Welcome to the Plant Physiology Short Course

Paula del Valle Escalona

1. **Basics**
2. **General growth & development**
3. **Environmental effects**
4. **Manipulations to growth & development**
    - **Blueberries**
    - **Strawberries**
    - **Blackberries**
    - **Raspberries**

1. Basics

- Plant body
  - morphology/anatomy
  - membranes
- Water uptake/movement
- Nutrient uptake
- Photosynthesis
- Source/sink relations

Plant body – Structure/Function

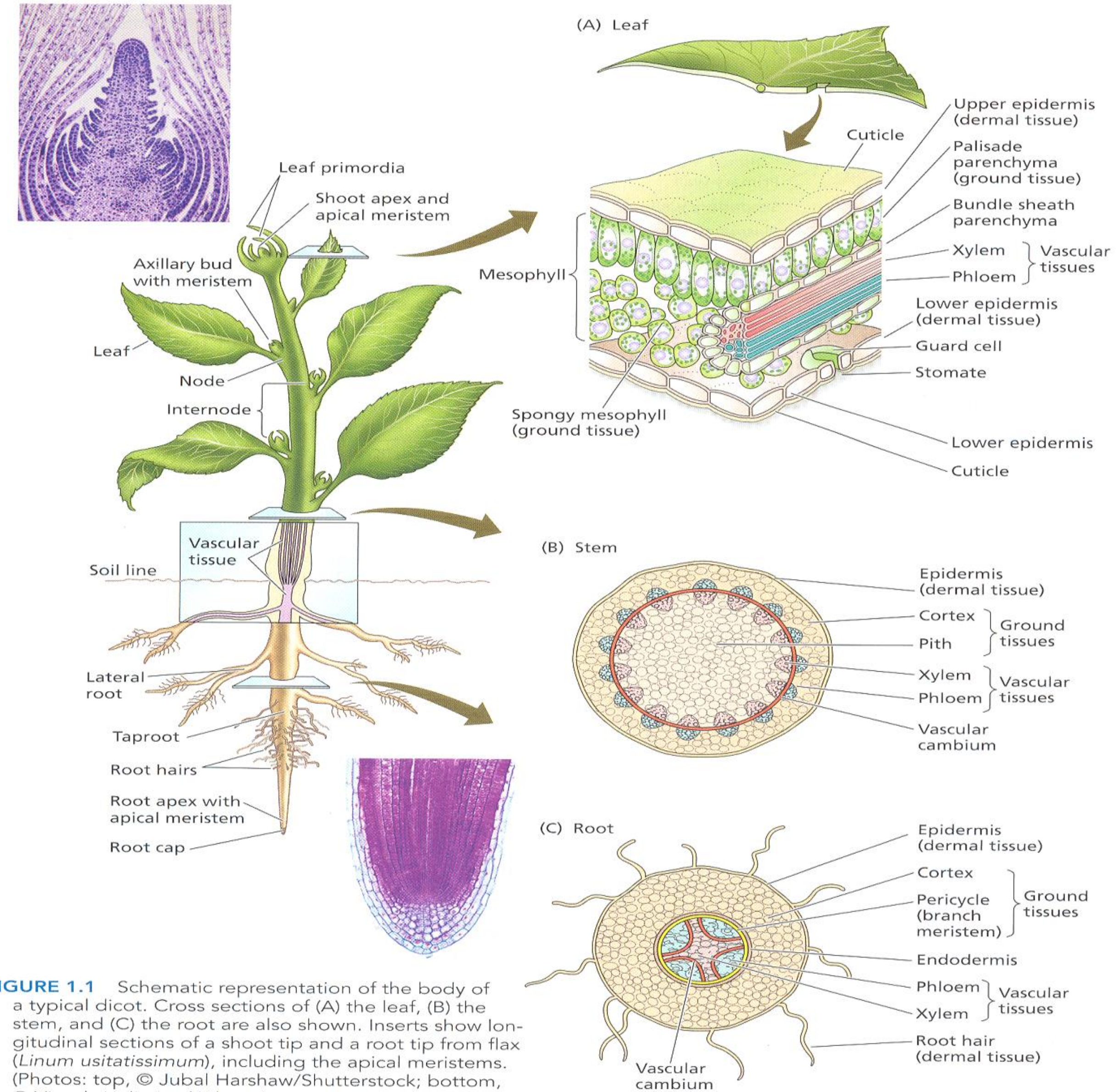
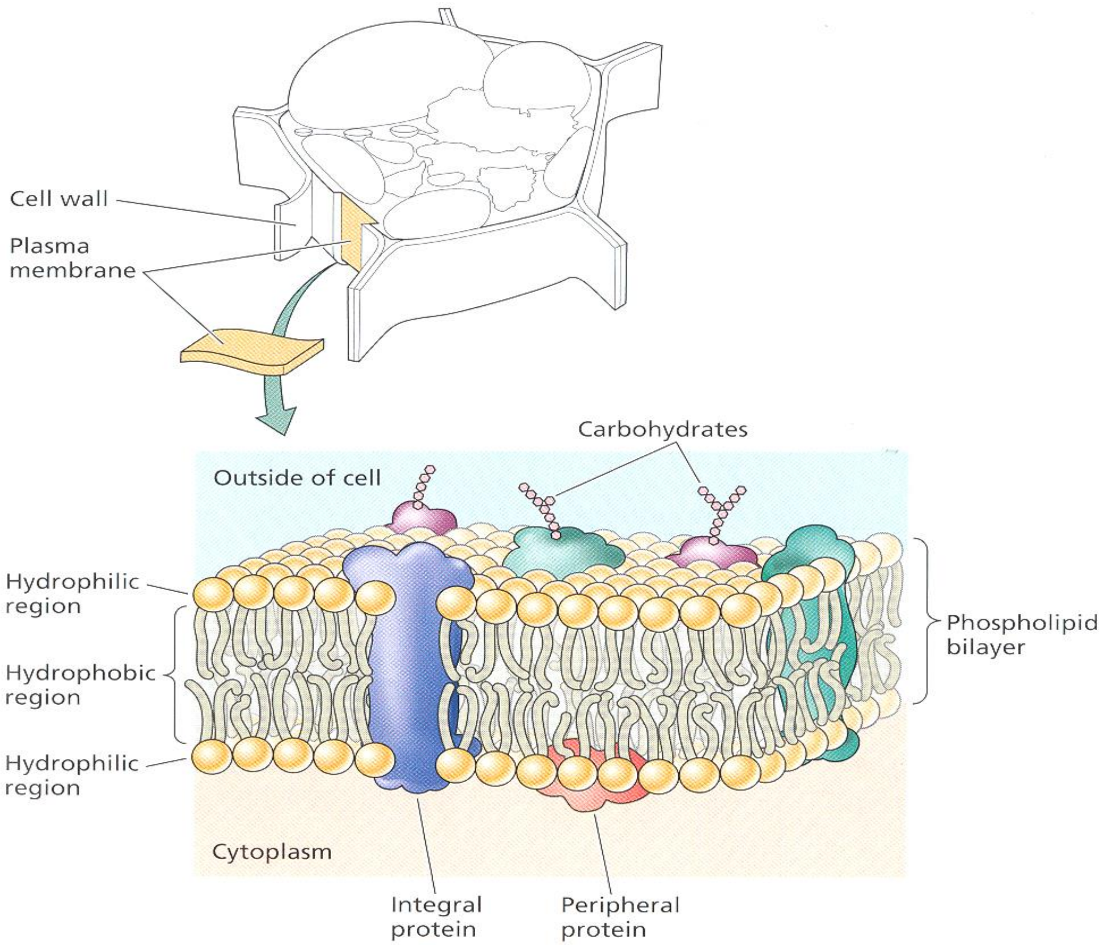


FIGURE 1.1 Schematic representation of the body of a typical dicot. Cross sections of (A) the leaf, (B) the stem, and (C) the root are also shown. Inserts show longitudinal sections of a shoot tip and a root tip from flax (*Linum usitatissimum*), including the apical meristems. (Photos: top, © Jubal Harshaw/Shutterstock; bottom, © Visuals Unlimited/Alamy.)

Plant membranes



Water Uptake & Movement

Water movement from soil to leaves

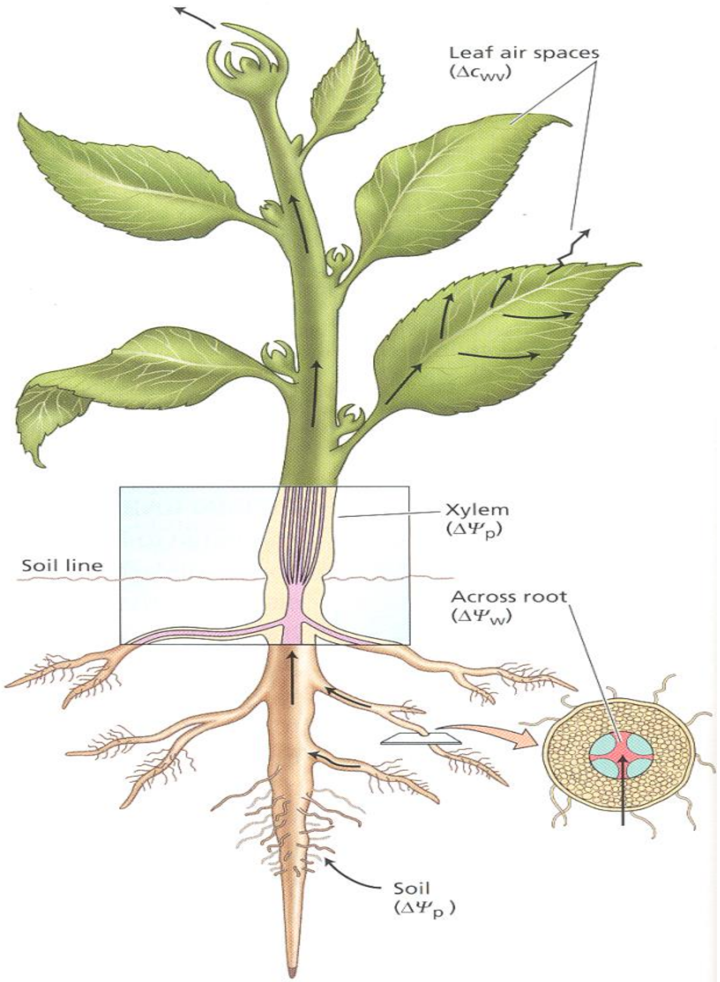


FIGURE 4.1 Main driving forces for water flow from the soil through the plant to the atmosphere: differences in water vapor concentration (Δc_{wv}), hydrostatic pressure ($\Delta \Psi_p$), and water potential ($\Delta \Psi_w$).

