Agribon-19 (Outred)
Perforated plastic (outred)
No covering (PI)
Agribon-19 (PI)
Perforated plastic (PI)



Color intensity of leaves in fall plantings
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Bars with different letters within a variety for a harvest are significantly different at P<0.5.
b
a
a
b
a
a
b
a
a
Fall 2015-H1
Fall 2016-H1
Fall 2016-H2
No covering (Outred)
Agribon-19 (Outred)
Perforated plastic (Outred)
No covering (PI)
Agribon-19 (PI)
Perforated plastic (PI)



Bars with different letters within a variety for a harvest are significantly different at P<0.5.



Bars with different letters within a variety for a harvest are significantly different at P<0.5.

Growth Rates and Quality of Baby-sized Greens Grown in High Tunnels during Fall and Spring

30’ x 80’ high tunnels covered with single layer of 6-mil poly film

Each high tunnel contains twenty 4’ x 12’ raised beds

Each covered with low tunnel of Agribon as needed

‘Parris Island’ lettuce

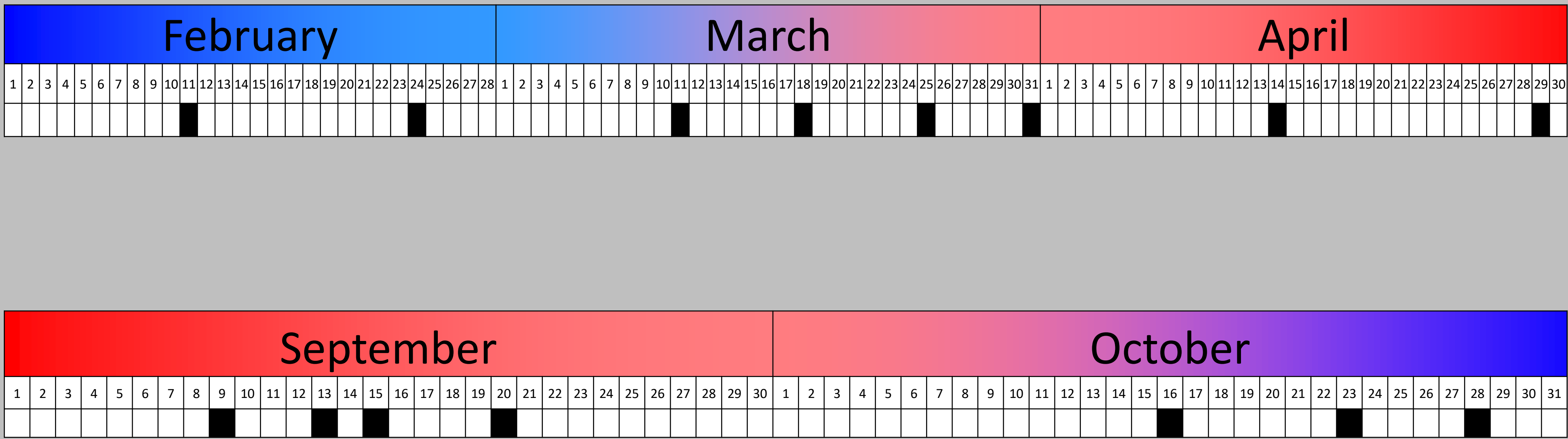
‘Fordhook’ Swiss chard

‘Outredgeous’ lettuce

‘Ovation’ mesclun mix

‘Oriole’ Swiss chard

Seeding dates



Targeted Seeding Rates

Lettuce & mesclun mix-360 seed/ft2

Swiss chard-240 seed/ft2

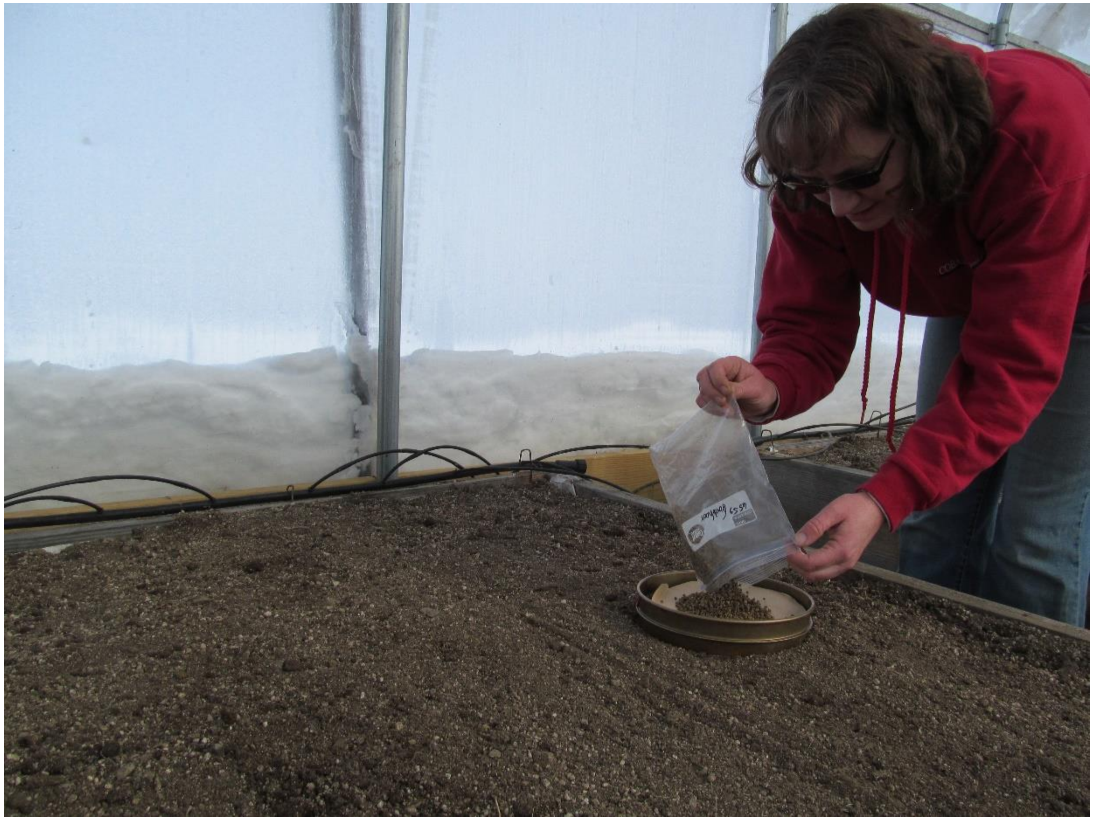
Pictures taken on 8.5"x11" paper

Heated soil vs unheated soil

October 16, 2014
October 23, 2014
March 11, 2015
March 18, 2015

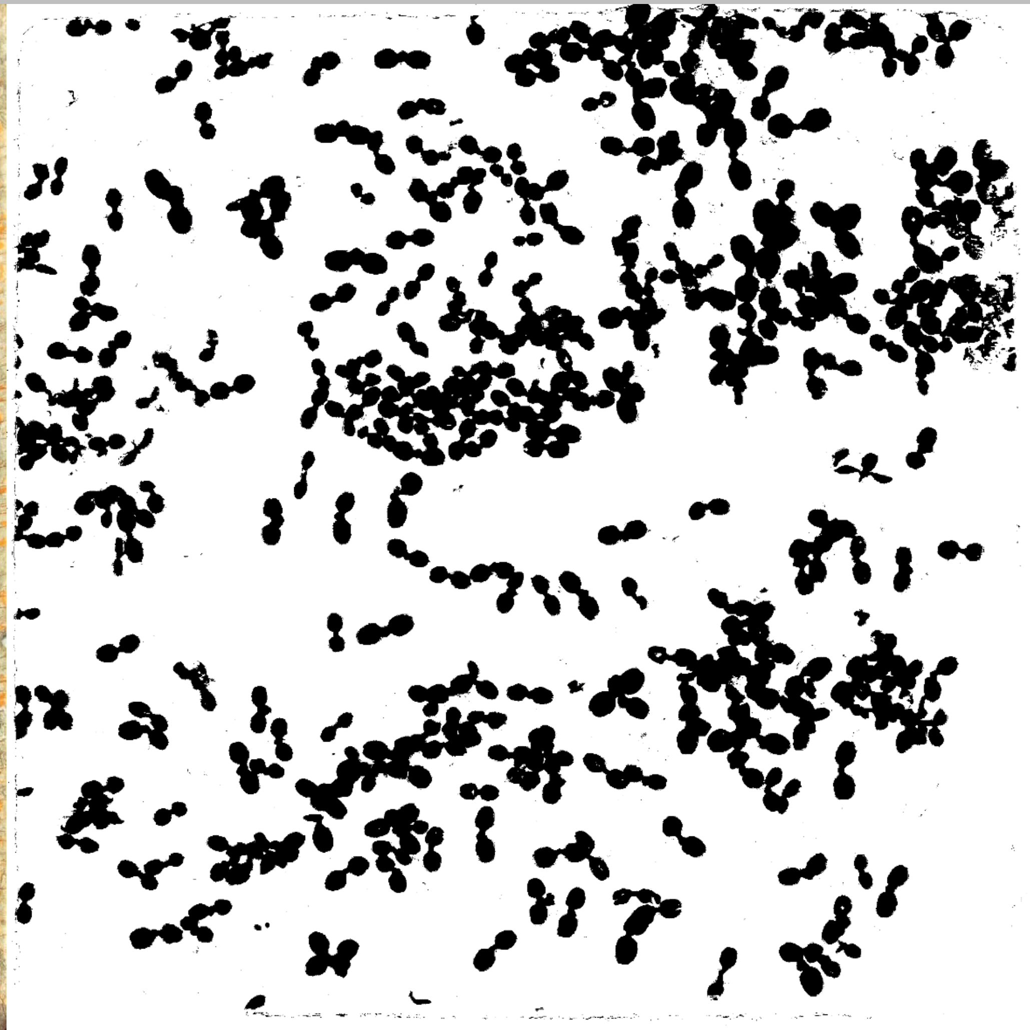
Seeding dates

Soil heating cables used to raise soil temperature. Cables ran at 74F.