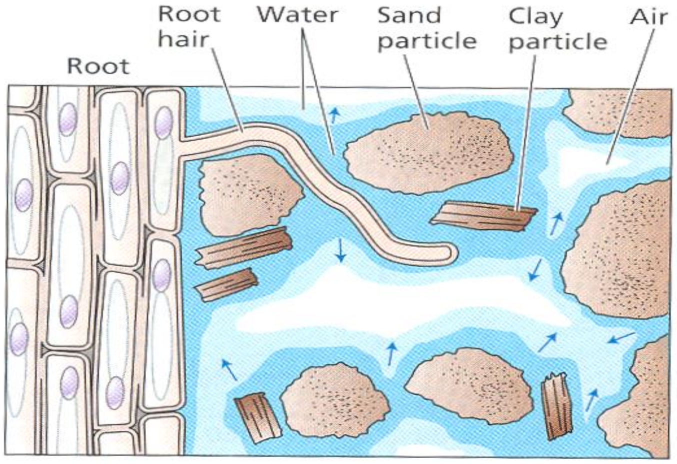


FIGURE 4.2 Root hairs make intimate contact with soil particles and greatly amplify the surface area that can be used for water absorption by the plant. The soil is a mixture of particles (sand, clay, silt, and organic material), water, dissolved solutes, and air. Water is adsorbed to the surface of the soil particles. As water is absorbed by the plant, the soil solution recedes into smaller pockets, channels, and crevices between the soil particles. At the air–water interfaces, this recession causes the surface of the soil solution to develop concave menisci (curved interfaces between air and water marked in the figure by arrows), and brings the solution into tension (negative pressure) by surface tension. As more water is removed from the soil, more curved menisci are formed, resulting in greater tensions (more negative pressures).

Water absorption and transpiration

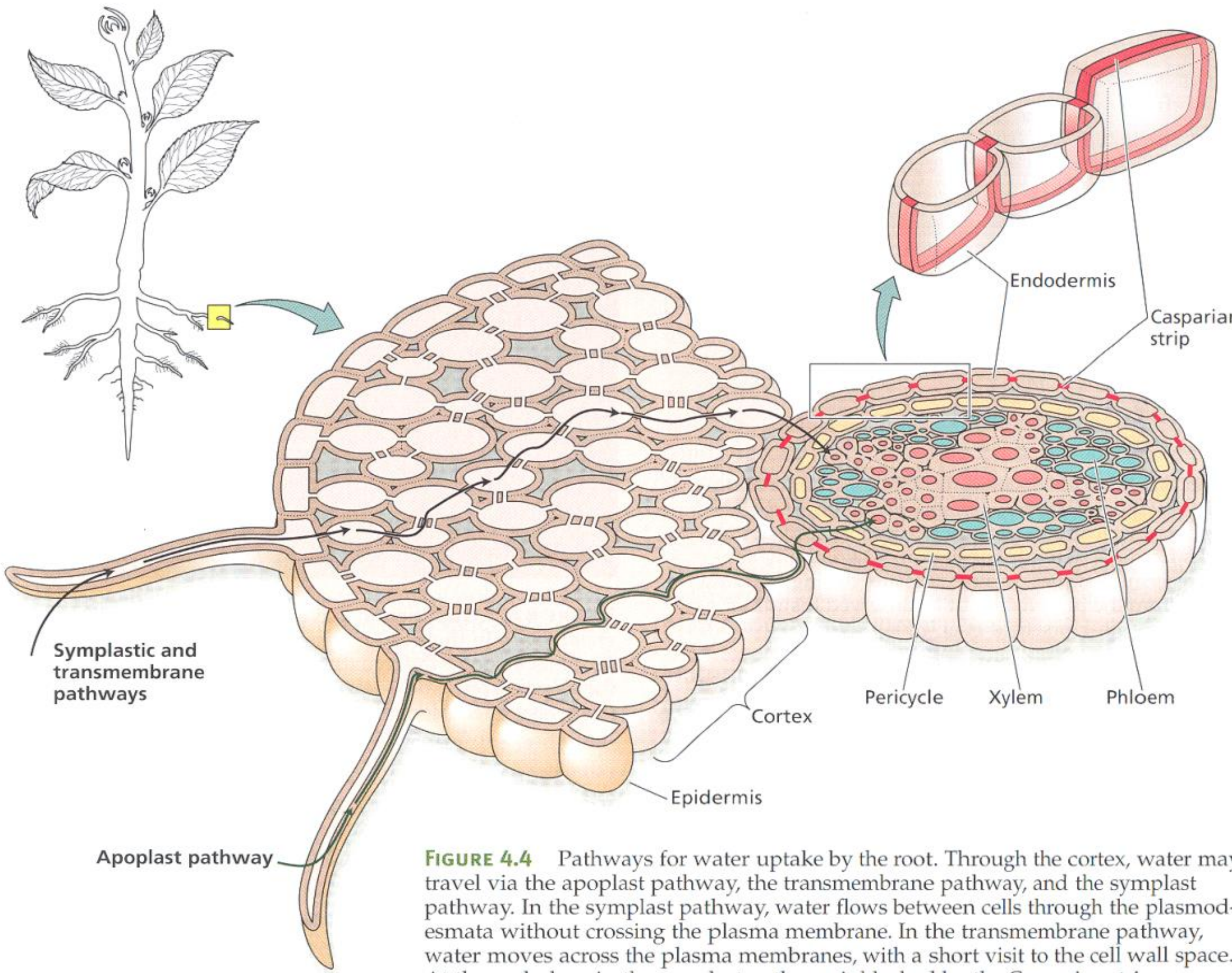
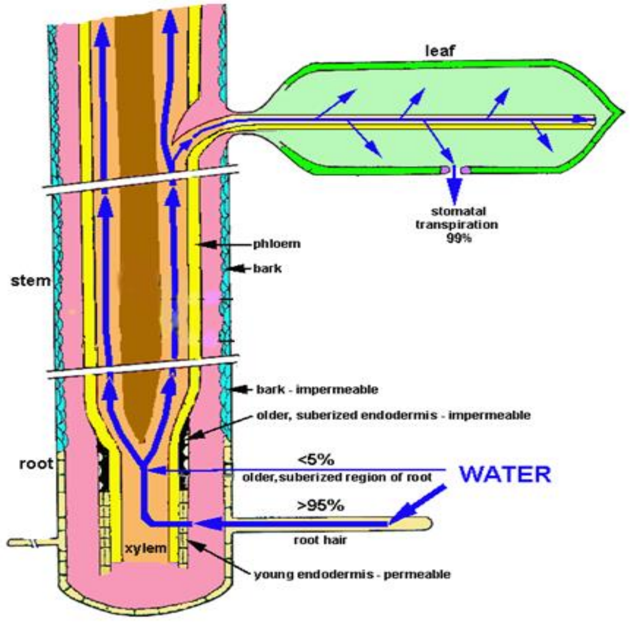
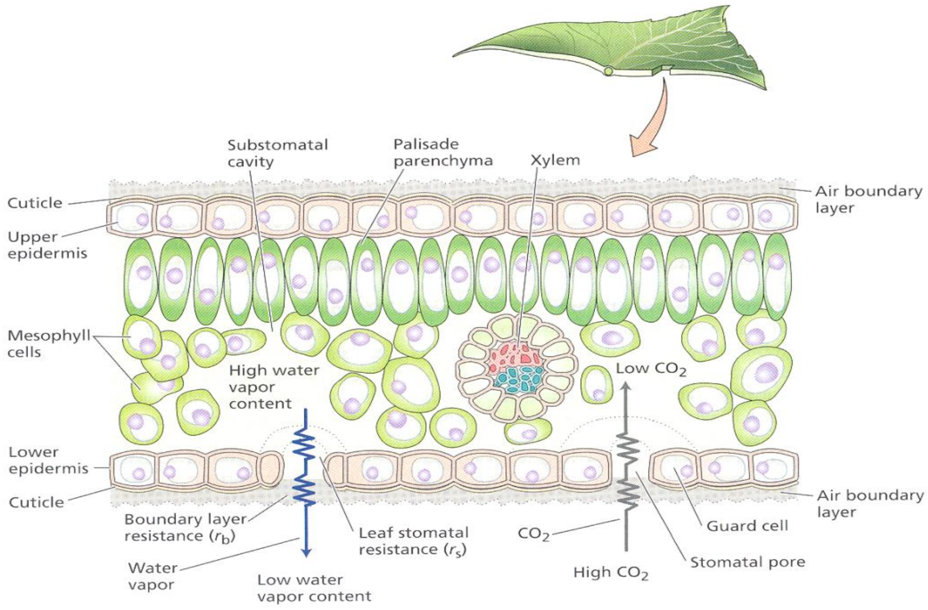


FIGURE 4.4 Pathways for water uptake by the root. Through the cortex, water may travel via the apoplast pathway, the transmembrane pathway, and the symplast pathway. In the symplast pathway, water flows between cells through the plasmodesmata without crossing the plasma membrane. In the transmembrane pathway, water moves across the plasma membranes, with a short visit to the cell wall space. At the endodermis, the apoplast pathway is blocked by the Casparian strip.

Water movement from root to shoot is driven by transpiration

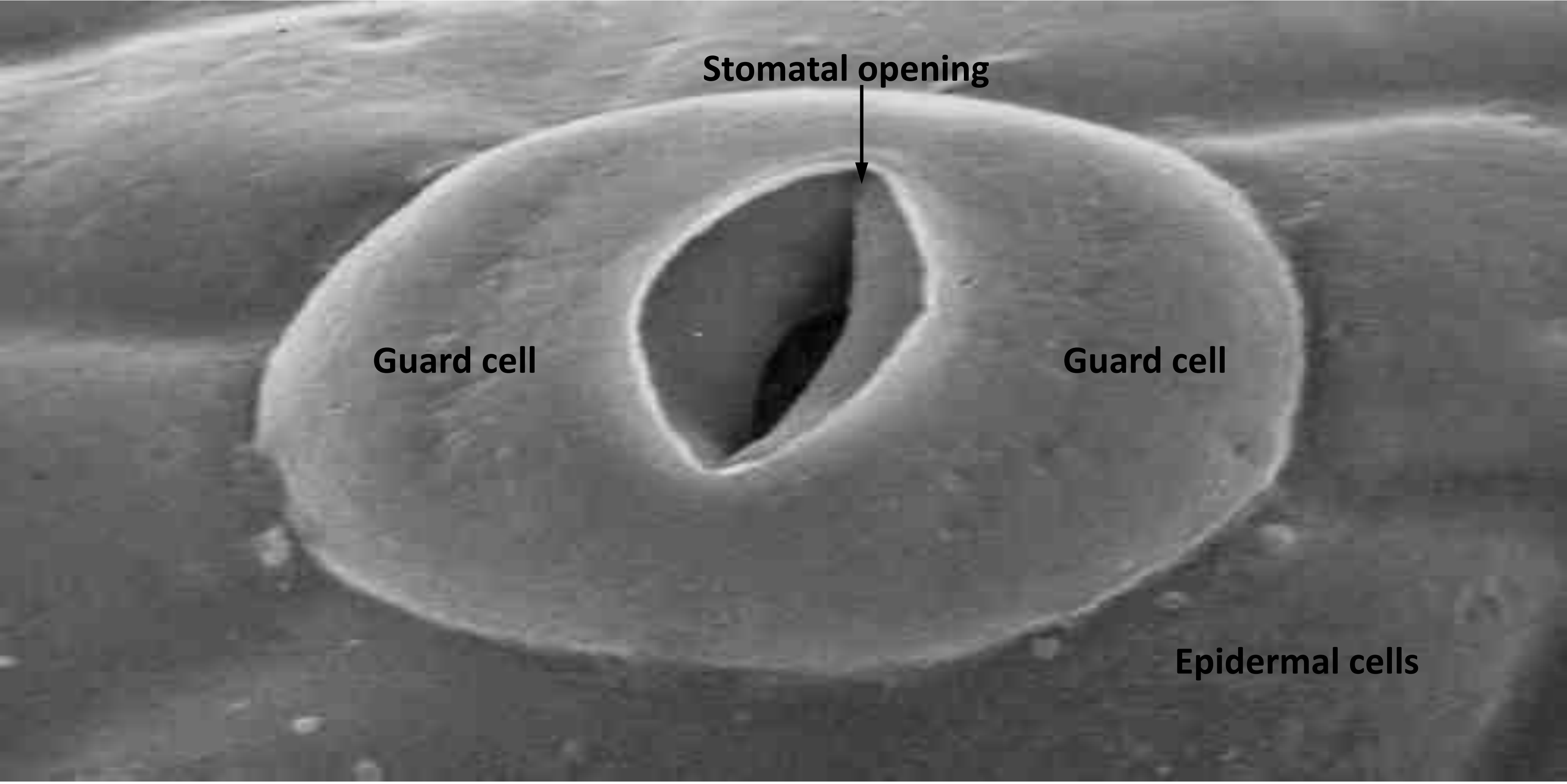




Water from xylem enters air and cell wall spaces of the leaf.

Water exits the leaf by diffusion through stomata, which open and close in response to environmental signals.

Transpiration cools the leaf and may speed the transport of nutrients



Factors affecting Transpiration

- Light – affects stomatal opening
- Water – affects stomatal opening
- RH – affects rate of H_2O evaporation
- Temp - affects rate of H_2O evaporation

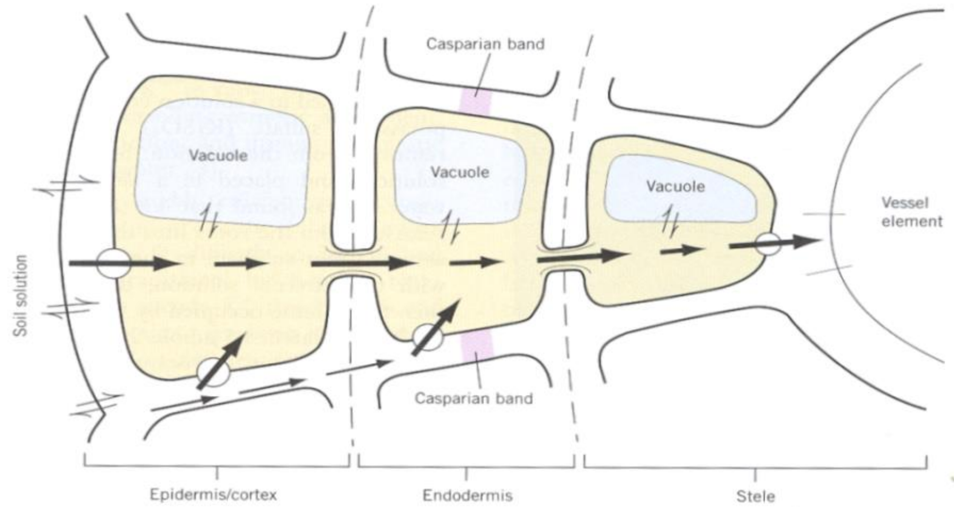
Although transpiration cools the leaf, it can lead to excess water loss!

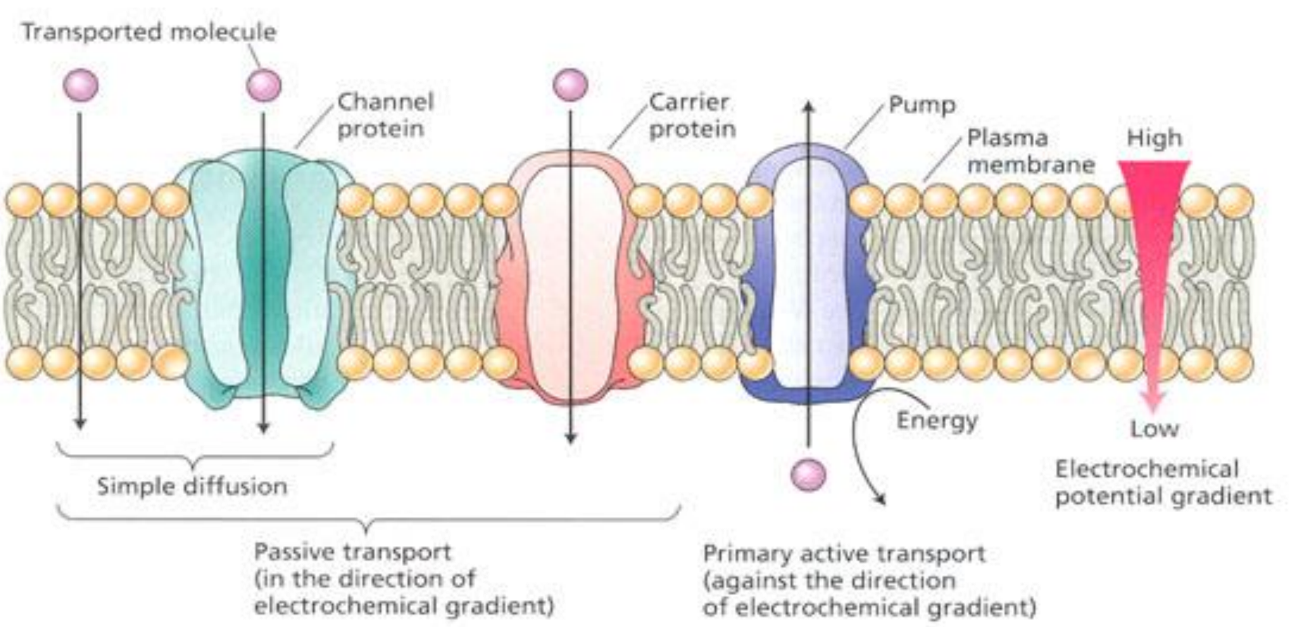
Decreased photosynthesis
Growth reduction
Decreased postharvest life