Feb. 11, 2016

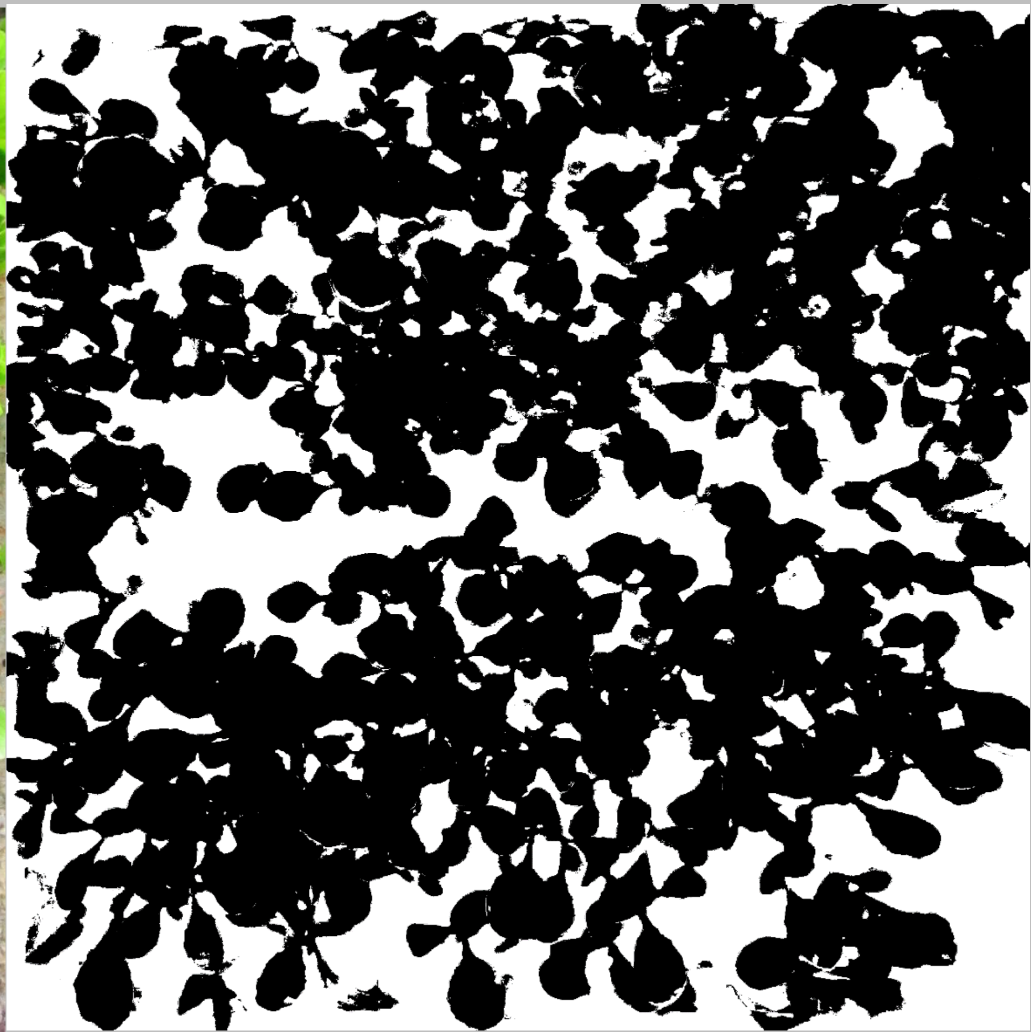
Canopy analysis



Sept 25, 2015

20.39% canopy cover

Canopy analysis



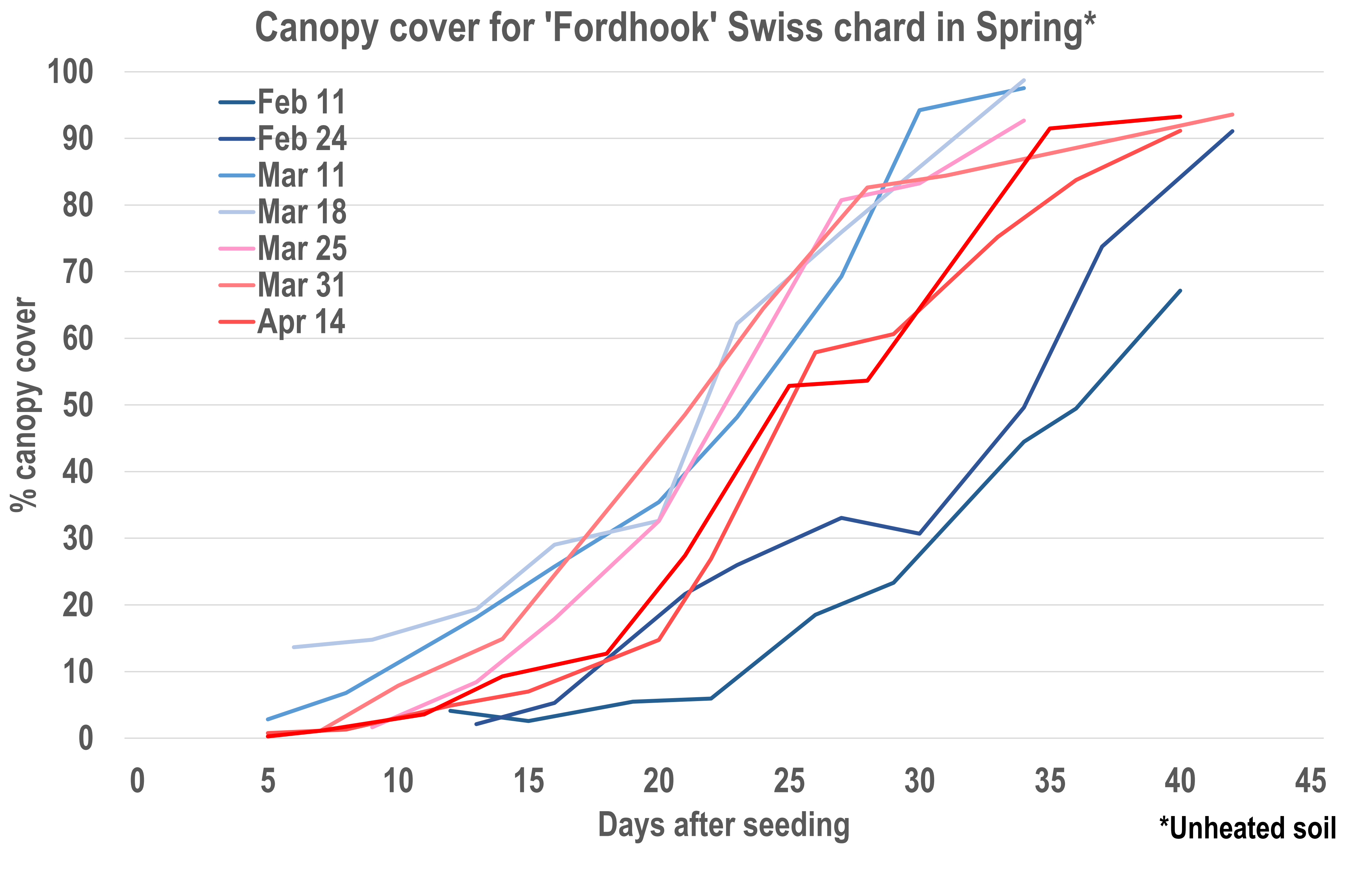
Oct. 6, 2015

63.98% canopy cover

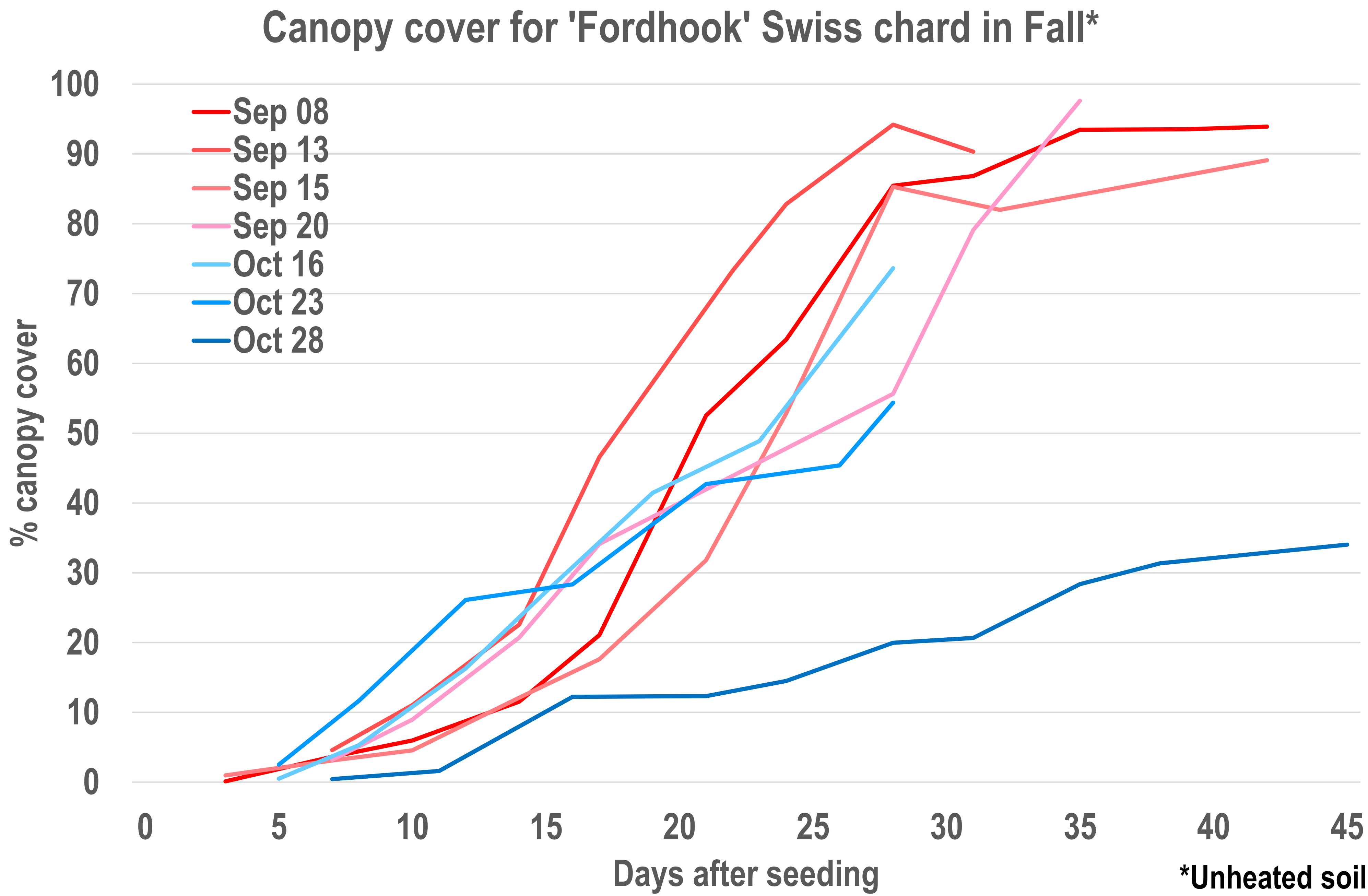
Harvested 1ft^2 areas

Each seeding date harvested 2-3 times

tracking yield and quality



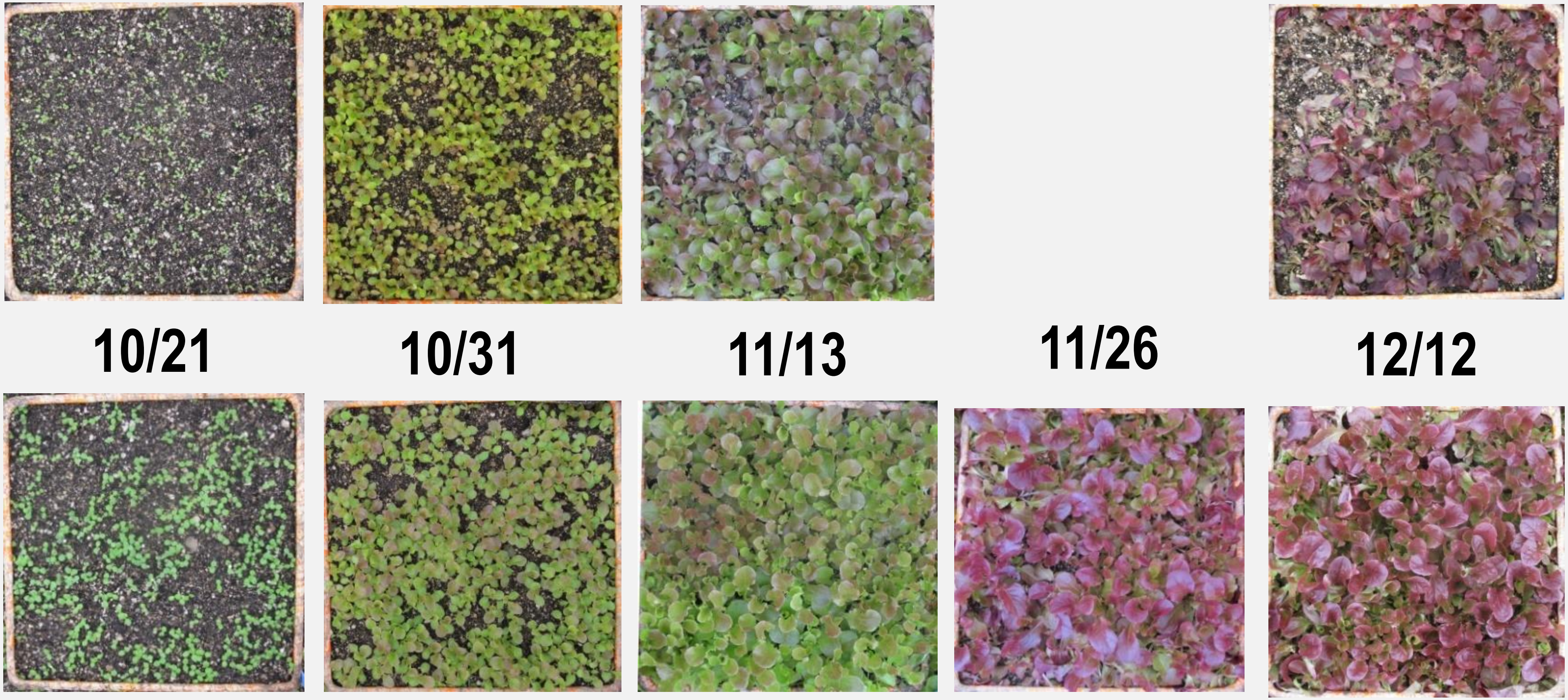
Canopy cover for 'Fordhook' Swiss chard in Spring*
100
90
80
70
60
50
40
30
20
10
0
% canopy cover
Feb 11
Feb 24
Mar 11
Mar 18
Mar 25
Mar 31
Apr 14
0
5
10
15
20
25
30
35
40
45
Days after seeding
*Unheated soil

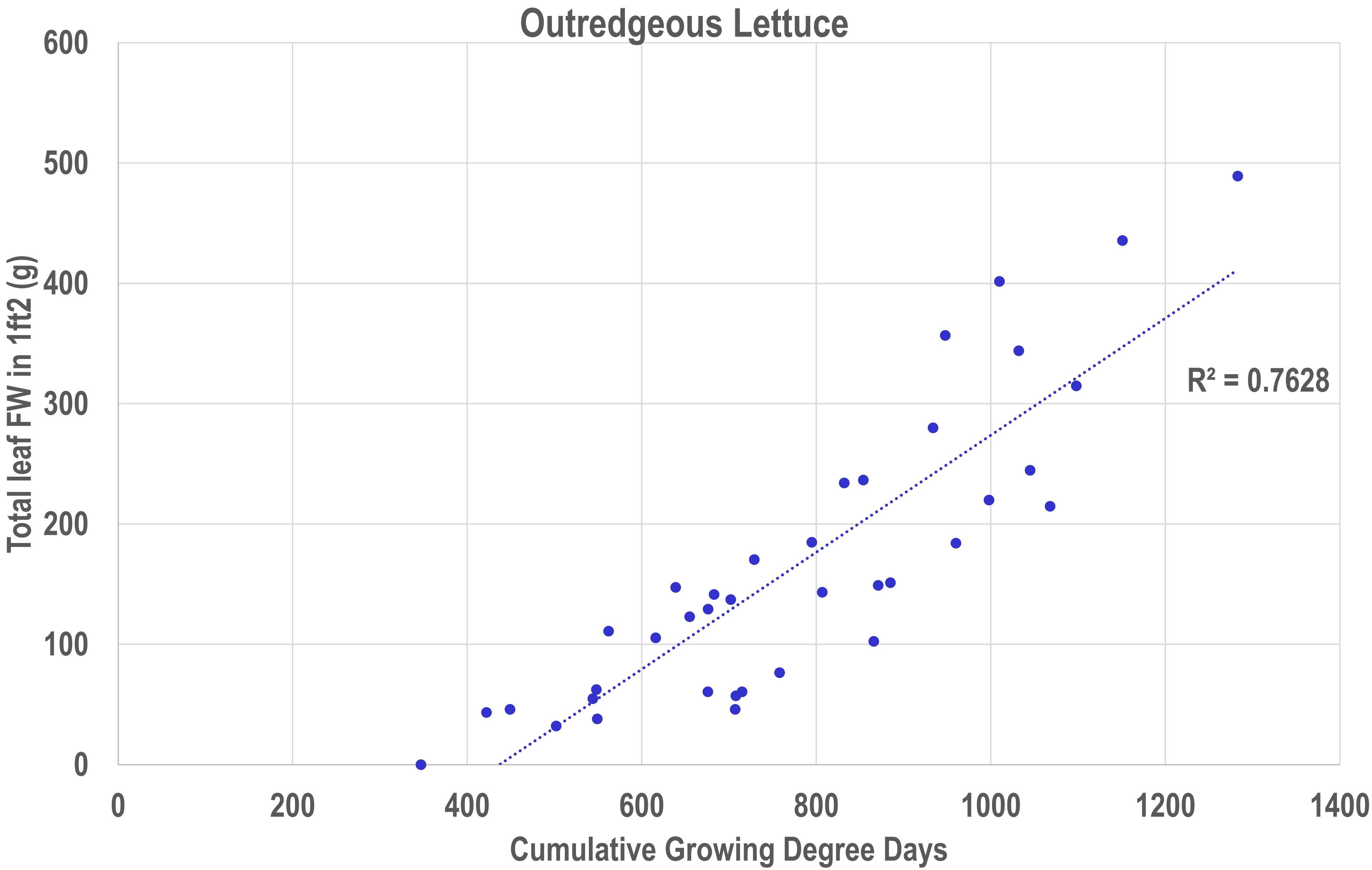


Canopy cover for 'Fordhook' Swiss chard in Fall*
Sep 08
Sep 13
Sep 15
Sep 20
Oct 16
Oct 23
Oct 28
% canopy cover
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
40
45
Days after seeding
*Unheated soil

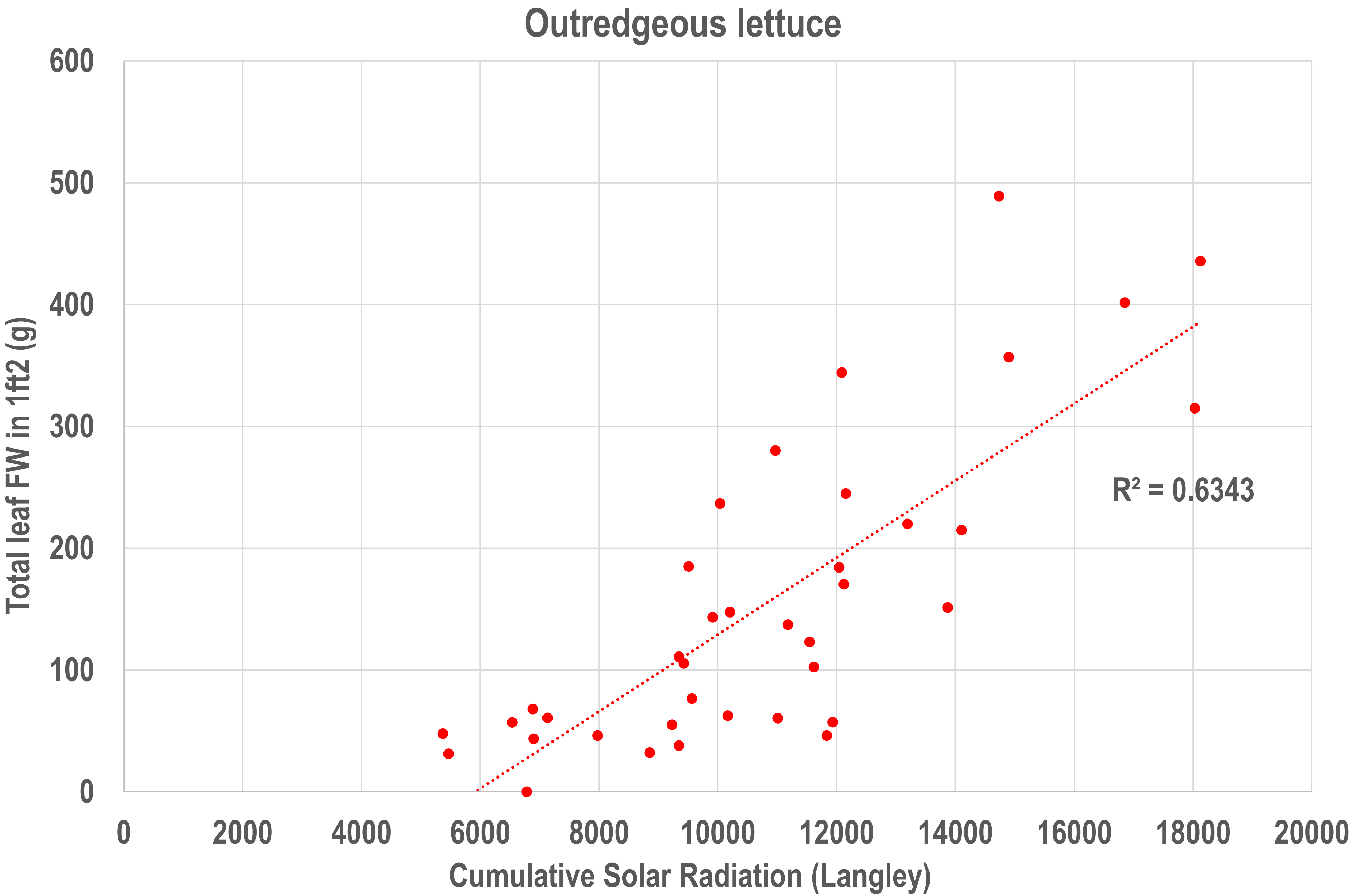
Outredgeous Lettuce seeded 10/16/14

top row (unheated soil); bottom row (heated soil)