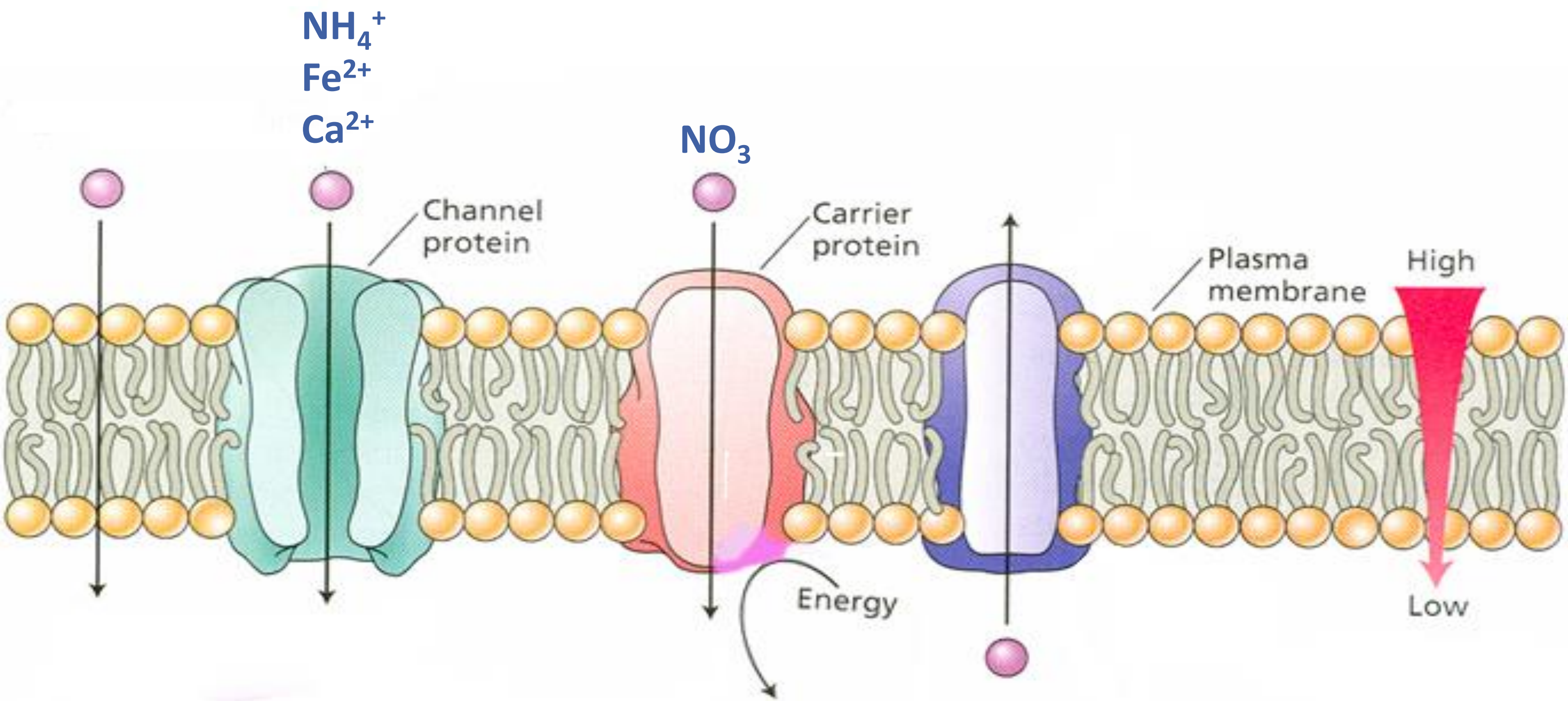
Nutrient Uptake & Movement

Name	Chemical symbol	Relative % in plant to N	Function in plant
Primary macronutrients			
Nitrogen	N	100	Proteins, amino acids
Phosphorus	P	6	Nucleic acids, ATP
Potassium	K	25	Catalyst, ion transport
Secondary macronutrients			
Calcium	Ca	12.5	Cell wall component
Magnesium	Mg	8	Part of chlorophyll
Sulfur	S	3	Amino acids
Iron	Fe	0.2	Chlorophyll synthesis
Micronutrients			
Copper	Cu	0.01	Component of enzymes
Manganese	Mn	0.1	Oxygen evolution
Zinc	Zn	0.03	Activates enzymes
Boron	B	0.2	Cell wall component
Chlorine	Cl	0.3	Photosynthesis reactions
Molybdenum	Mo	0.0001	Nitrogen fixation

Nutrient uptake

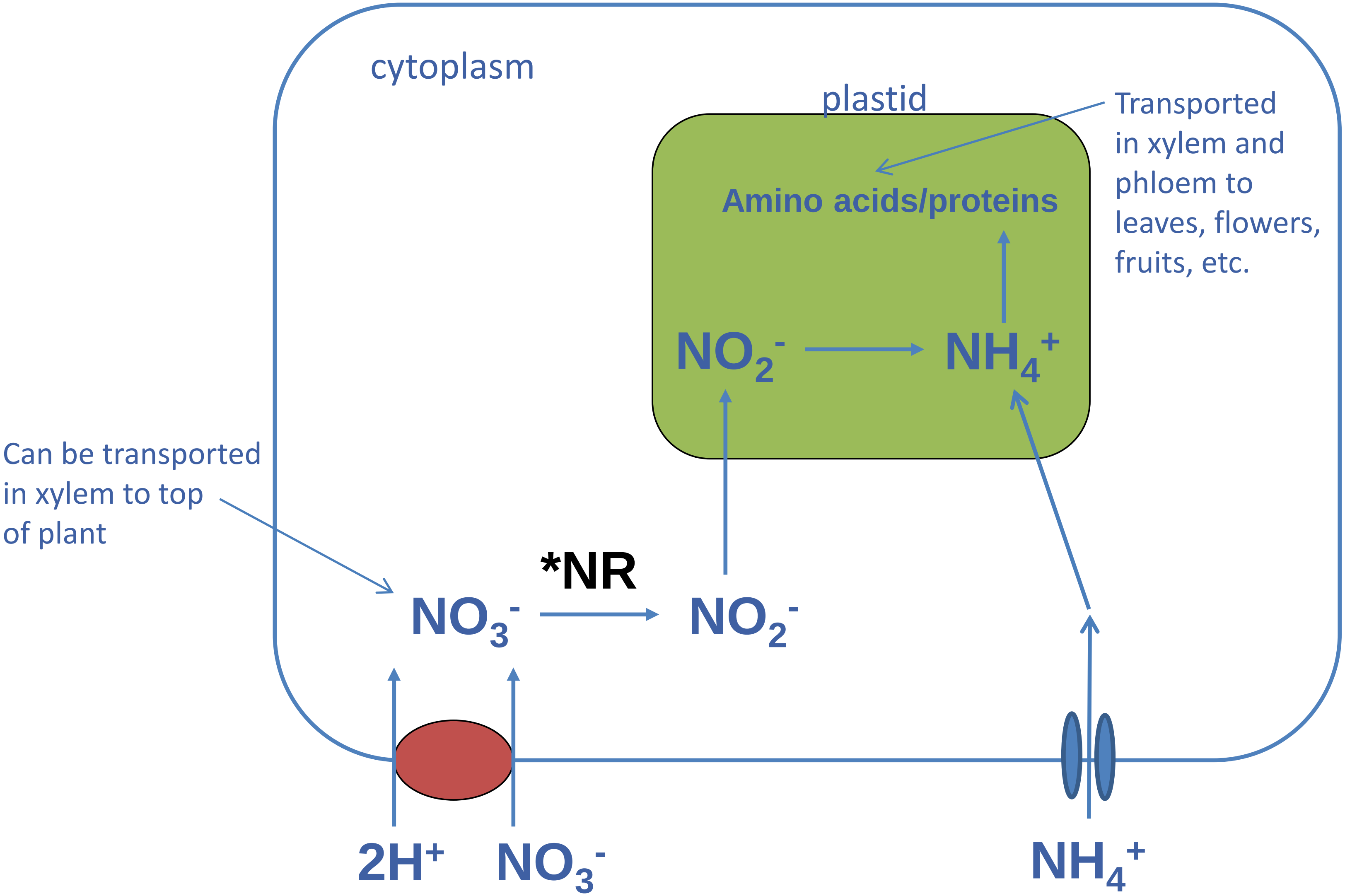






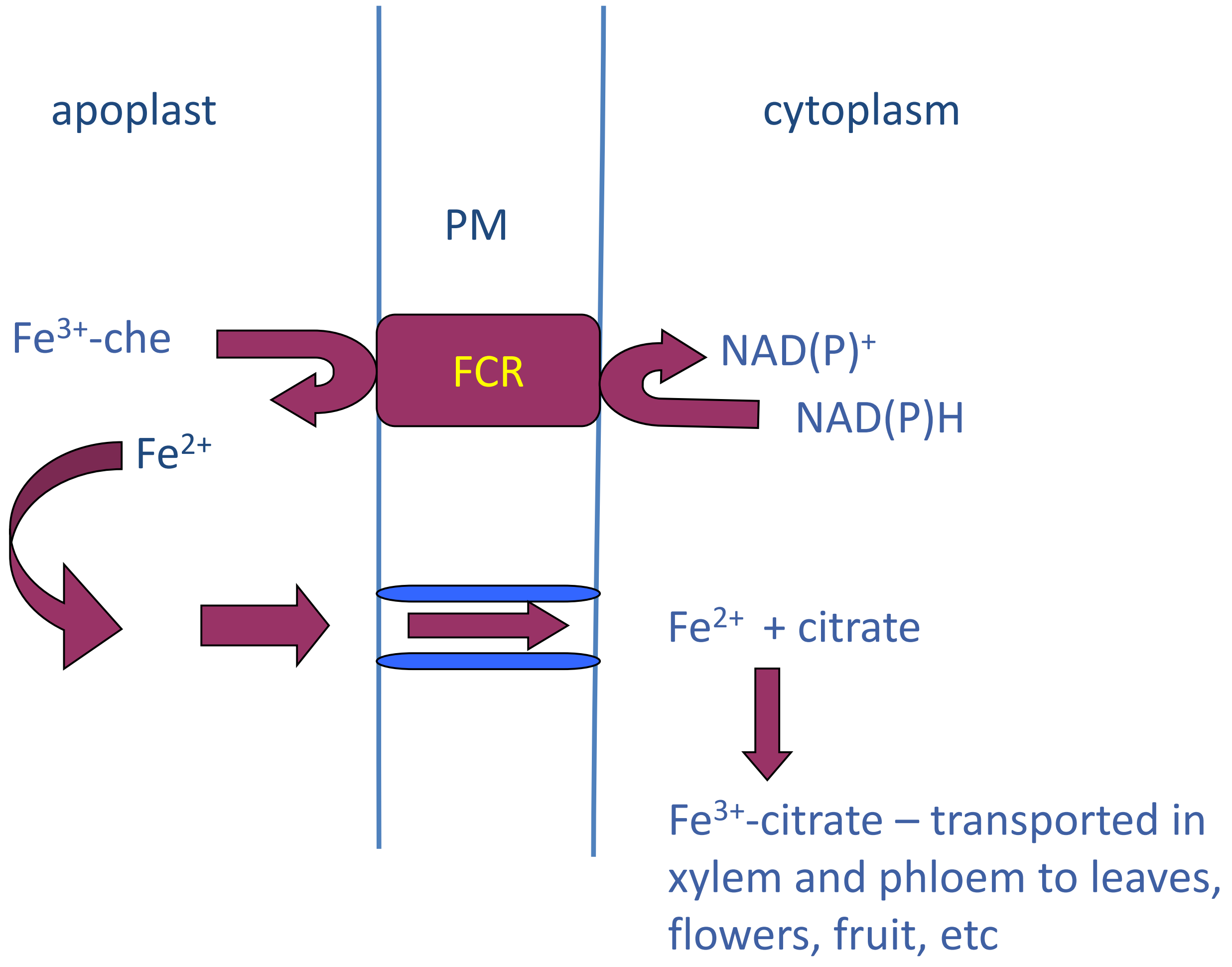
NH_4^+
Fe^{2+}
Ca^{2+}
NO_3
Channel protein
Carrier protein
Plasma membrane
High
Low
Energy

N uptake and assimilation
- occurs in roots and/or leaves



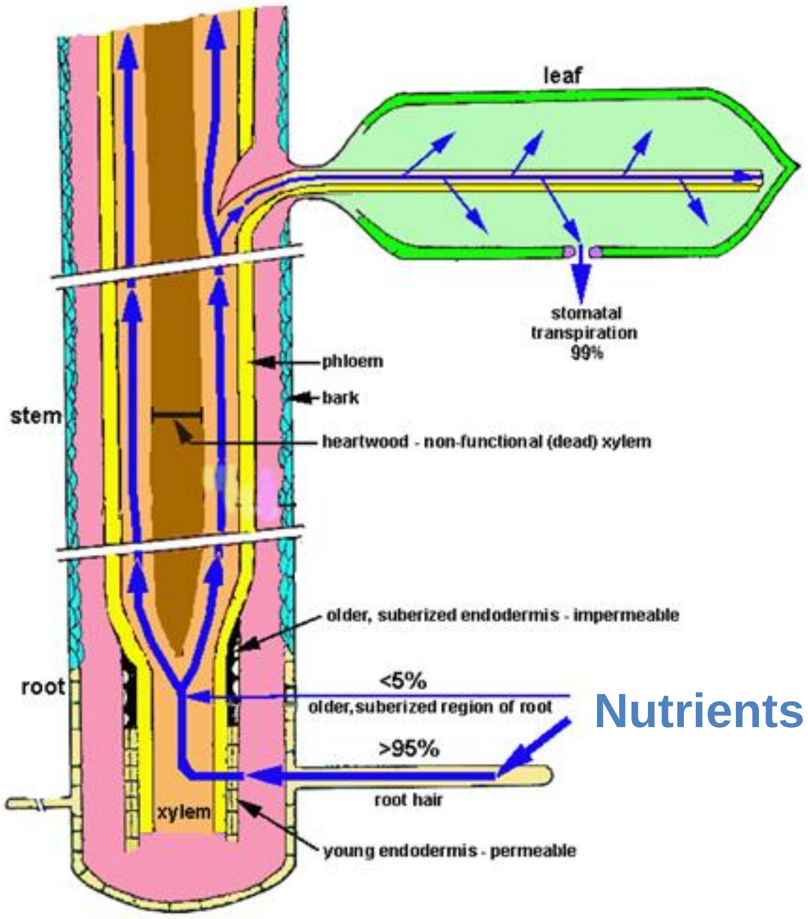
***NR = nitrate reductase**

Fe^{2+} uptake and transport
- occurs in roots <u>and</u> leaves



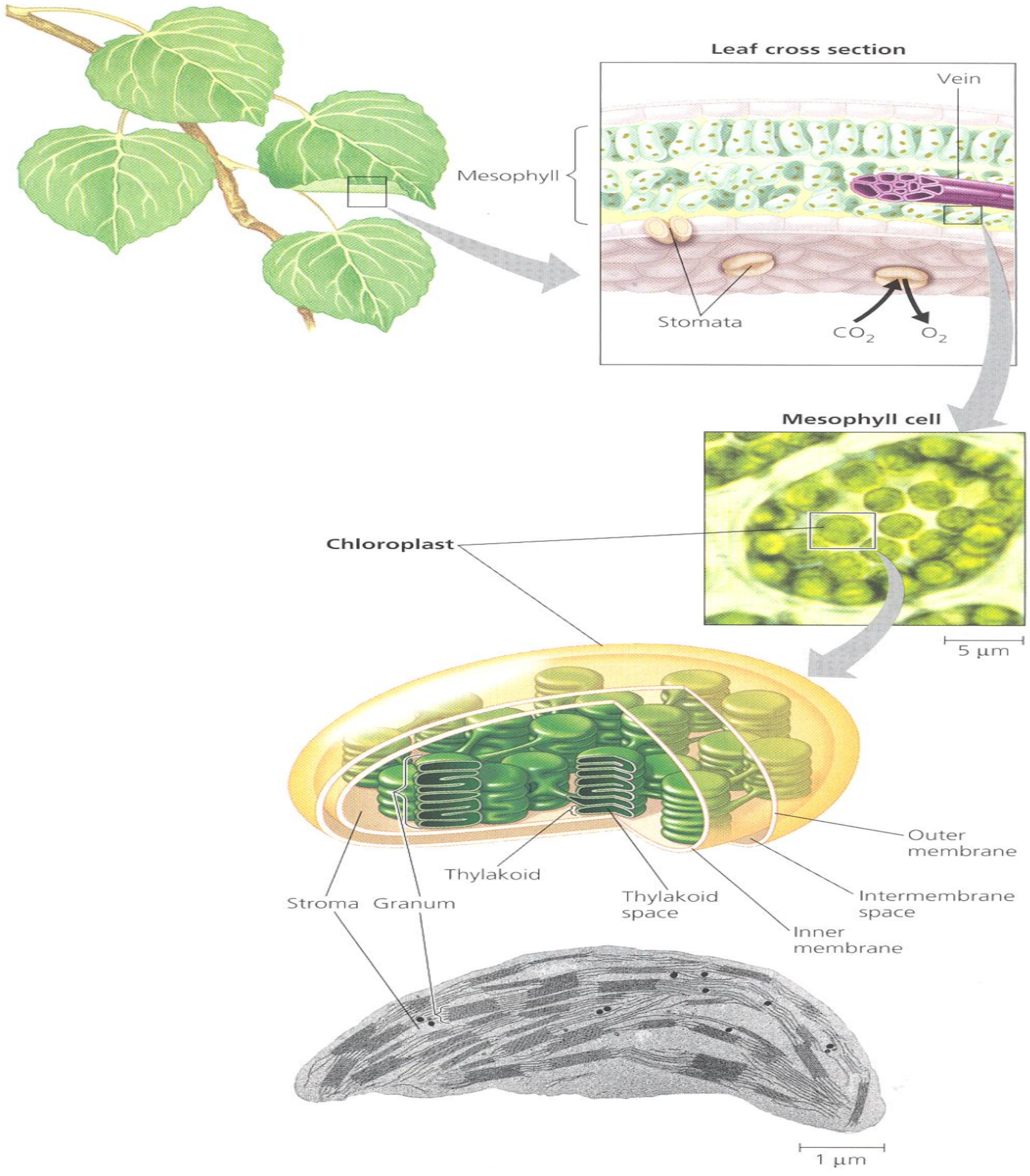
	FCR activity (nmol/g FW/h)	
Species	**Root**	**Leaf**
Peach	100 - 300	-
Apple	100 - 600	-
Grape	200 - 600	-
Kiwifruit	-	240-960
HB Blueberry	100 - 120	45-50