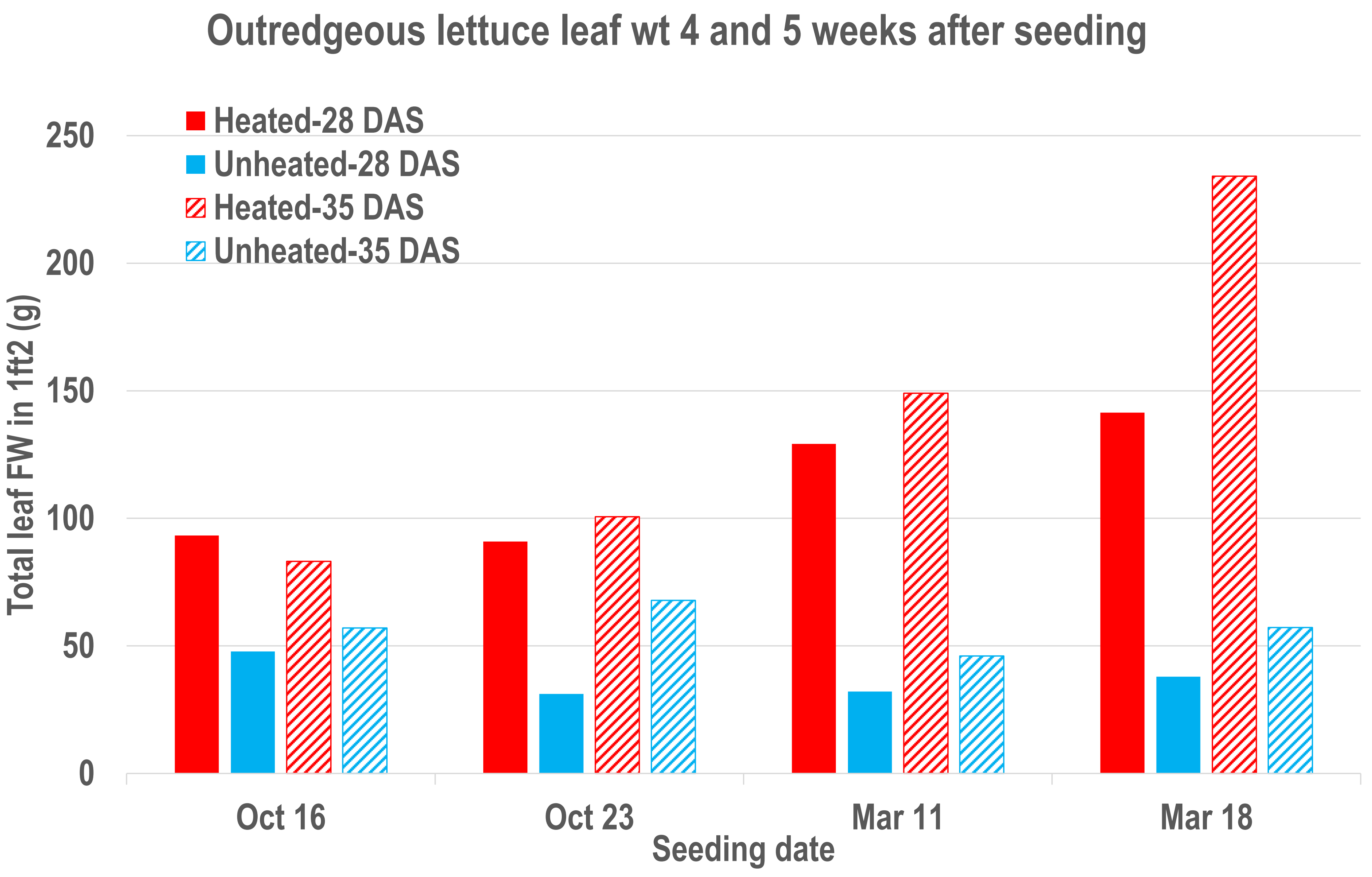




Outredgeous Lettuce
600
500
400
300
200
100
0
Total leaf FW in 1ft2 (g)
R² = 0.7628
0
200
400
600
800
1000
1200
1400
Cumulative Growing Degree Days



Outredgeous lettuce
Total leaf FW in 1ft2 (g)
600
500
400
300
200
100
0
R² = 0.6343
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
Cumulative Solar Radiation (Langley)


Outredgeous lettuce leaf wt 4 and 5 weeks after seeding
Heated-28 DAS
Unheated-28 DAS
Heated-35 DAS
Unheated-35 DAS
Total leaf FW in 1ft2 (g)
250
200
150
100
50
0
Oct 16
Oct 23
Mar 11
Mar 18
Seeding date

SUMMARY

THANK-YOU
and
GOOD LUCK!

THE OHIO STATE UNIVERSITY

COLLEGE OF FOOD, AGRICULTURAL, AND ENVIRONMENTAL SCIENCES

QUESTIONS?

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SETTING X MICROCLIMATE

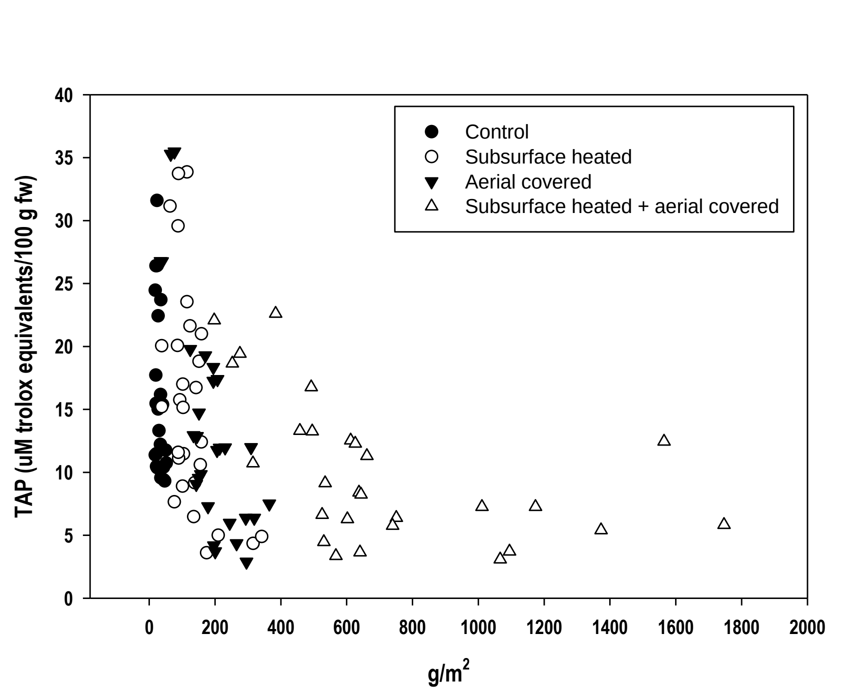
Outdoor	Fall 08	Spring 09	Fall 09	Spring 10
Control	31.2 a	21.5 a	43.1 a	28.0 a
Subsurface heated	250.8 b	110.9 b	110.9 b	80.7 b
Aerial covered	235.7 b	241.1 c	153.9 c	104.4 b
Subsurface heated + aerial covered	807.3 c	959.1 d	552.2 d	402.6 c
Outredgeous	197.0	174.4 B	146.4	132.4 B
Flagship	NA	134.6 A	137.8	73.2 A

SETTING X MICROCLIMATE

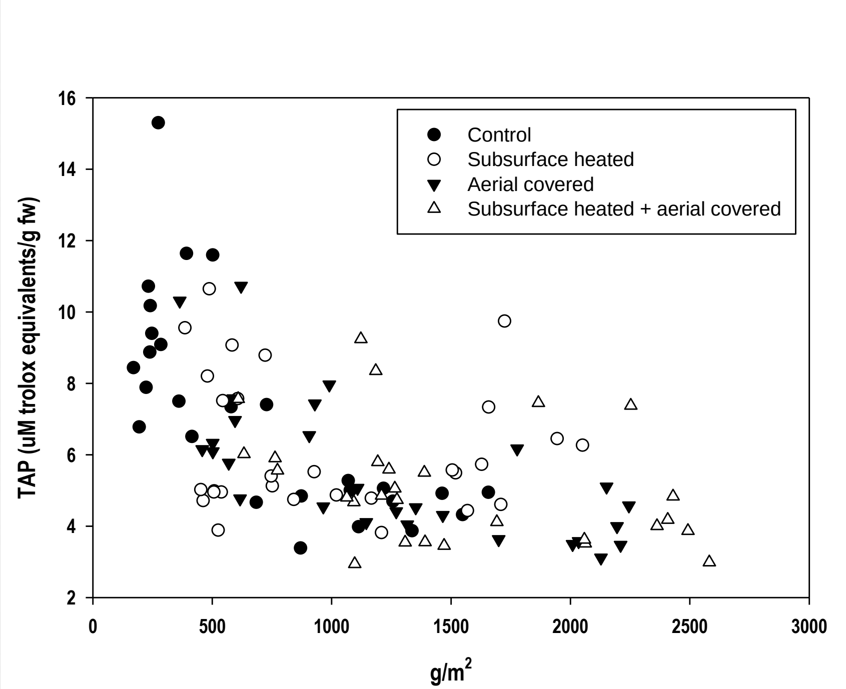
High tunnel	Fall 08	Spring 09	Fall 09	Spring 10
Control	1217.4	1162.5 a	233.6 a	460.7 a
Subsurface heated	1197.0	1717.9 b	484.4 b	730.9 b
Aerial covered	1458.5	2093.6 c	517.7 b	992.4 c
Subsurface heated + aerial covered	1286.3	2306.7 c	887.0 c	1417.6 d
Outredgeous	1289.5	1785.7	475.8	1035.5 B
Flagship	NA	1854.6	479.0	765.3 A

BIOMASS AND COMPOSITION

Outdoor setting



High tunnel setting



BIOMASS AND COMPOSITION RELATIONSHIPS

Fertility x Micro

Pearson Correlation Coefficients	Fall 09	Spring 10
	Biomass	
Antho	-0.70	-0.76
Chl A	-0.86	NS
Antioxidant	-0.74	-0.76
Vit. C	-0.60	-0.52
Brix	-0.84	-0.51

Setting x Micro

Pearson Correlation Coefficients	Outdoor	High tunnel
	Biomass	
Antho	-0.37	-0.59
Chl A	-0.50	-0.66
Antioxidant	-0.43	-0.55
Vit. C	-0.26	-0.43
Quercetin	-0.47	-0.45

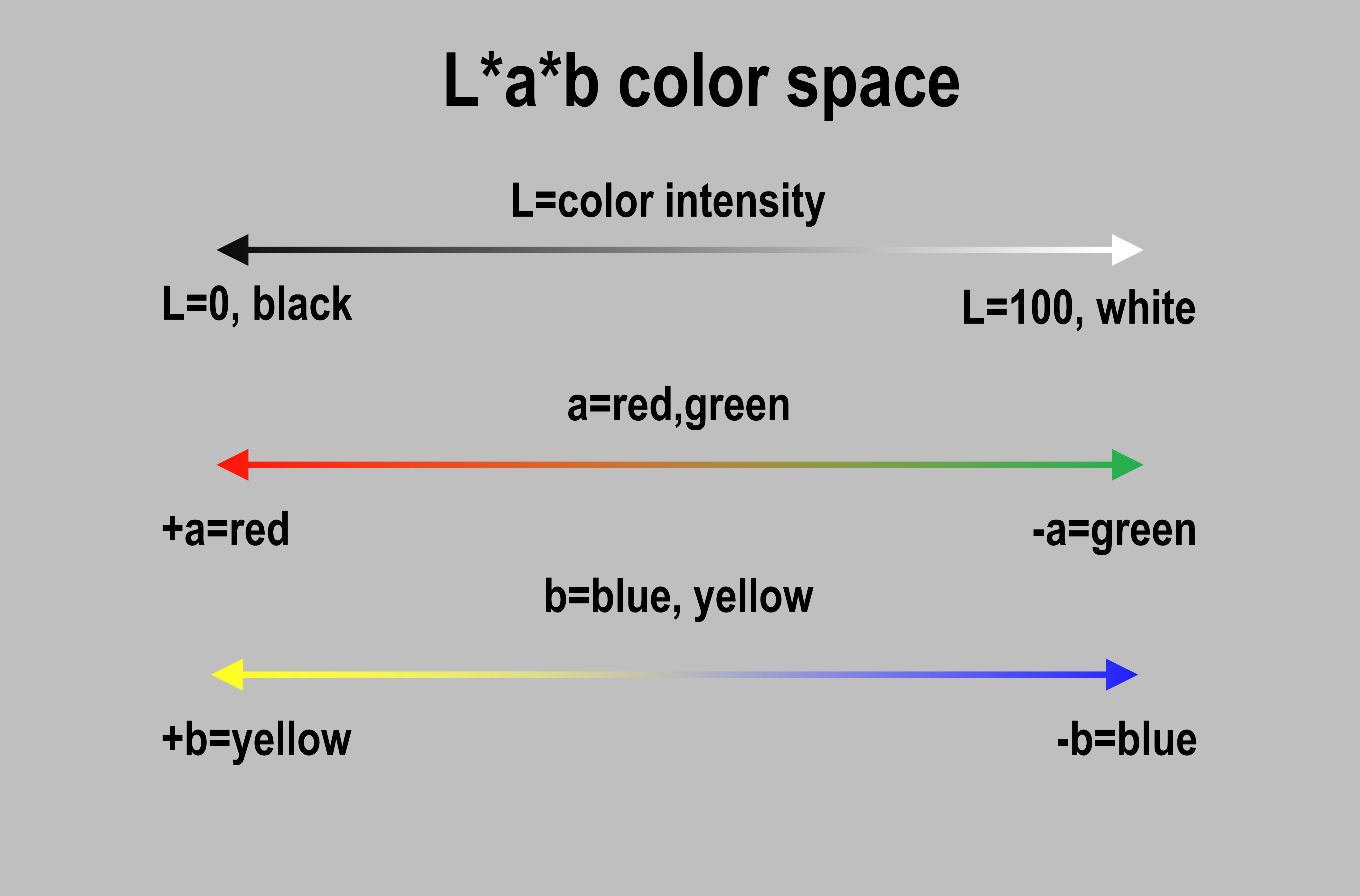
Outdoor Spring 09	Unheated + uncovered	Subsurface heated	Aerial covered	Subsurface heated + aerial covered
Yield (g/m²)	21.5 a	110.9 b	241.1 c	959.1 d
Anthocyanin mg/100g fw	33.9 c	30.0 bc	24.9 ab	22.6 a

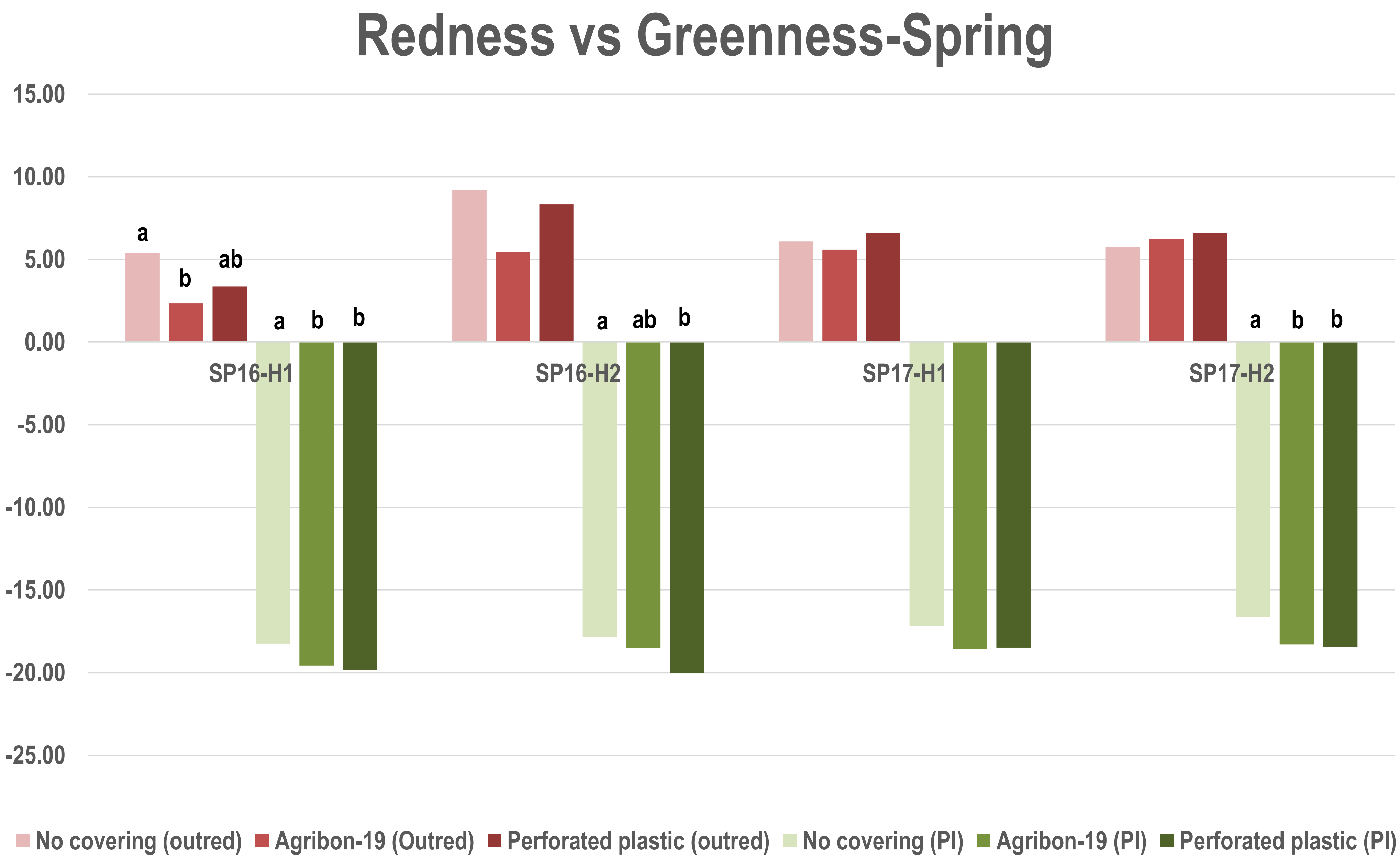

November 6, 2015

Average plant fresh weight (g)