Blueberry susceptible to the “iron paradox “

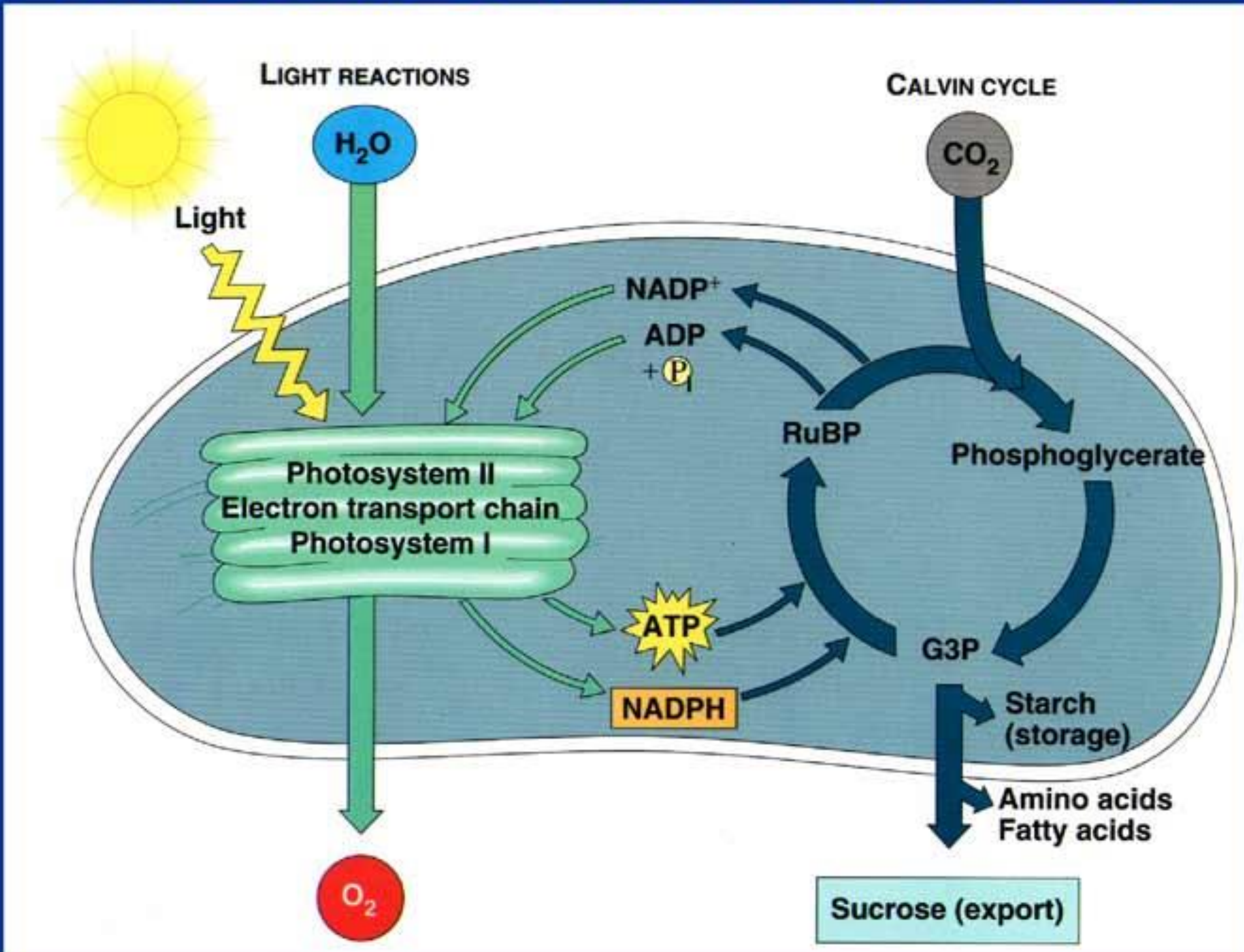


Once taken up by roots, nutrients are translocated in the transpiration stream to shoots (leaves, stems, flowers, fruits). Translocation also occurs in phloem, except for Ca and Mn.

Photosynthesis

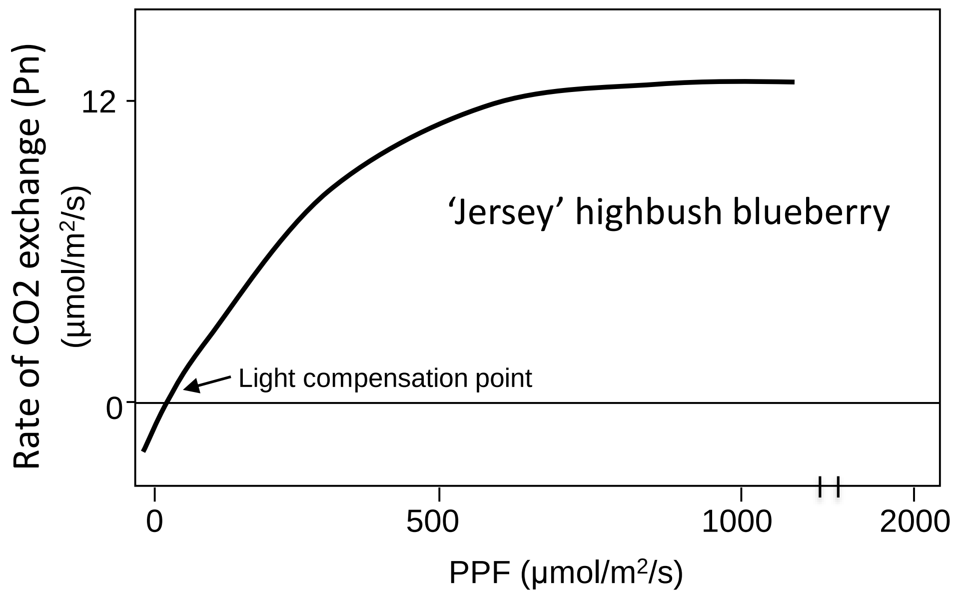

Leaf cross section
Vein
Mesophyll
Stomata
CO_2
O_2
Mesophyll cell
Chloroplast
5 µm
Outer membrane
Intermembrane space
Inner membrane
Thylakoid space
Thylakoid
Stroma
Granum
1 µm

A REVIEW OF PHOTOSYNTHESIS

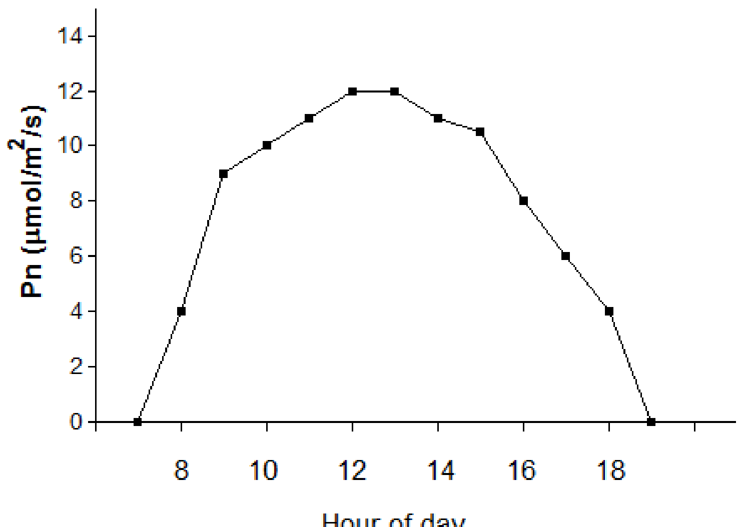


Limitations to photosynthesis

- Light
- Temperature
- Water
- Nitrogen

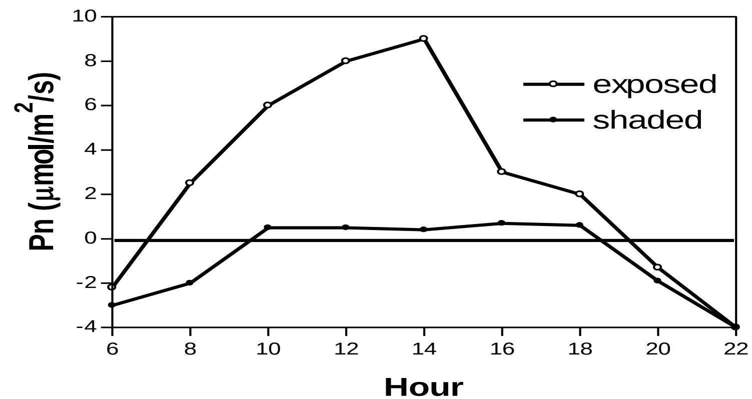


Modified from Moon et al., 1987



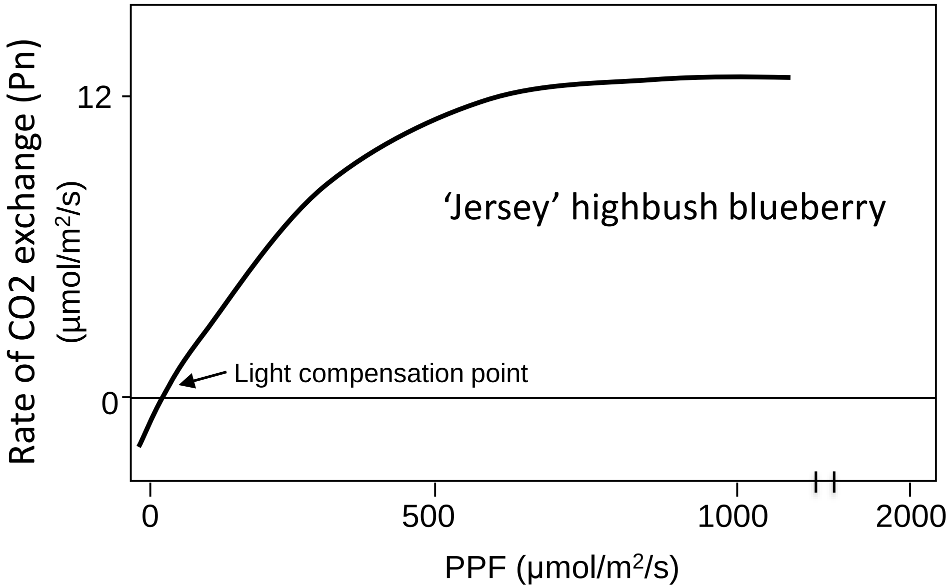
Daily net photosynthesis in 'Bluecrop' highbush blueberry

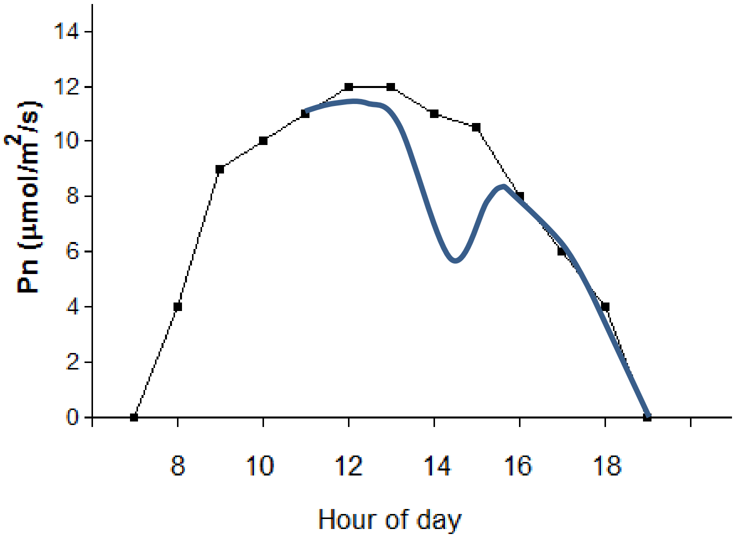
Modified from Kim et al., 2011



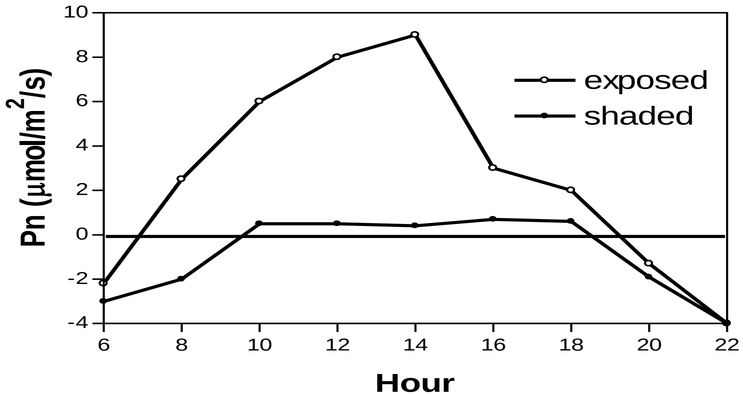
Daily trend of net photosynthesis of kiwifruit leaves

Modified from Grant & Ryugo, 1984

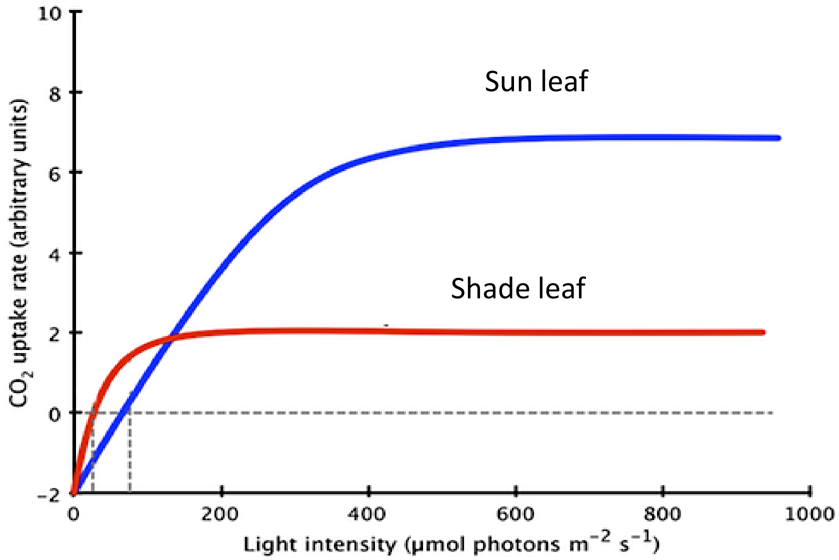




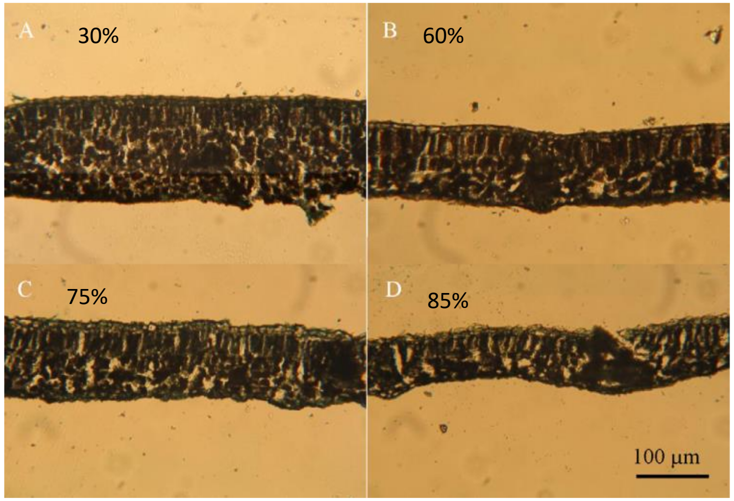
Daily net photosynthesis in 'Bluecrop' highbush blueberry



Daily trend of net photosynthesis of kiwifruit leaves



Light response curves of net photosynthesis in sun and shade leaves. Shade leaves typically have lower light compensation points (LCP), lower light saturation points (LSP),and lower maximum Pn rates than do sun leaves.



'Bluecrop' blueberry leaf thickness under various shade levels

From Kim et al., 2011

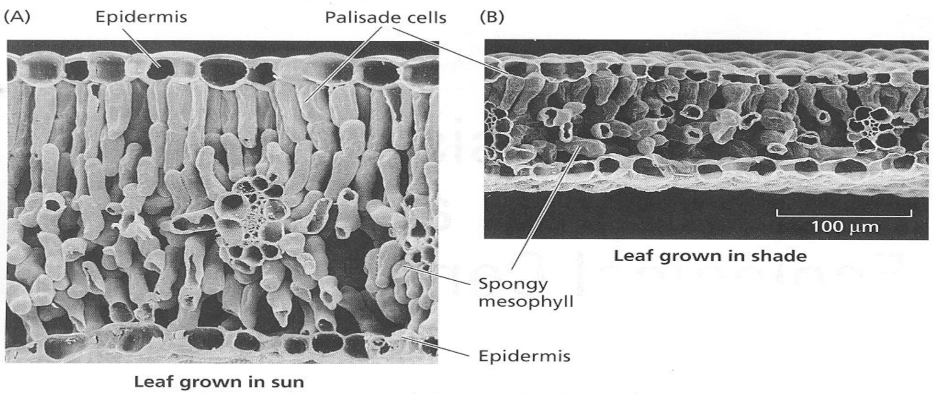
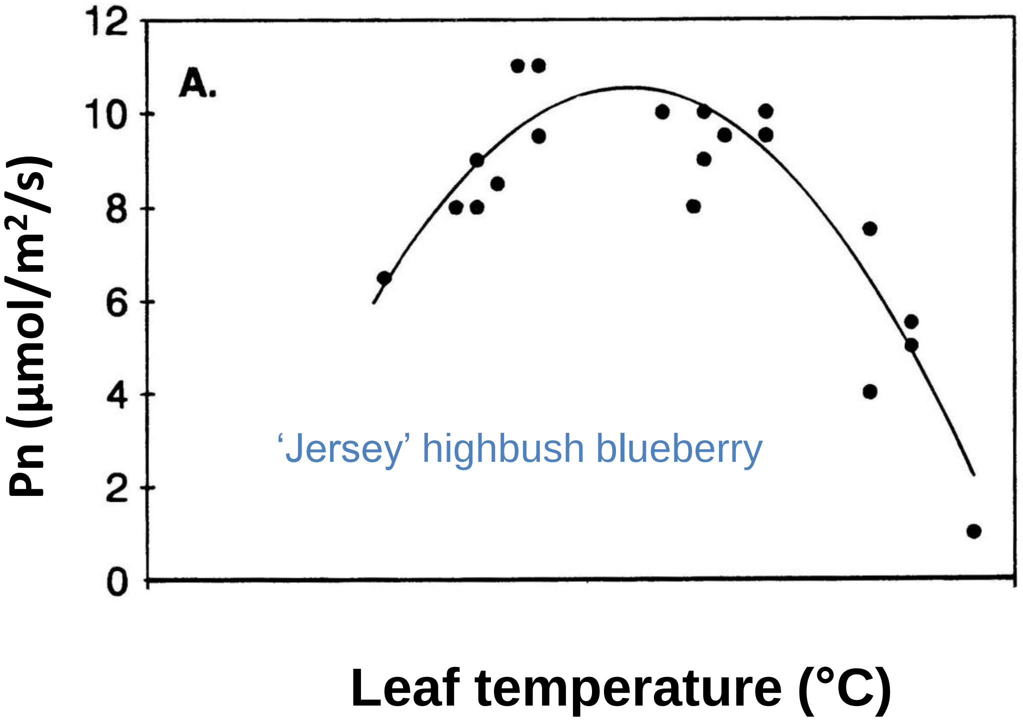