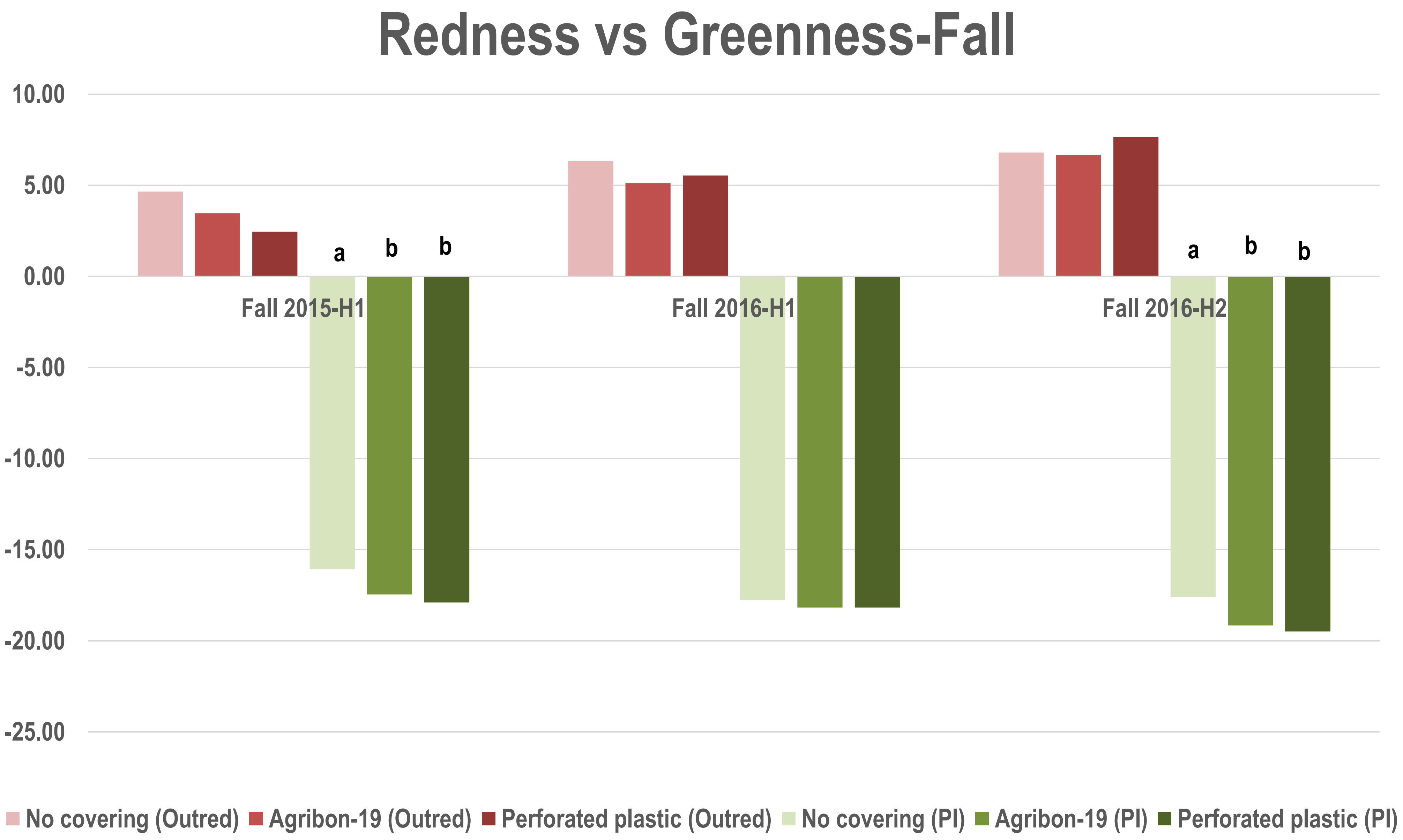
Variety	Covering	Season / Harvest	Fall 2015	Fall 2016		Spring 2016		Spring 2017	
			1	1	2	1	2	1	2
Outredgeous	No covering		44.09	109.15	129.23	41.67 c	166.20	14.56 b	45.50 b
	Agribon-19		38.77	143.50	154.31	50.81 b	170.07	26.05 a	101.76 a
	Perforated film		51.18	154.76	158.96	67.96 a	185.00	33.50 a	80.95 a
Parris Island	No covering		37.70	157.84	148.16 b	52.94 b	190.76	10.59 b	62.97 b
	Agribon-19		44.02	200.18	201.93 a	59.67 ab	197.86	15.36 b	78.25 ab
	Perforated film		57.35	207.34	200.70 a	76.83 a	202.73	25.47 a	136.57 a

Means with different letters within a variety for a harvest are significantly different at P<0.5.

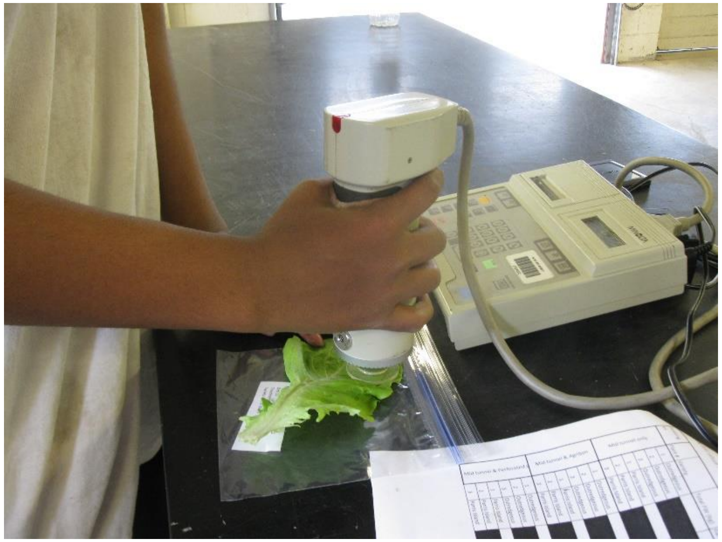

L*a*b color space
L=color intensity
L=0, black
L=100, white
a=red,green
+a=red
-a=green
b=blue, yellow
+b=yellow
-b=blue



Bars with different letters within a variety for a harvest are significantly different at P<0.5.



Bars with different letters within a variety for a harvest are significantly different at P<0.5.



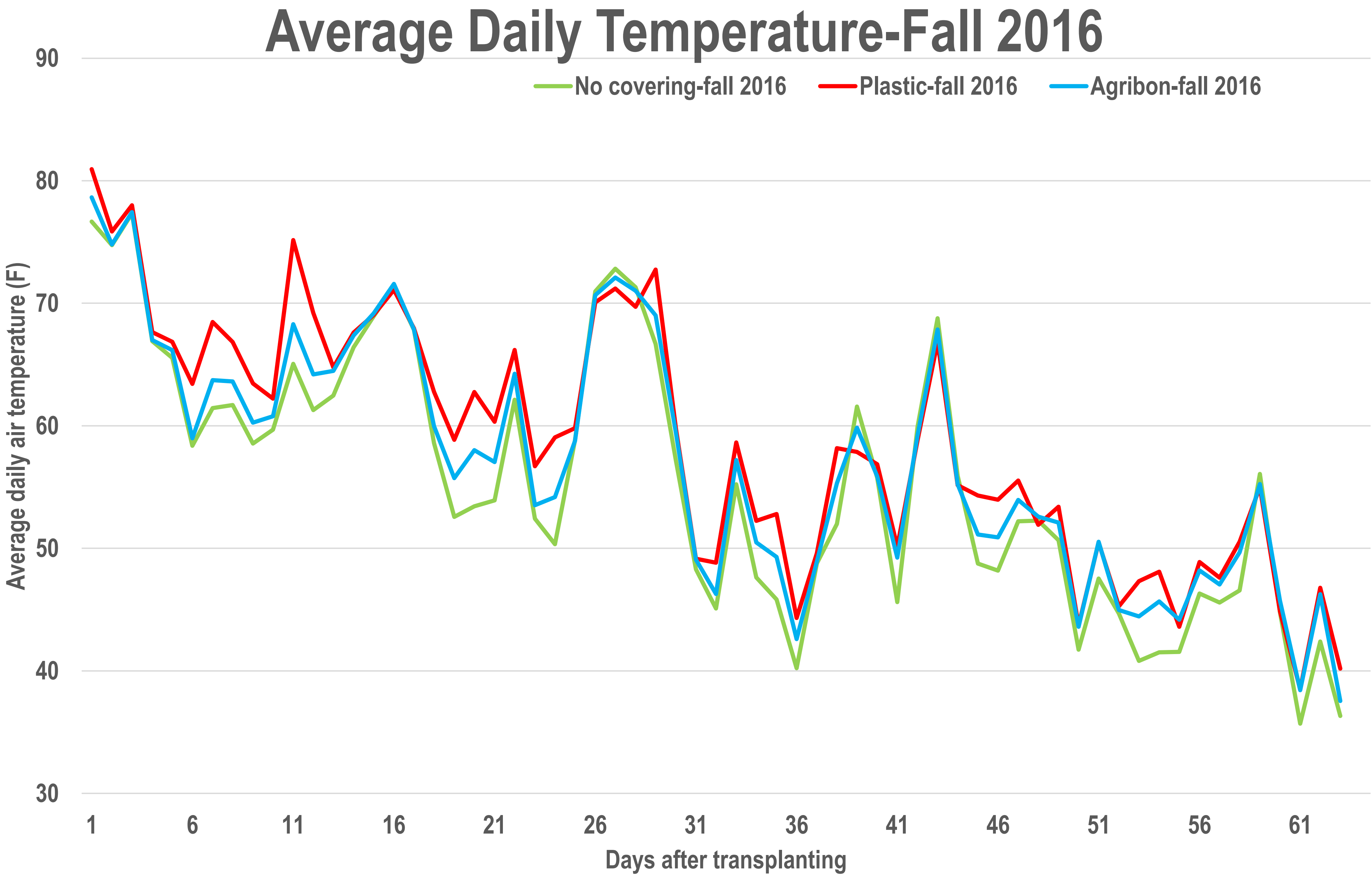
Need Pictures of BRix

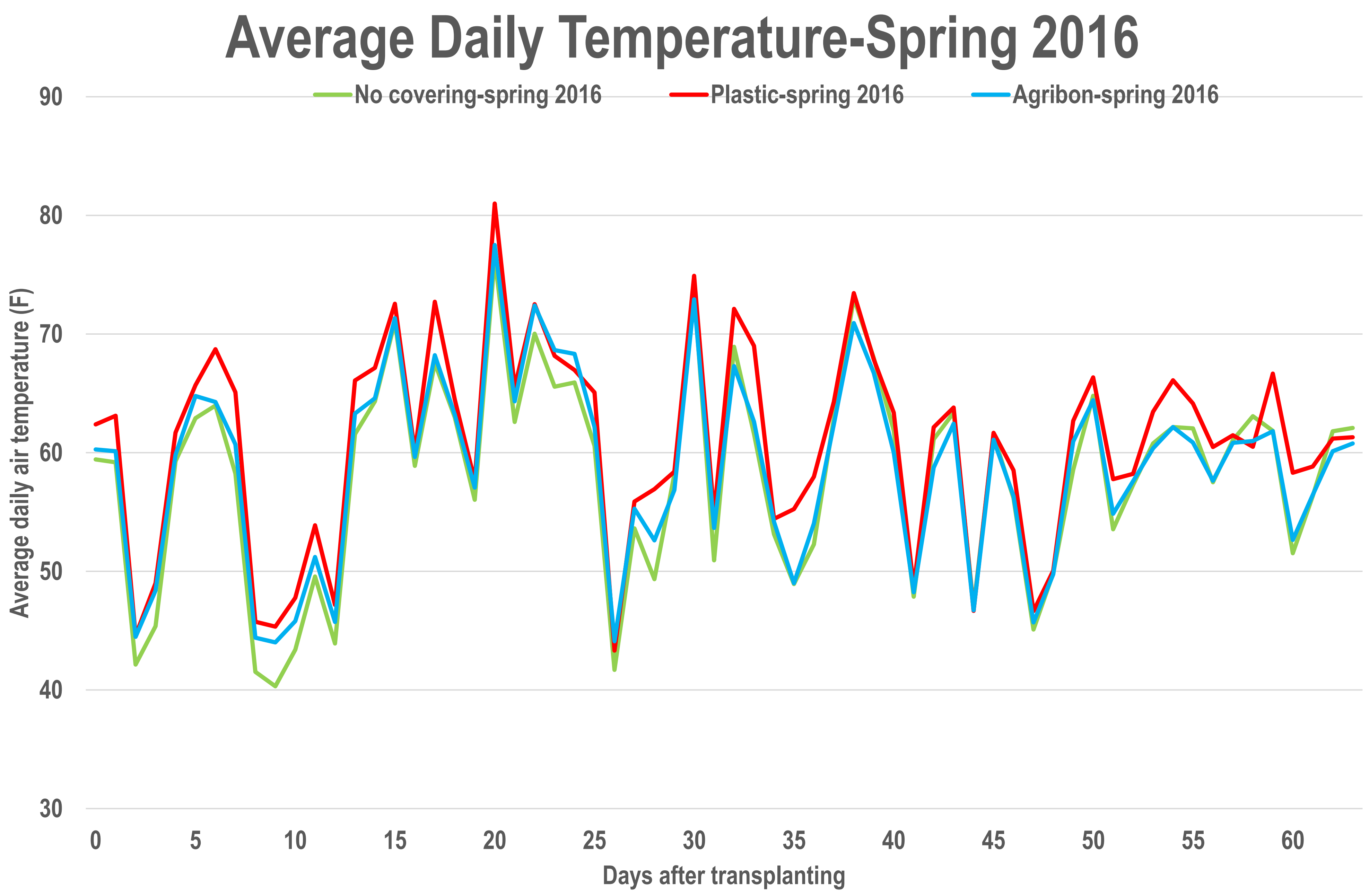
Perforated film

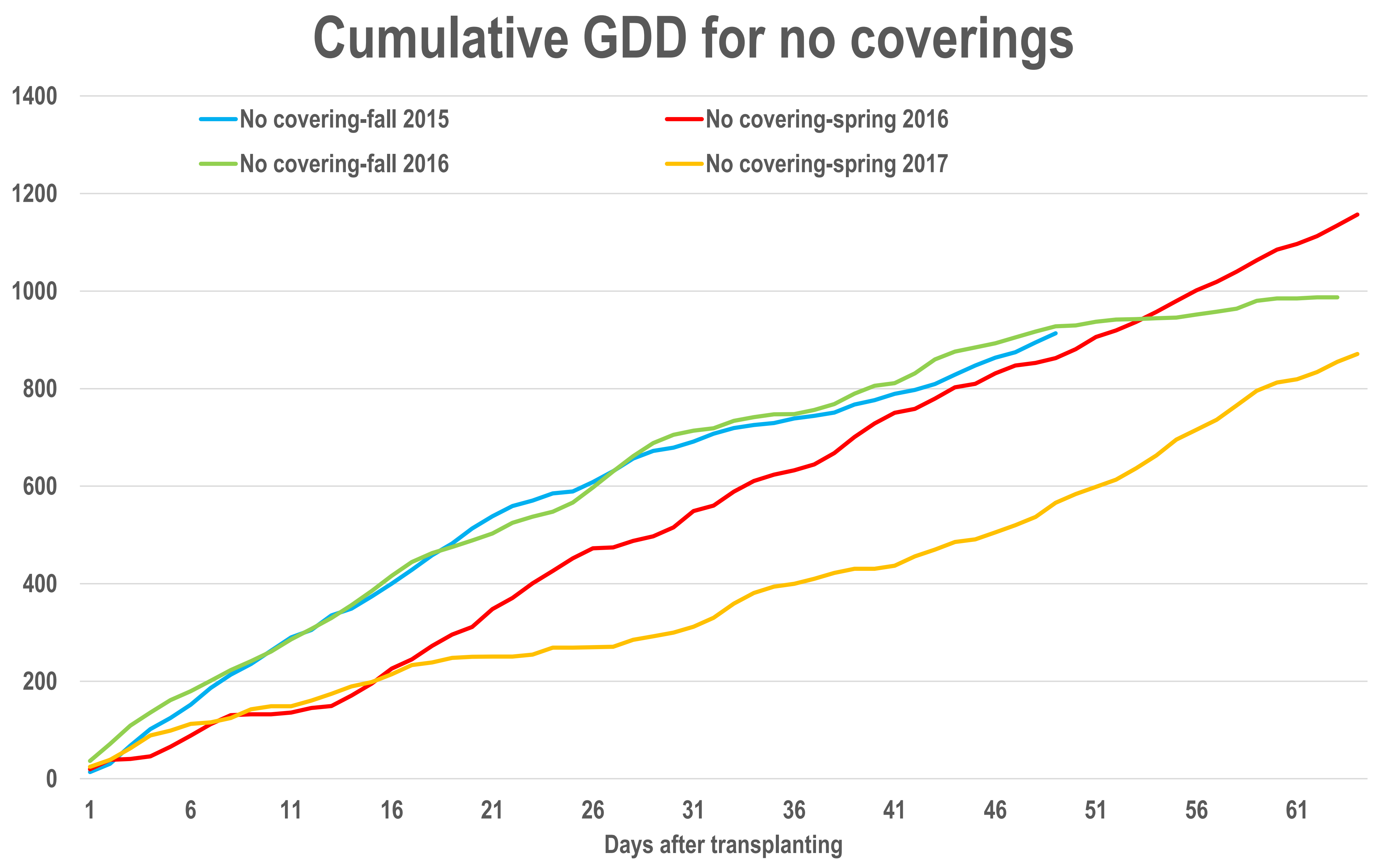
Agribon

No cover

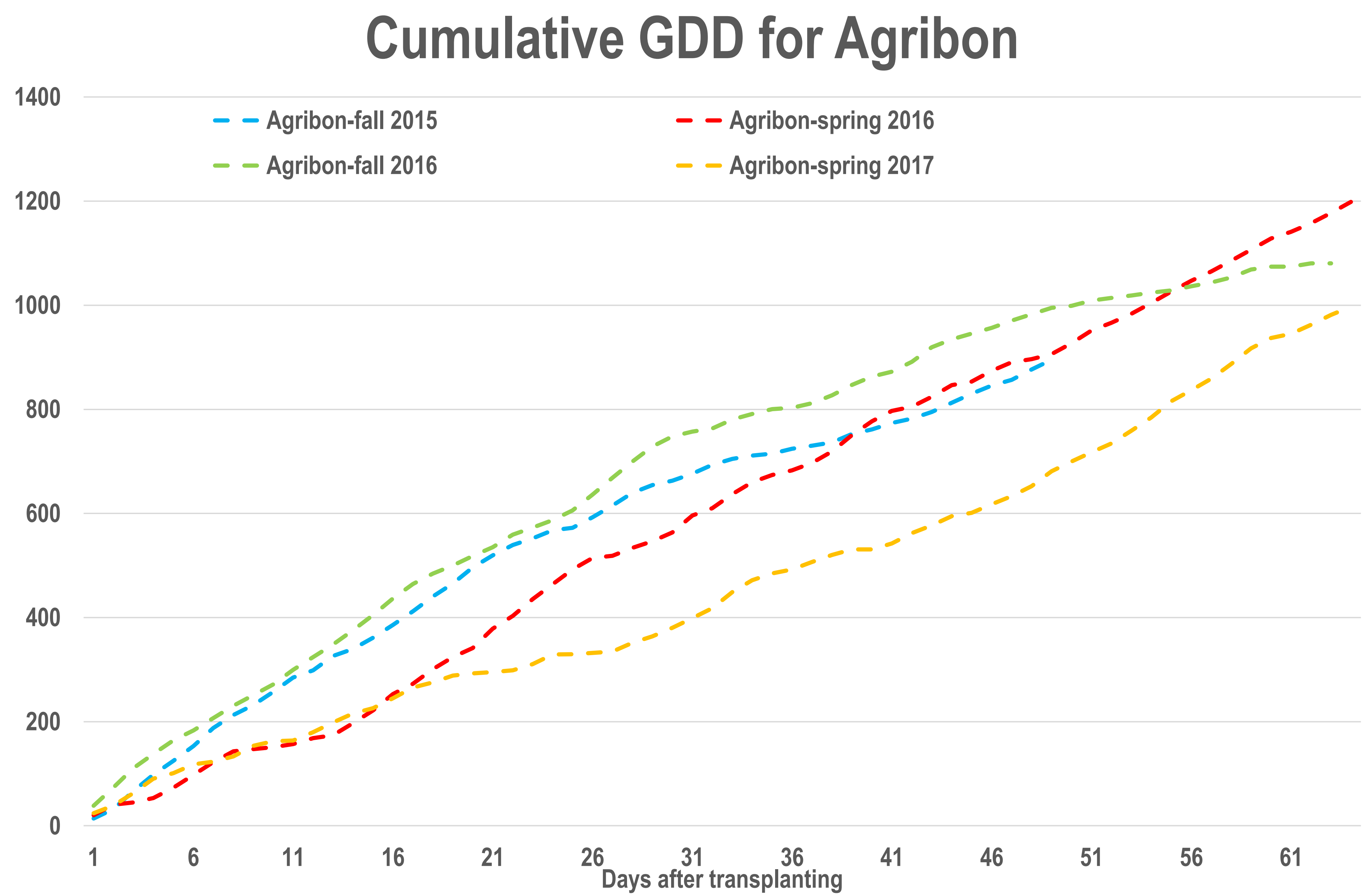
March 29, 2016

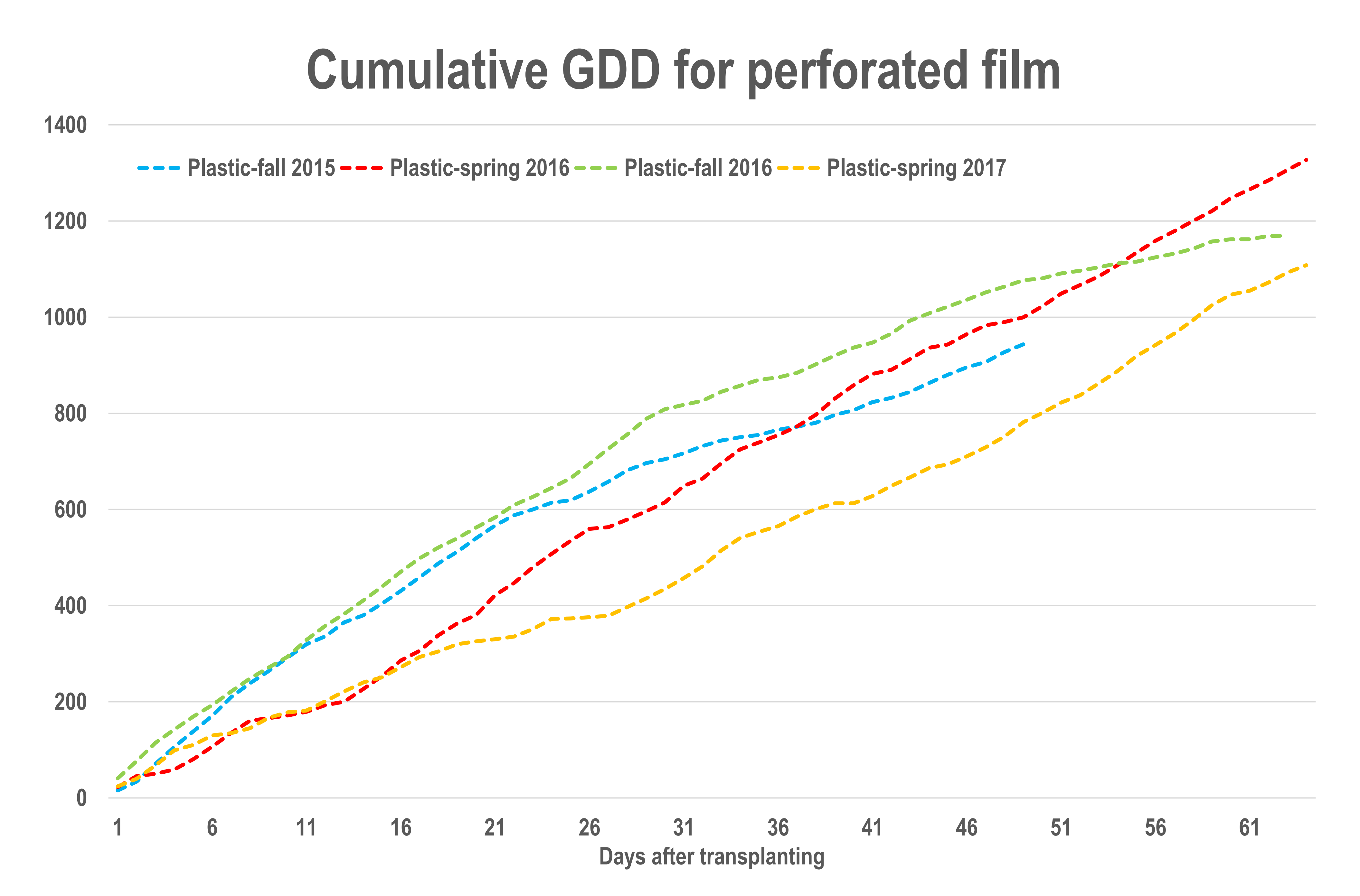

Average Daily Temperature-Fall 2016
No covering-fall 2016
Plastic-fall 2016
Agribon-fall 2016
Average daily air temperature (F)
90
80
70
60
50
40
30
1
6
11
16
21
26
31
36
41
46
51
56
61
Days after transplanting


Average Daily Temperature-Spring 2016
No covering-spring 2016
Plastic-spring 2016
Agribon-spring 2016
Average daily air temperature (F)
90
80
70
60
50
40
30
0
5
10
15
20
25
30
35
40
45
50
55
60
Days after transplanting

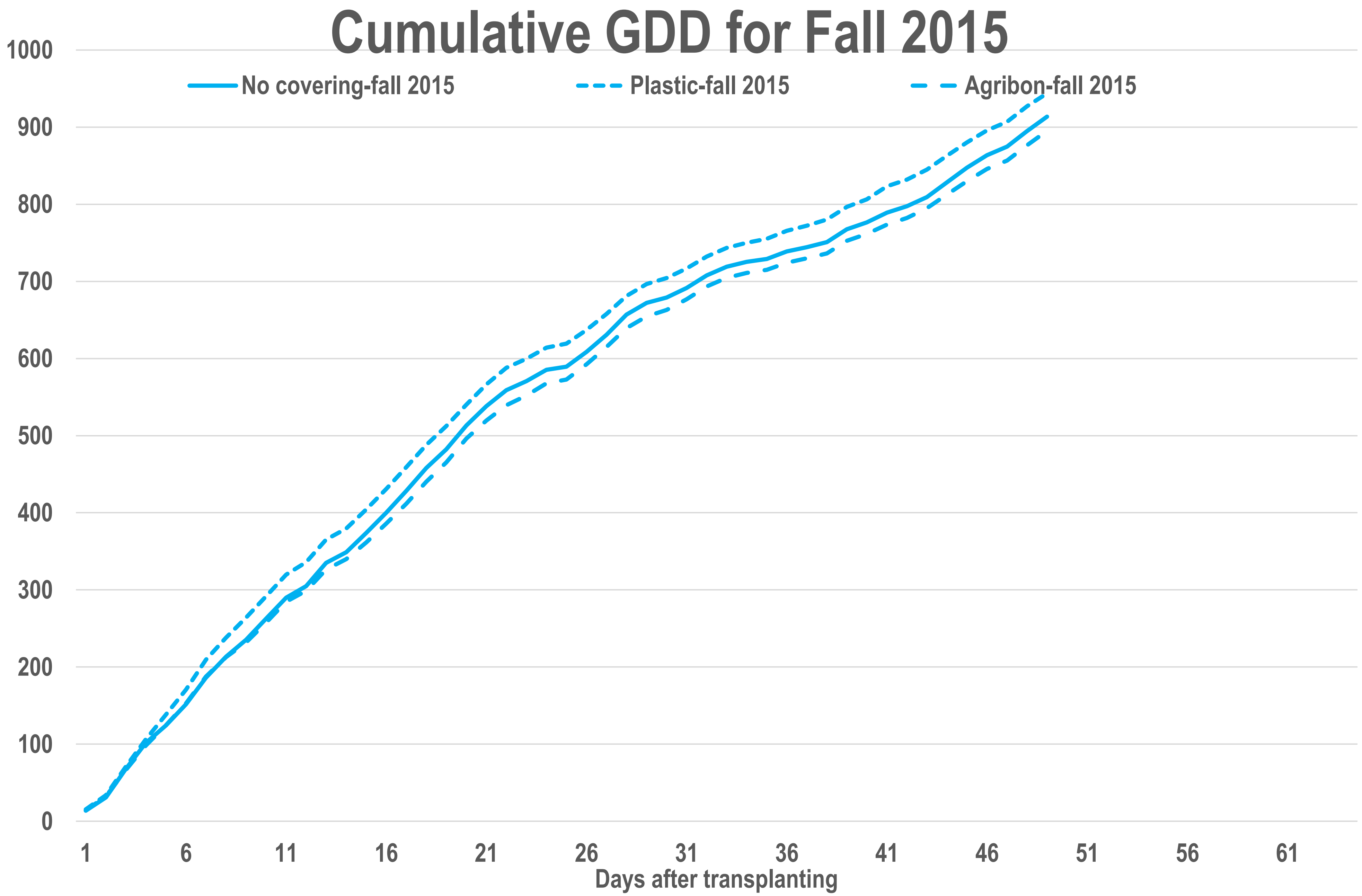


Cumulative GDD for no coverings
No covering-fall 2015
No covering-spring 2016
No covering-fall 2016
No covering-spring 2017
1400
1200
1000
800
600
400
200
0
1
6
11
16
21
26
31
36
41
46
51
56
61
Days after transplanting

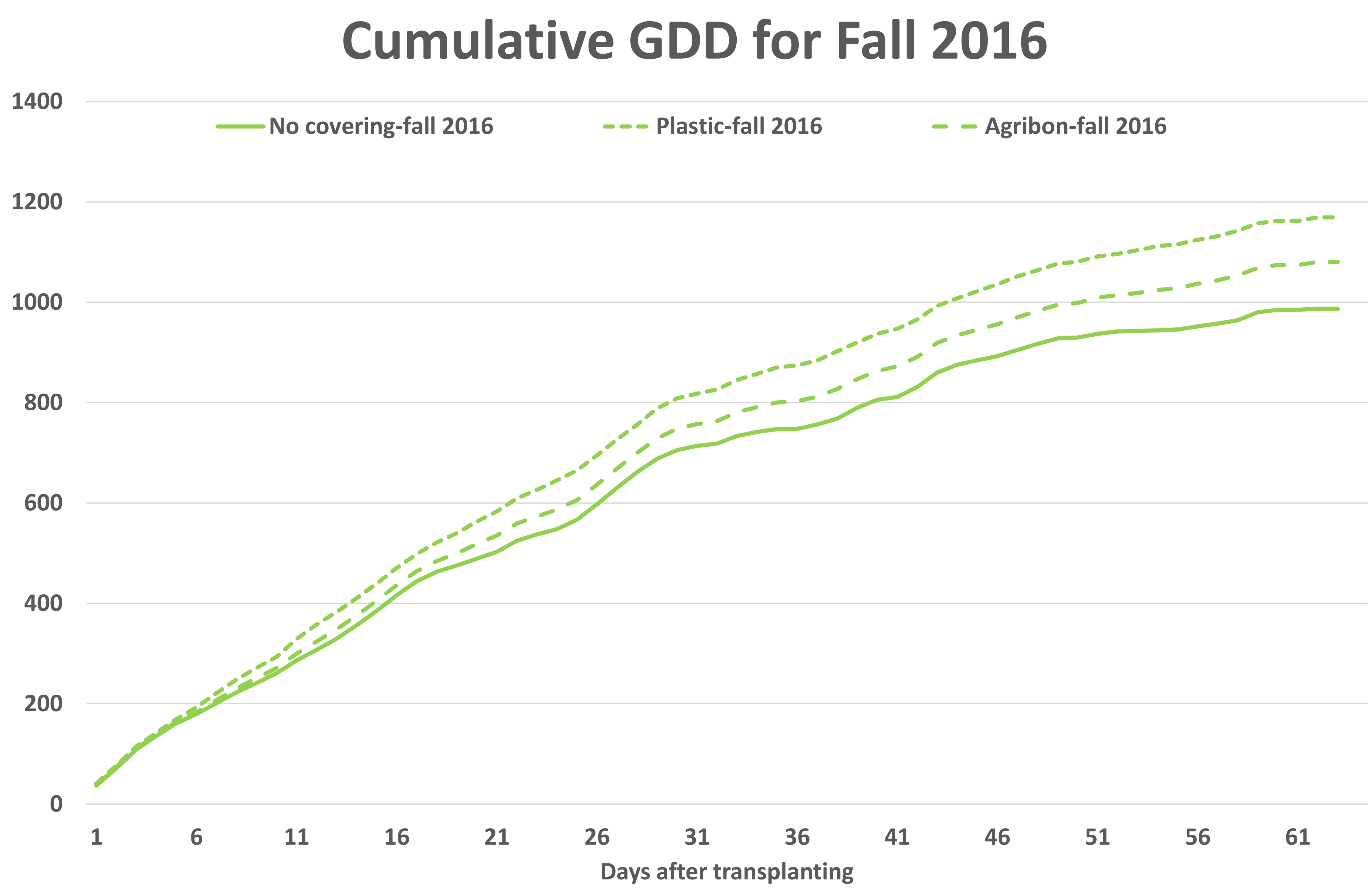

Cumulative GDD for Agribon
Agribon-fall 2015
Agribon-spring 2016
Agribon-fall 2016
Agribon-spring 2017
1400
1200
1000
800
600
400
200
0
1
6
11
16
21
26
31
36
41
46
51
56
61
Days after transplanting

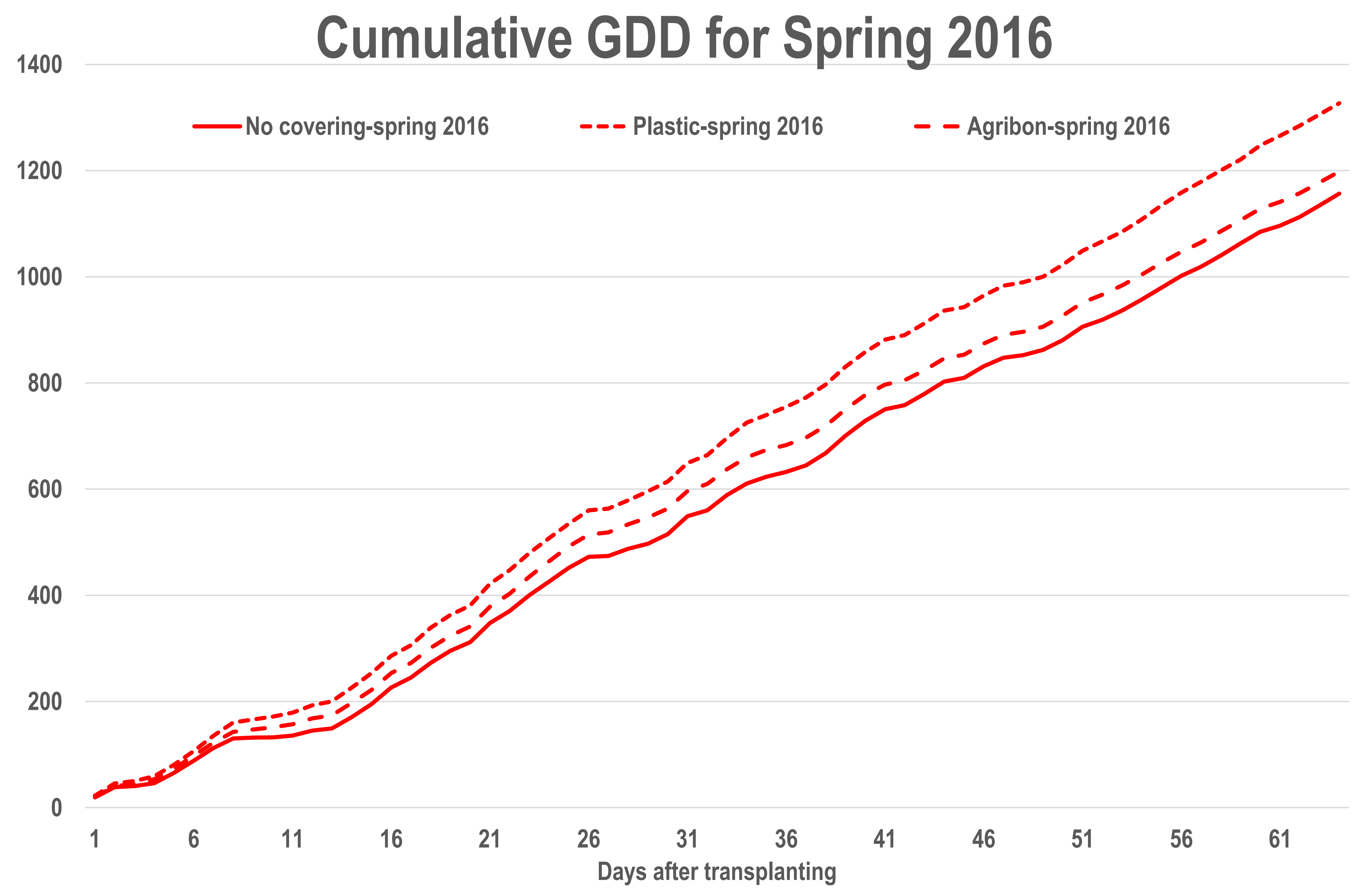


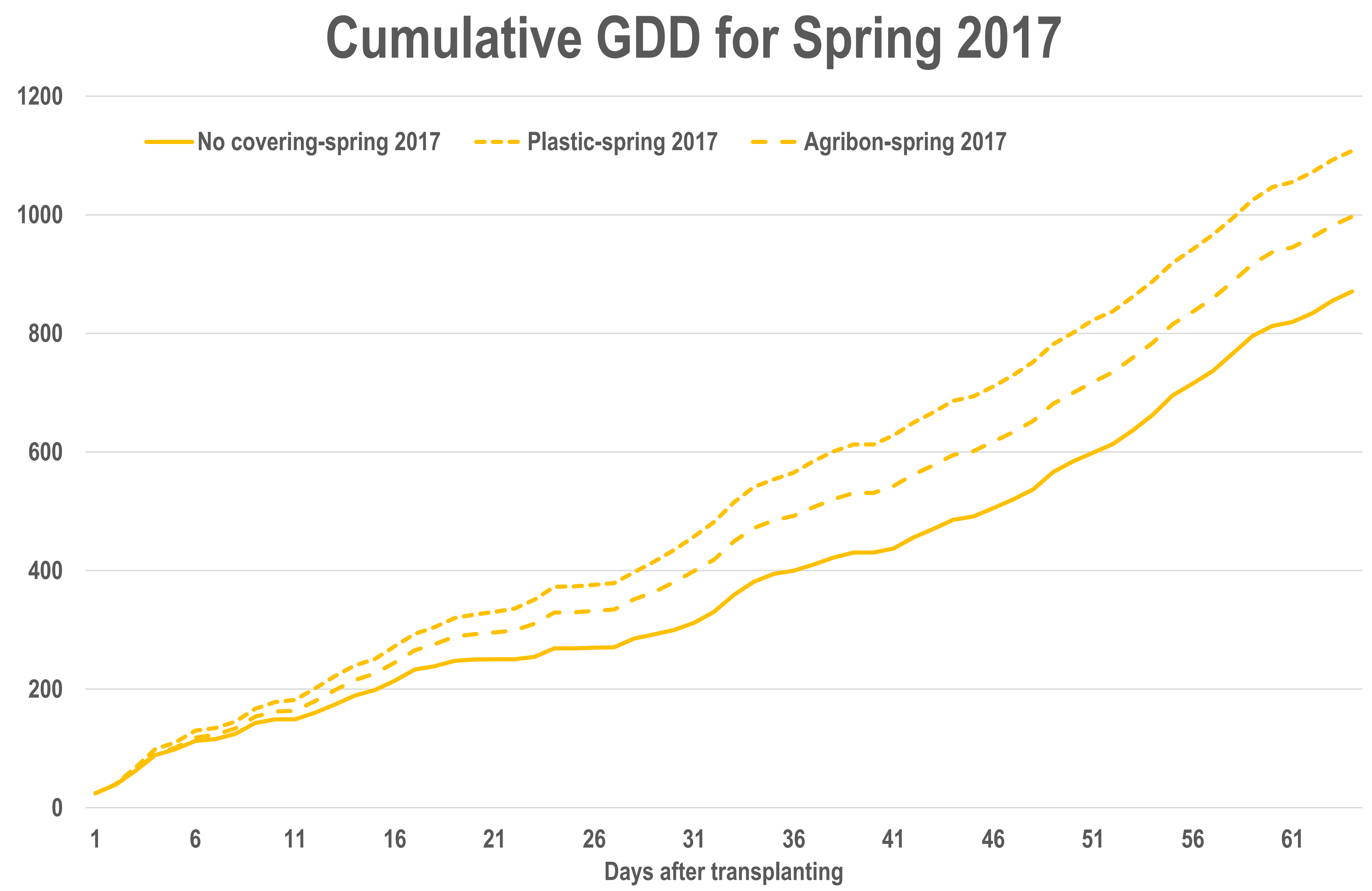
Cumulative GDD for perforated film
Plastic-fall 2015
Plastic-spring 2016
Plastic-fall 2016
Plastic-spring 2017
0
200
400
600
800
1000
1200
1400
1
6
11
16
21
26
31
36
41
46
51
56
61
Days after transplanting

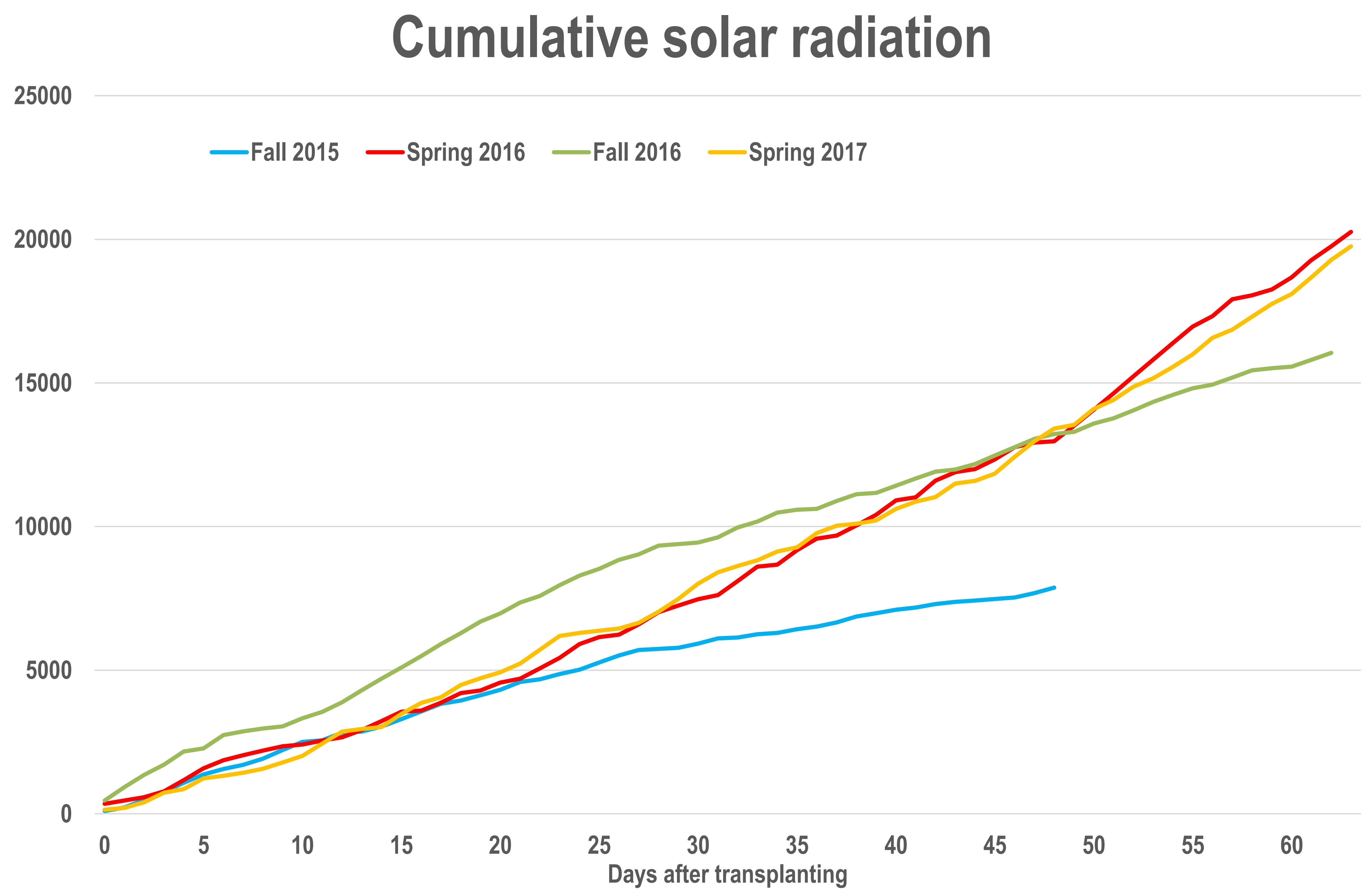


Cumulative GDD for Fall 2015
No covering-fall 2015
Plastic-fall 2015
Agribon-fall 2015
1000
900
800
700
600
500
400
300
200
100
0
1
6
11
16
21
26
31
36
41
46
51
56
61
Days after transplanting

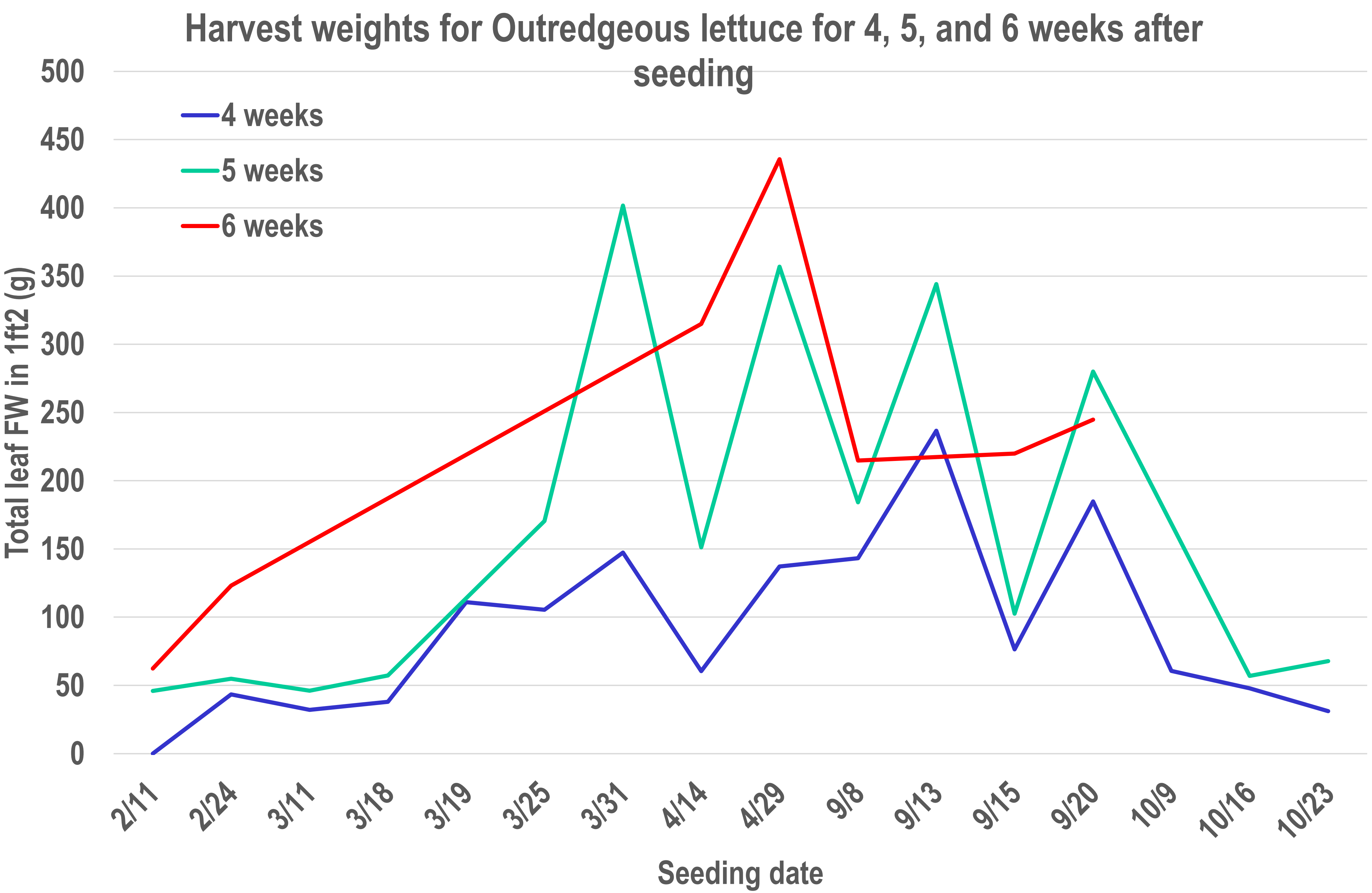

Cumulative GDD for Fall 2016
1400
1200
1000
800
600
400
200
0
No covering-fall 2016
Plastic-fall 2016
Agribon-fall 2016
1
6
11
16
21
26
31
36
41
46
51
56
61
Days after transplanting


Cumulative GDD for Spring 2016
No covering-spring 2016
Plastic-spring 2016
Agribon-spring 2016
1400
1200
1000
800
600
400
200
0
1
6
11
16
21
26
31
36
41
46
51
56
61
Days after transplanting

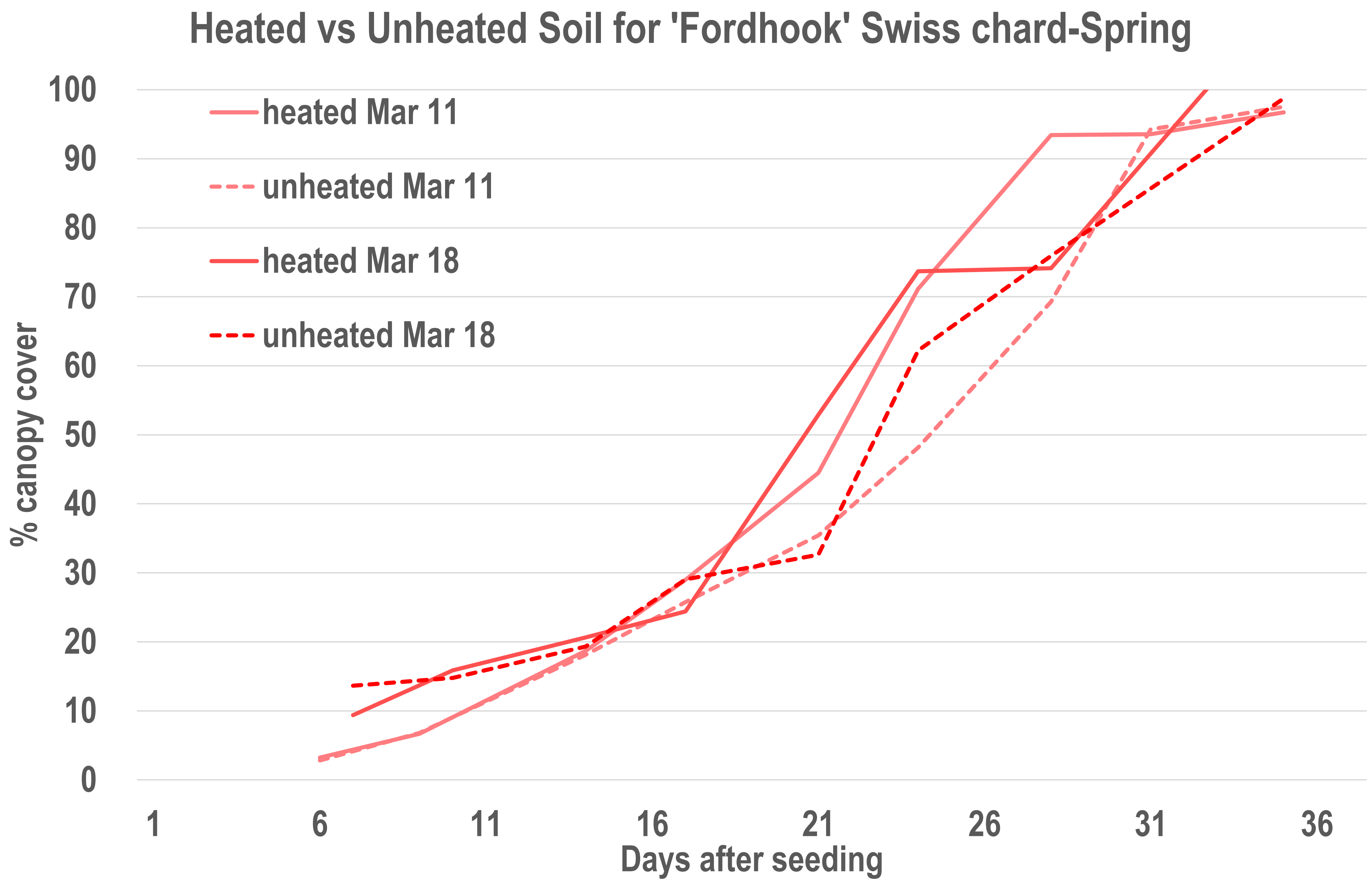

Cumulative GDD for Spring 2017
No covering-spring 2017
Plastic-spring 2017
Agribon-spring 2017
1200
1000
800
600
400
200
0
1
6
11
16
21
26
31
36
41
46
51
56
61
Days after transplanting

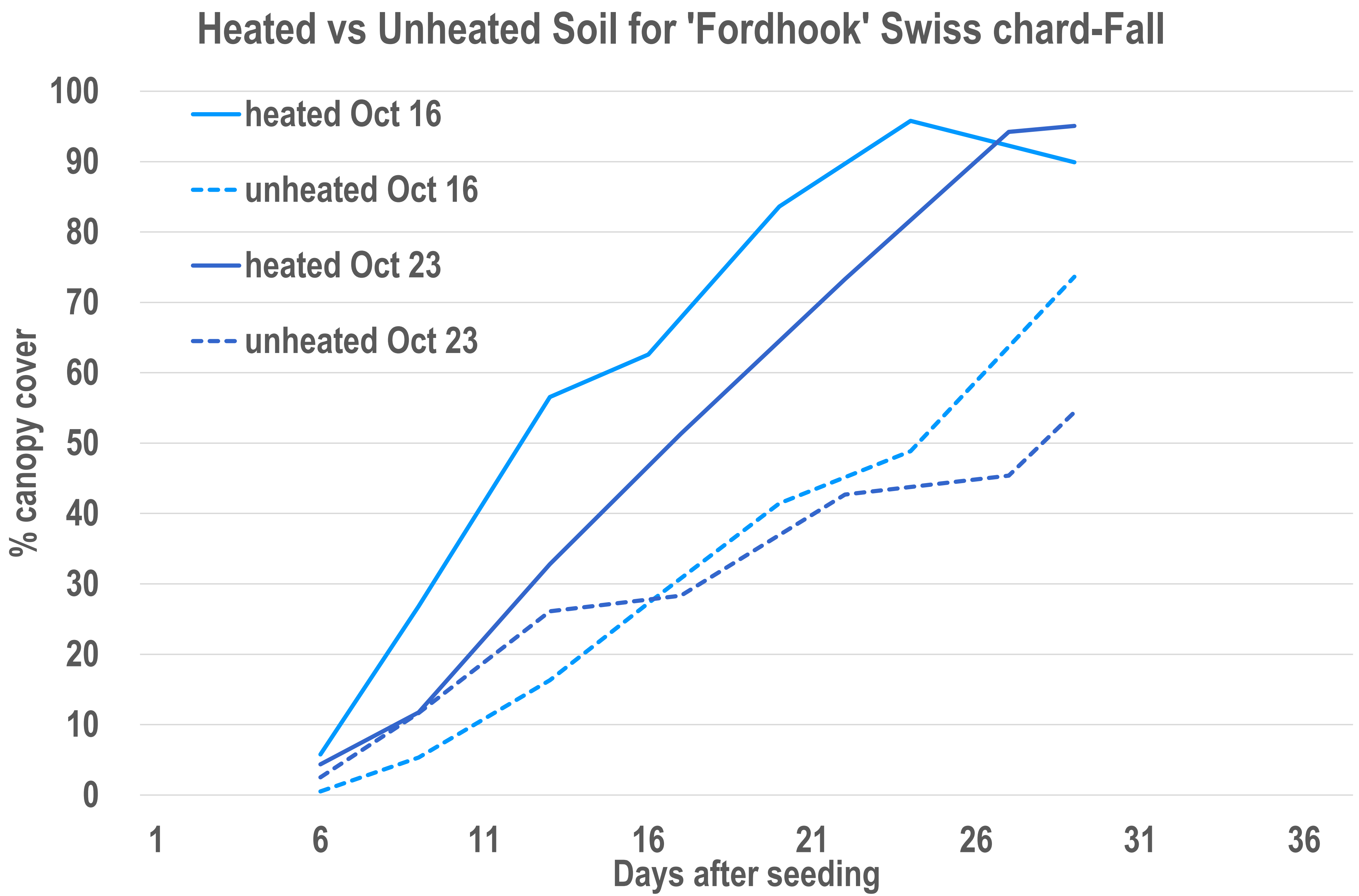


Cumulative solar radiation
Fall 2015
Spring 2016
Fall 2016
Spring 2017
25000
20000
15000
10000
5000
0
0
5
10
15
20
25
30
35
40
45
50
55
60
Days after transplanting

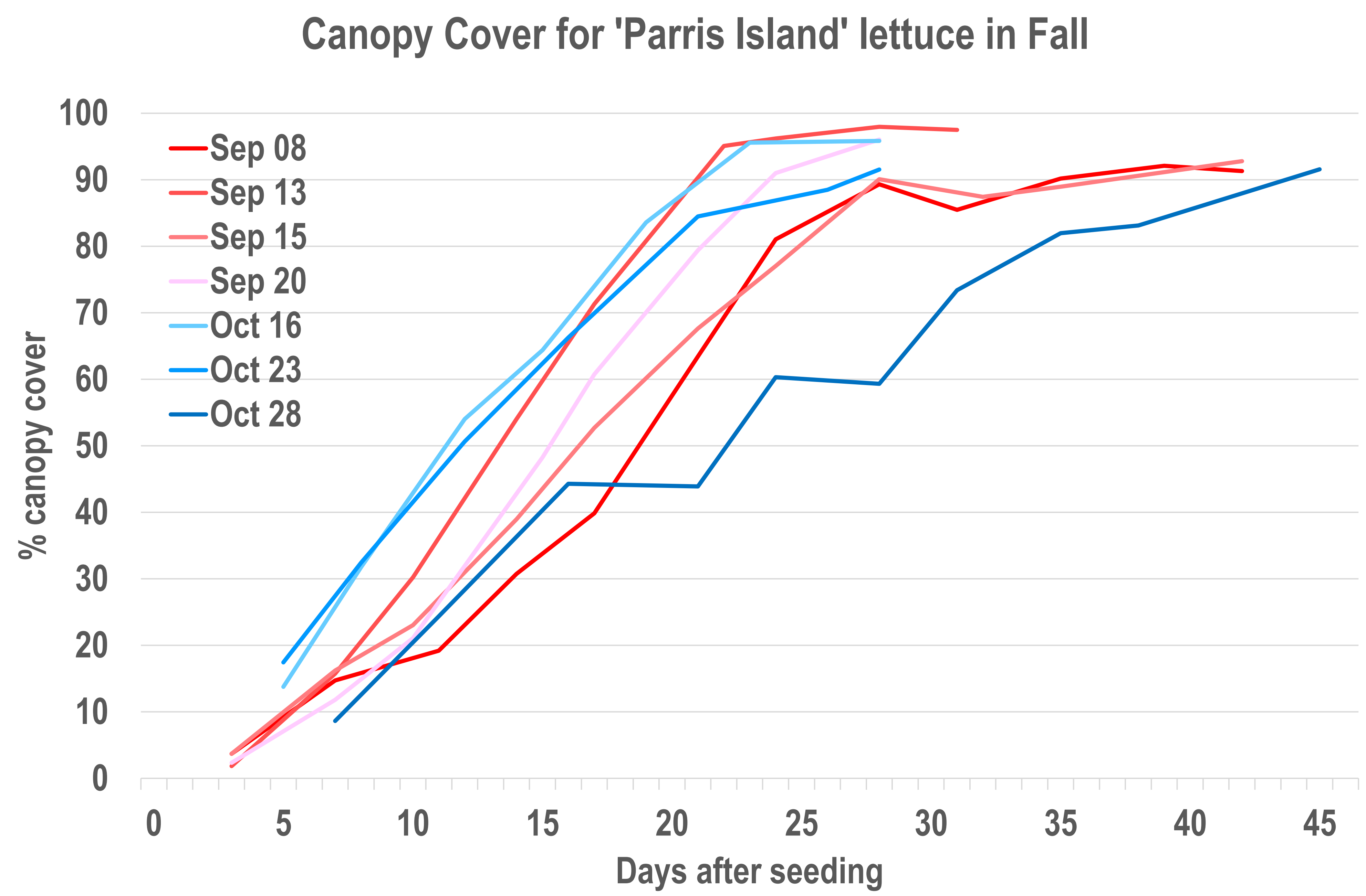


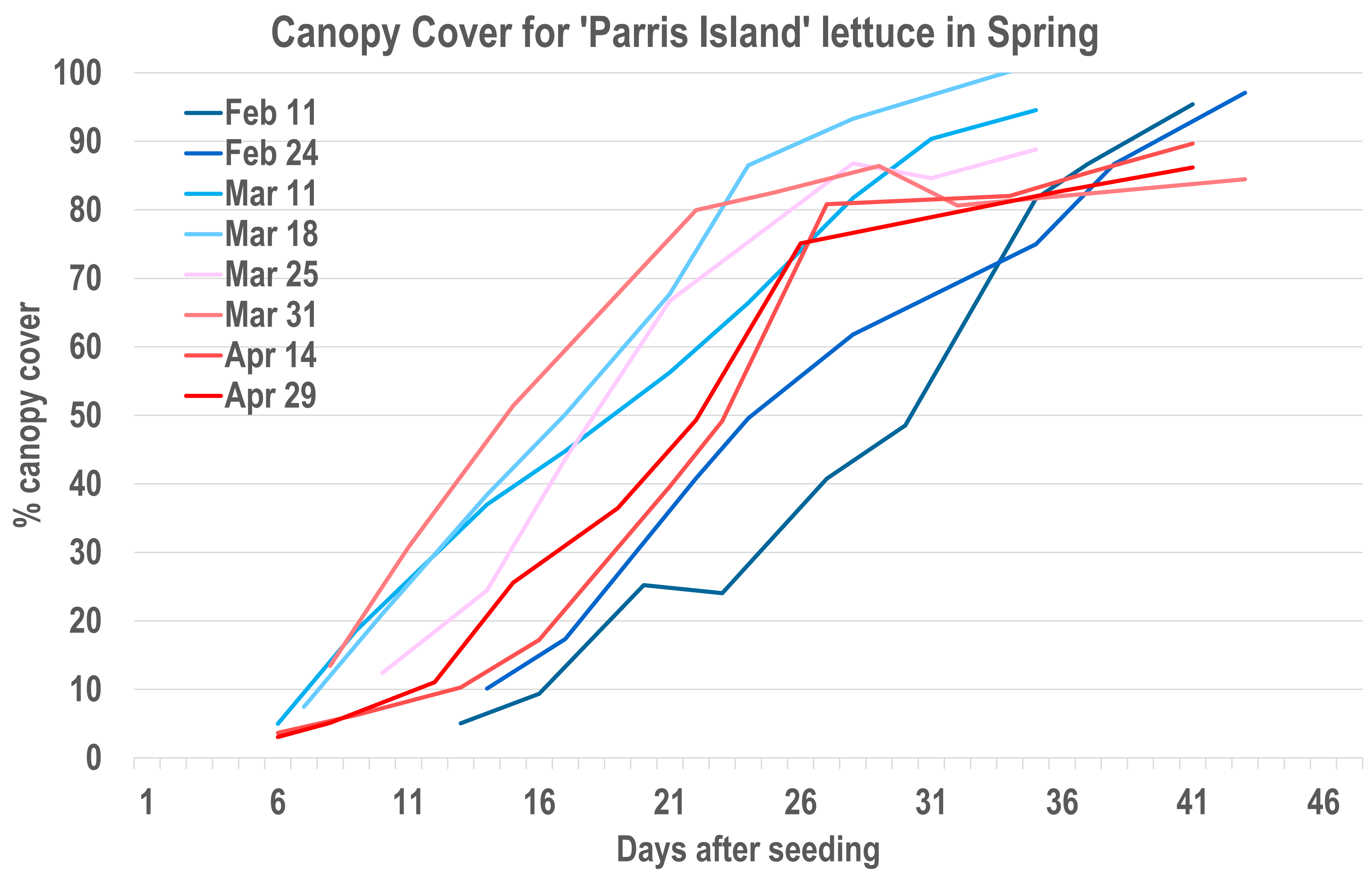
Harvest weights for Outredgeous lettuce for 4, 5, and 6 weeks after seeding
4 weeks
5 weeks
6 weeks
Total leaf FW in 1ft2 (g)
0
50
100
150
200
250
300
350
400
450
500
2/11
2/24
3/11
3/18
3/19
3/25
3/31
4/14
4/29
9/8
9/13
9/15
9/20
10/9
10/16
10/23
Seeding date

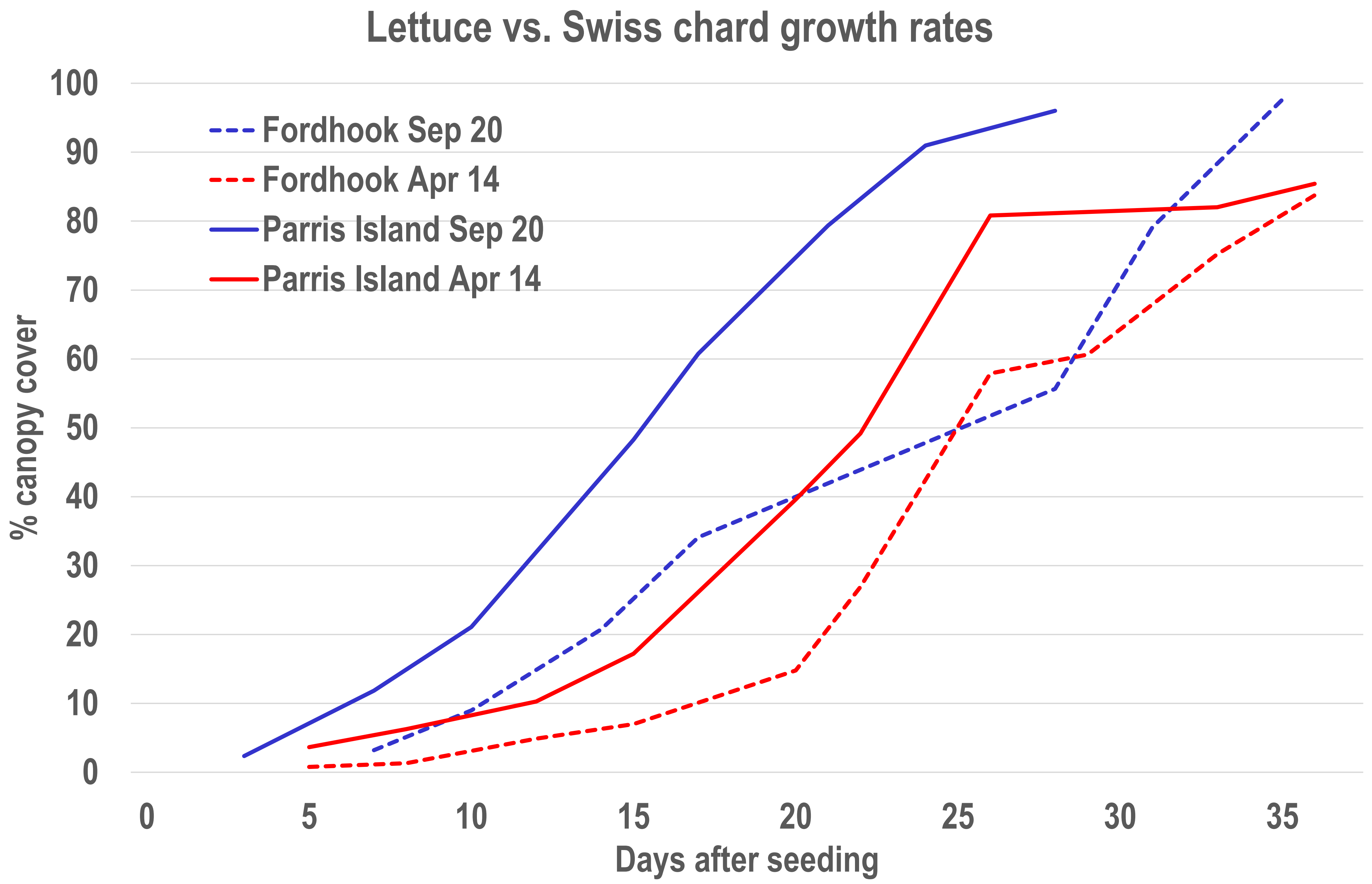

Heated vs Unheated Soil for 'Fordhook' Swiss chard-Spring
heated Mar 11
unheated Mar 11
heated Mar 18
unheated Mar 18
% canopy cover
0
10
20
30
40
50
60
70
80
90
100
1
6
11
16
21
26
31
36
Days after seeding



Heated vs Unheated Soil for 'Fordhook' Swiss chard-Fall
heated Oct 16
unheated Oct 16
heated Oct 23
unheated Oct 23
% canopy cover
0
10
20
30
40
50
60
70
80
90
100
1
6
11
16
21
26
31
36
Days after seeding


Canopy Cover for 'Parris Island' lettuce in Fall
% canopy cover
Days after seeding
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30
35
40
45
Sep 08
Sep 13
Sep 15
Sep 20
Oct 16
Oct 23
Oct 28


Canopy Cover for 'Parris Island' lettuce in Spring
100
90
80
70
60
50
40
30
20
10
0
% canopy cover
Feb 11
Feb 24
Mar 11
Mar 18
Mar 25
Mar 31
Apr 14
Apr 29
1
6
11
16
21
26
31
36
41
46
Days after seeding


Lettuce vs. Swiss chard growth rates
Fordhook Sep 20
Fordhook Apr 14
Parris Island Sep 20
Parris Island Apr 14
% canopy cover
Days after seeding
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30
35

Outredgeous Bed 22-heated (seeded 10/16/14)

Oct 21

Oct 24

Oct 28

Oct 31

Nov 4

Nov 8

Nov 13-harvested Nov 20

Nov 26

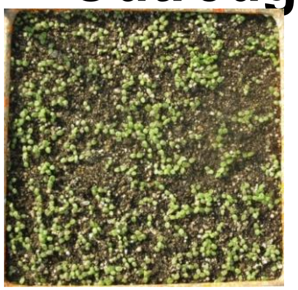
Dec 2

Dec 5

Dec 12

Outredgeous Bed 29-unheated (seeded 10/16/14)

Oct 21

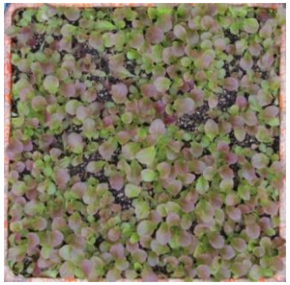


Oct 24

Oct 28

Oct 31

Nov 4



Nov 8

Nov 13-harvested

Dec 2

Dec 12

Parris Island Bed 23-heated (seeded 10/23/14)

Oct 28

Oct 31

Nov 4

Nov 8

Nov 13

Nov 18

Nov 20-harvested

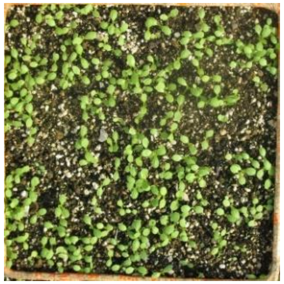
Dec 5

Dec 12

Parris Island Bed 37-unheated (seeded 10/23/14)

Oct 28

Oct 31



Nov 4

Nov 8

Nov 13

Nov 18

Nov 20-harvested Dec 5

Dec 12

Ovation Bed 31-heated (seeded 10/16/14)

Oct 21

Oct 24

Oct 28

Oct 31

Nov 4

Nov 8

Nov 13-harvested Dec 5

Dec 12

Ovation Bed 38-unheated (seeded 10/16/14)

Oct 21

Oct 24

Oct 28

Oct 31

Nov 4

Nov 8

Nov 13-harvested

Dec 5

Dec 12

Oriole Bed 32-heated (seeded 10/16/14)

Oct 21

Oct 24

Oct 28

Oct 31

Nov 4

Nov 8

Nov 13-harvested Dec 5

Dec 12

Oriole Bed 36-unheated (seeded 10/16/14)

Oct 21

Oct 24

Oct 28

Oct 31

Nov 4

Nov 8

Nov 13-harvested Dec 12

Fordhook Bed 21-heated (seeded 10/23/14)

Oct 28

Oct 31

Nov 4

Nov 8

Nov 13

Nov 18

Nov 20-harvested

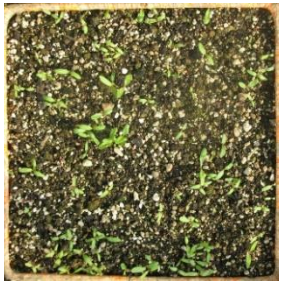
Dec 5

Dec 12

Fordhook Bed 39-unheated (seeded 10/23/14)

Oct 28

Oct 31



Nov 4

Nov 8

Nov 13

Nov 18

Nov 20-harvested

Dec 12

Parris Island Bed 23-heated (seeded 10/23/14)


Oct 28


Oct 31


Nov 4


Nov 8


Nov 13


Nov 18


Nov 20-harvested

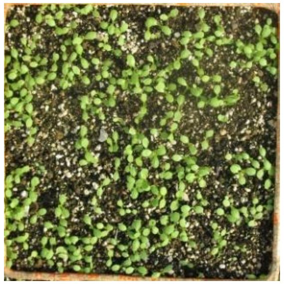

Dec 5


Dec 12

Parris Island Bed 37-unheated (seeded 10/23/14)

Oct 28

Oct 31



Nov 4

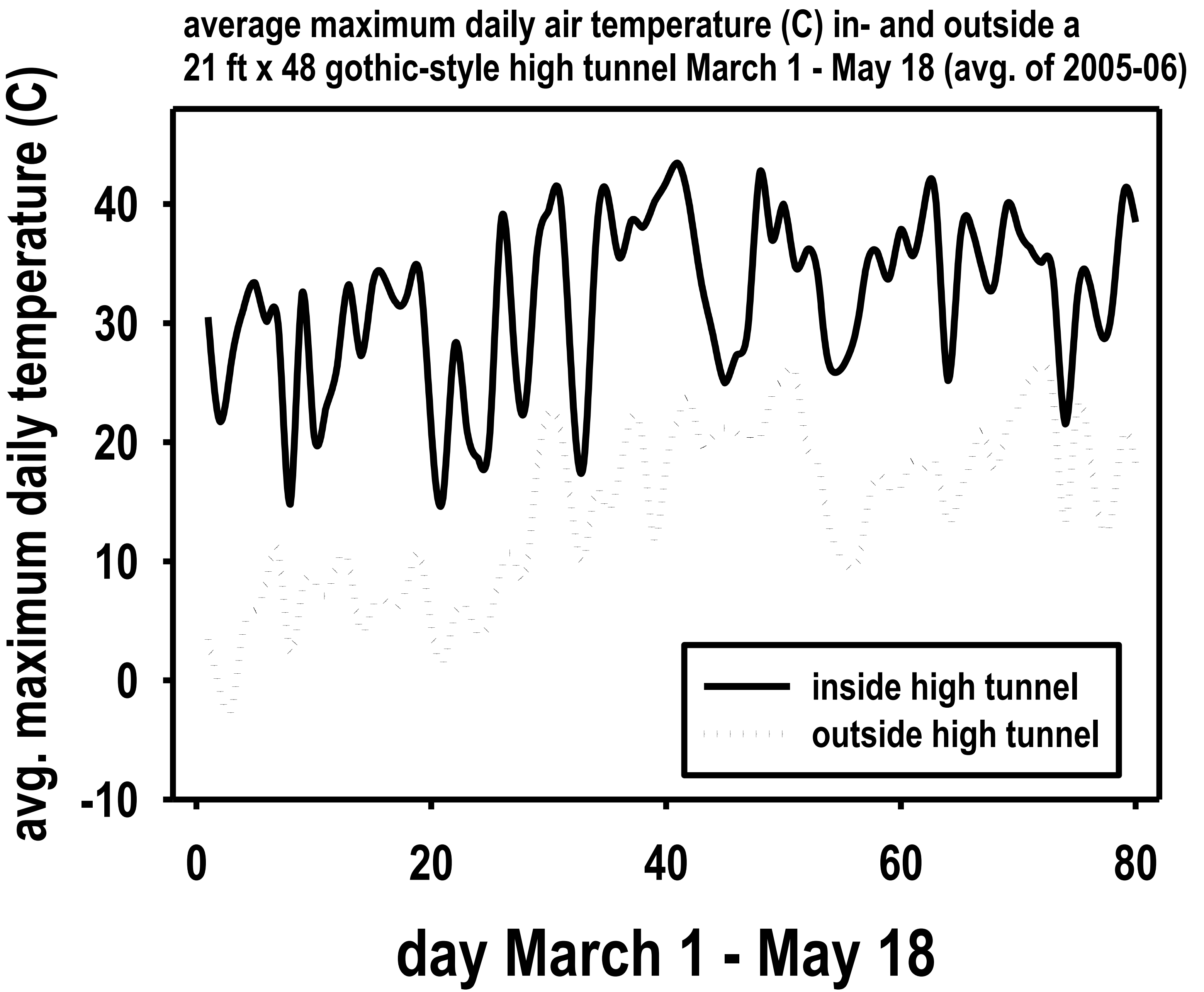
Nov 8

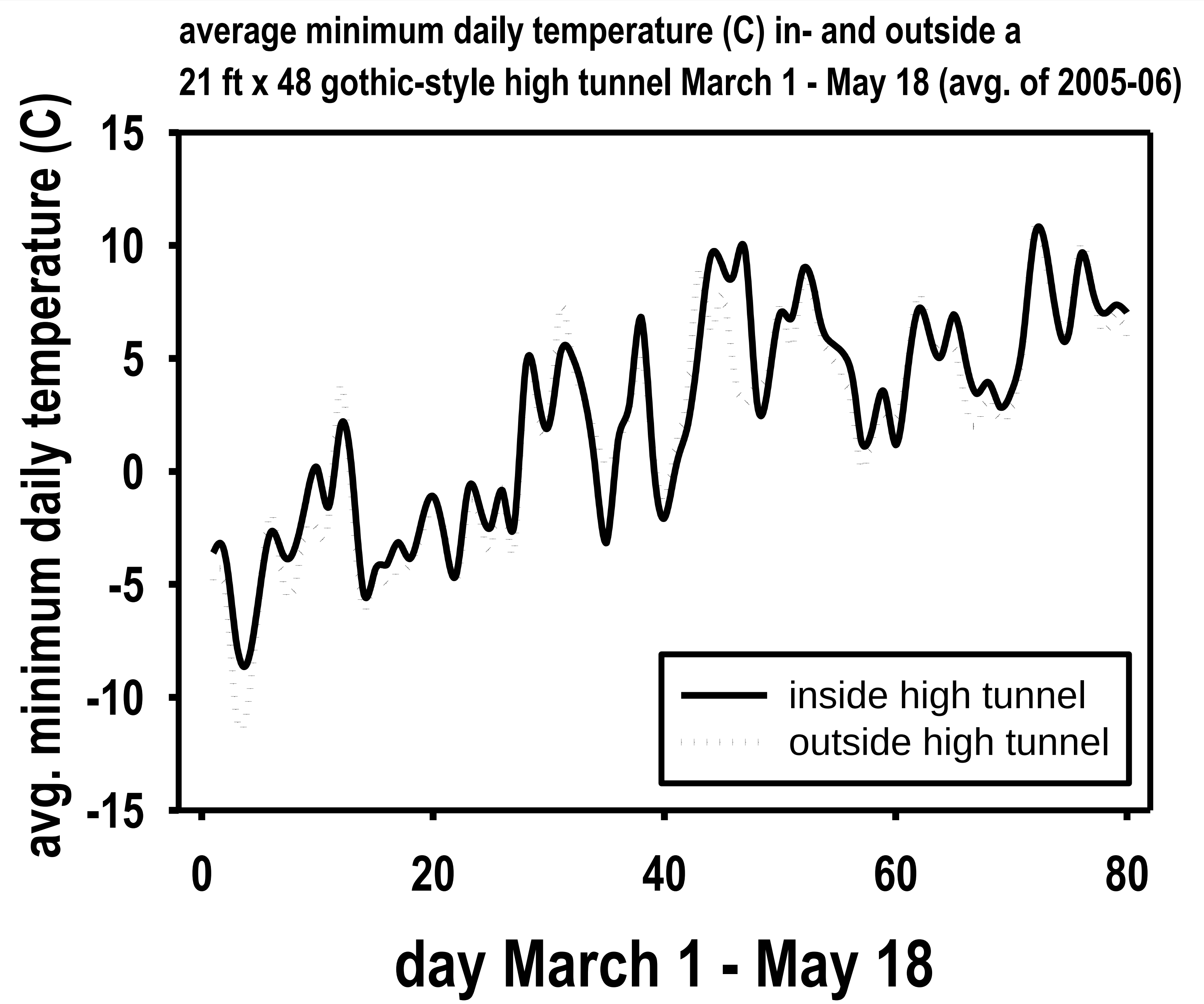
Nov 13

Nov 18

Nov 20-harvested Dec 5

Dec 12


average maximum daily air temperature (C) in- and outside a
21 ft x 48 gothic-style high tunnel March 1 - May 18 (avg. of 2005-06)
avg. maximum daily temperature (C)
40
30
20
10
0
-10
0
20
40
60
80
day March 1 - May 18
inside high tunnel
outside high tunnel


average minimum daily temperature (C) in- and outside a
21 ft x 48 gothic-style high tunnel March 1 - May 18 (avg. of 2005-06)
avg. minimum daily temperature (C)
15
10
5
0
-5
-10
-15
0
20
40
60
80
day March 1 - May 18
inside high tunnel
outside high tunnel

Growing Degree Days and Phenology for Ohio

THE OHIO STATE UNIVERSITY OARDC EXTENSION

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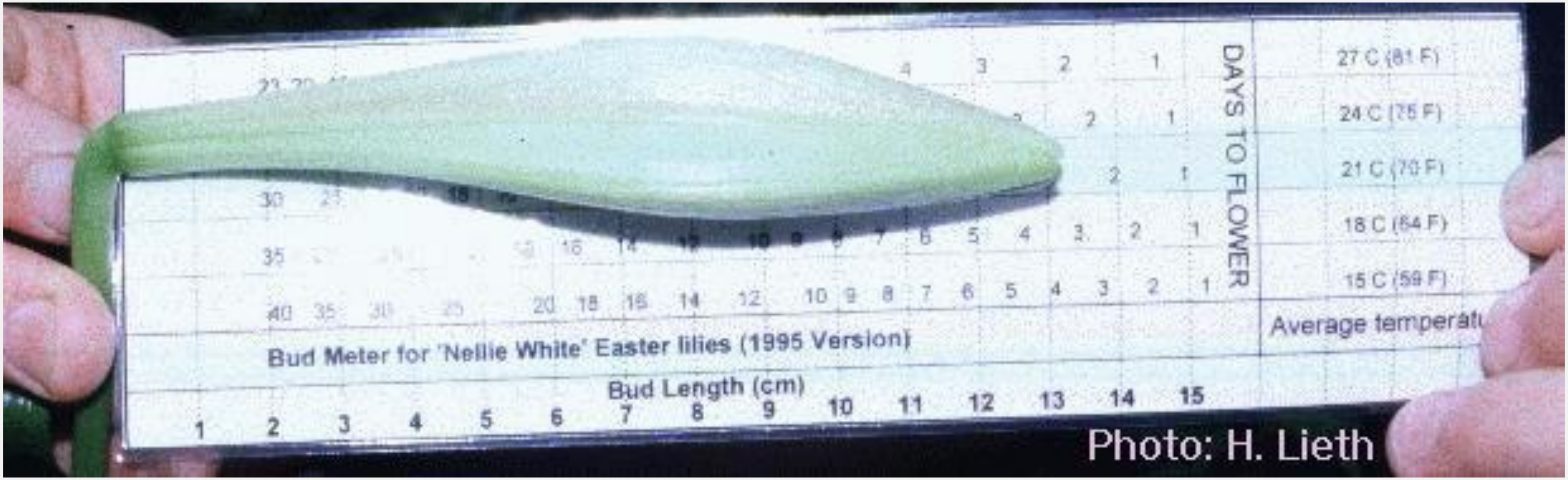
The GDD of Wooster on 3/25/2011 is 37

Summary of Phenological Events

Species	Phenological Event	GDD	Link
Silver Maple	first bloom	34	F P P
Species	**Event**	**Growing Degree Days**	**Link**
Wooster		37	
Corneliancherry Dogwood	first bloom	40	F F
Silver Maple	full bloom	42	F P P
Red Maple	first bloom	44	F P P
Speckled Alder	first bloom	52	F F
Northern Lights Forsythia	first bloom	58	F
Japanese Pieris	first bloom	60	F F
Red Maple	full bloom	75	F P
Star Magnolia	first bloom	83	P P F
White Pine Weevil	adult emergence	84	F
Border Forsythia	first bloom	86	F F
Eastern Tent Caterpillar	egg hatch	92	F
Manchu Cherry	first bloom	93	F F
Northern Lights Forsythia	full bloom	94	F
Speckled Alder	full bloom	97	F F
Corneliancherry Dogwood	full bloom	98	F F
Norway Maple	first bloom	116	F M
Border Forsythia	full bloom	116	F F
Chanticleer Callery Pear	first bloom	123	F F F
Sargent Cherry	first bloom	127	F F

Natural, seasonal events such as the blooming of landscape plants and emergence of insects can be predicted with GDD values.



Producing and marketing certain crops relies on GDD calculation.