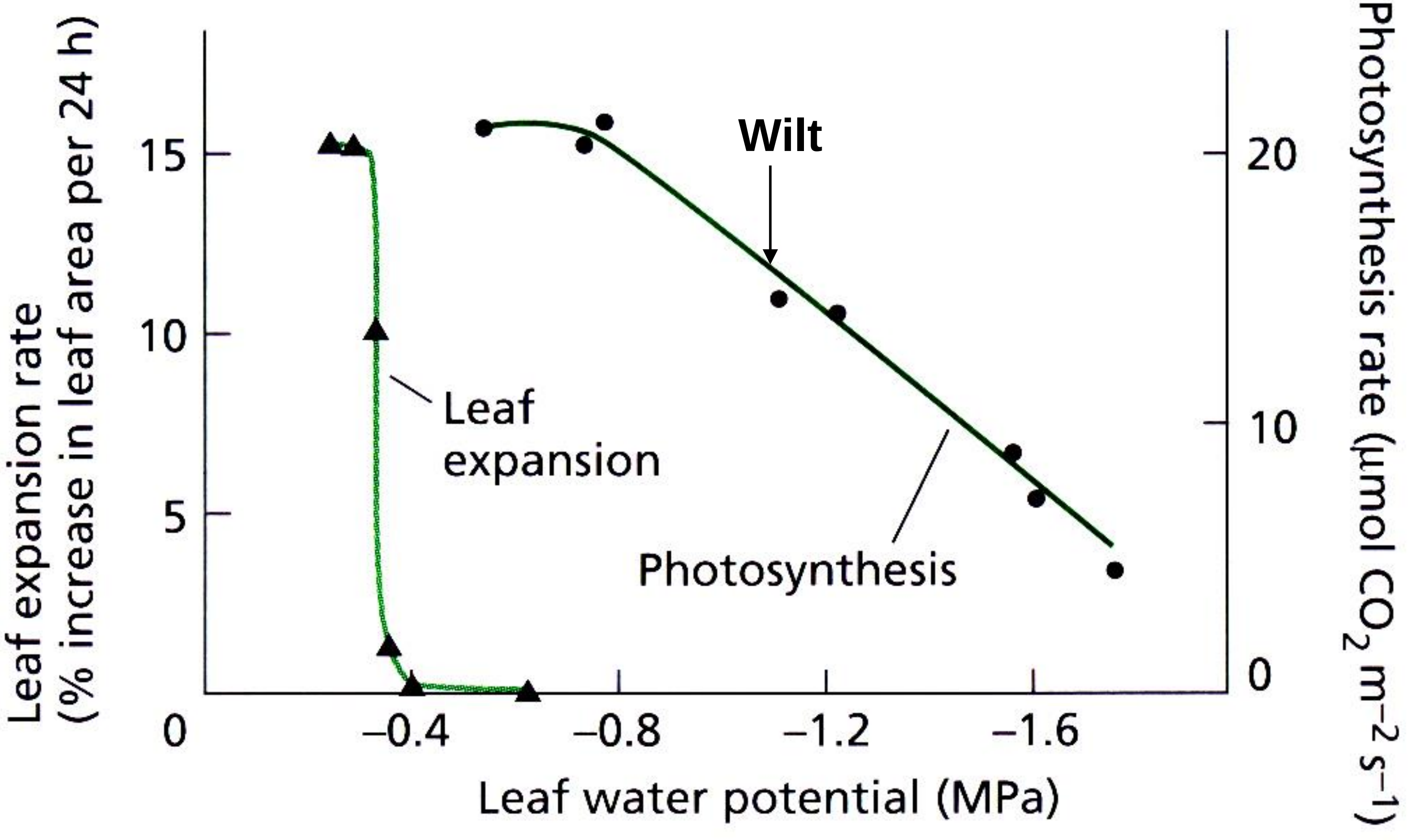
FIGURE 9.1 Scanning electron micrographs of the leaf anatomy from a legume (*Thermopsis montana*) grown in different light environments. Note that the sun leaf (A) is much thicker than the shade leaf (B) and that the palisade (columnlike) cells are much longer in the leaves grown in sunlight. Layers of spongy mesophyll cells can be seen below the palisade cells. (Courtesy of T. Vogelmann.)

Temperature effects on photosynthesis

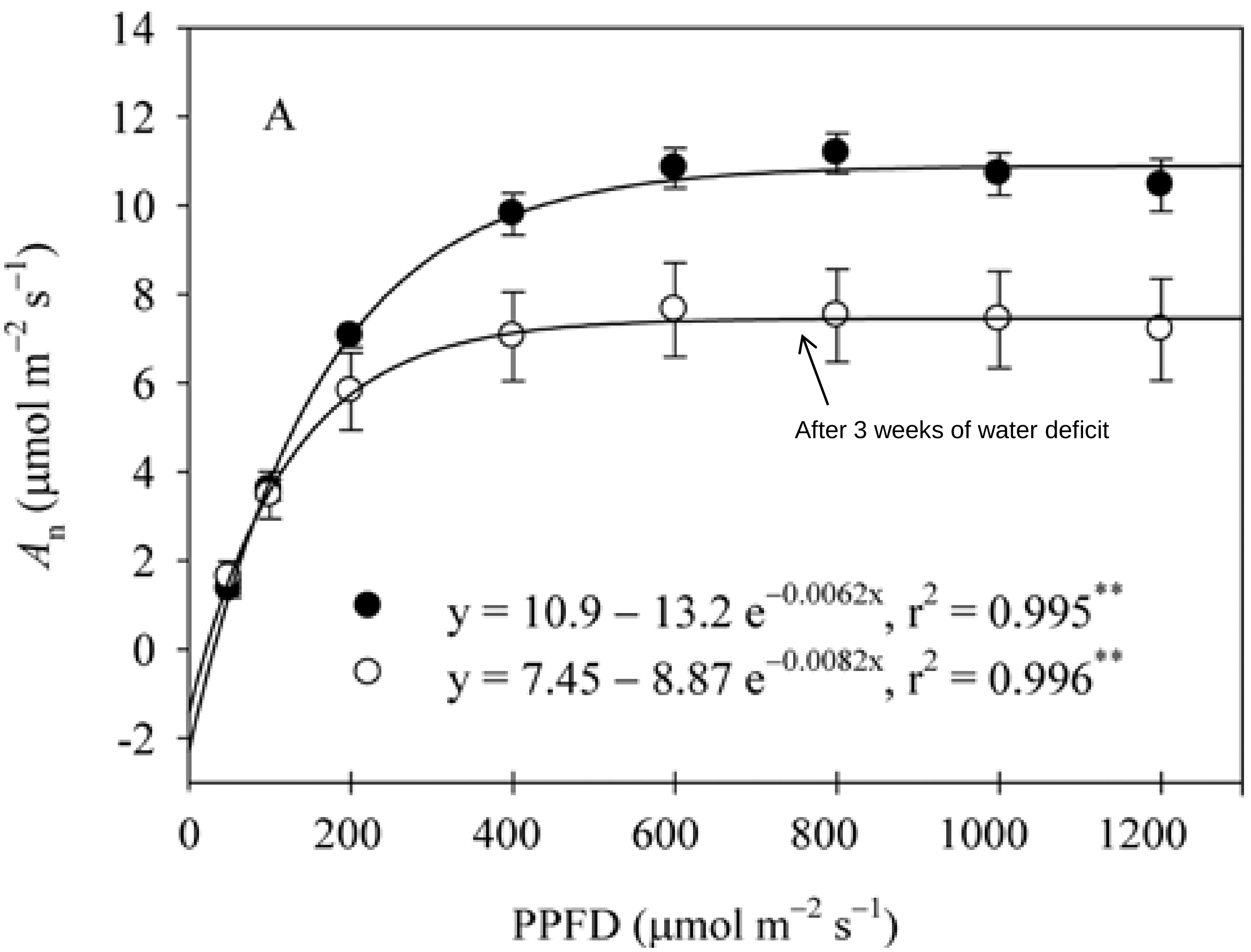


From Moon et al., 1987

Water deficit effects on photosynthesis



Water deficit effects on photosynthesis in 'Bluecrop'

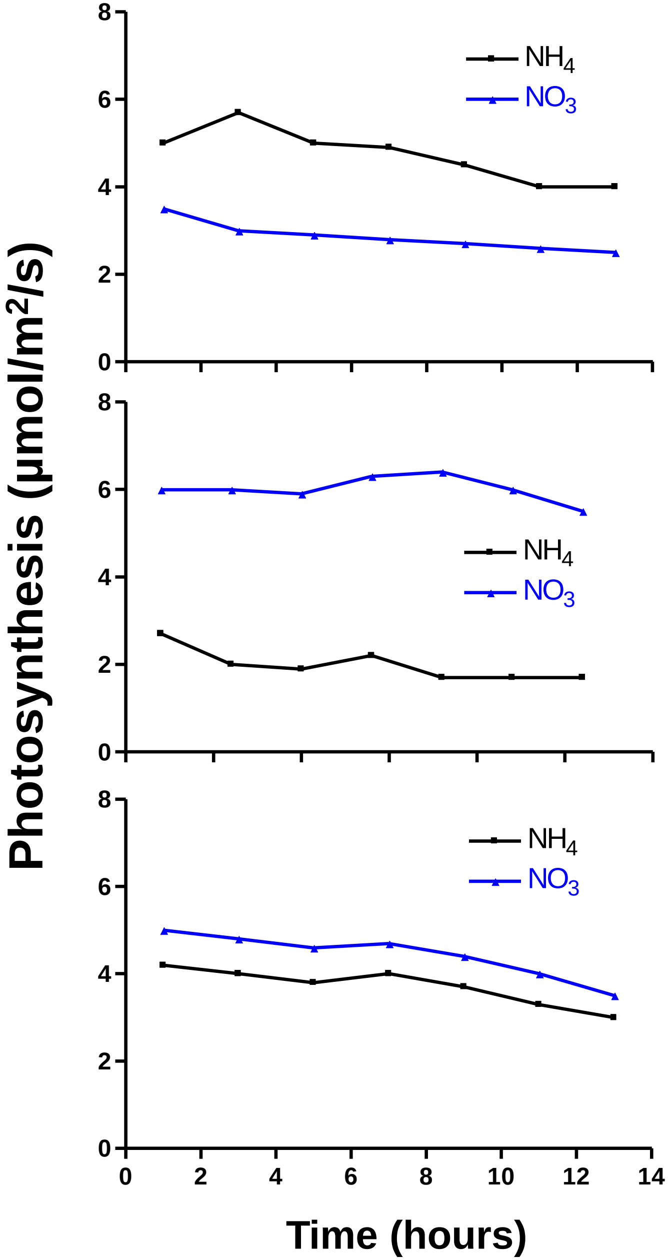


From Rho et al., 2012

Drought will also cause stomatal closure, limiting CO_2-fixation and resulting in photo-oxidation.

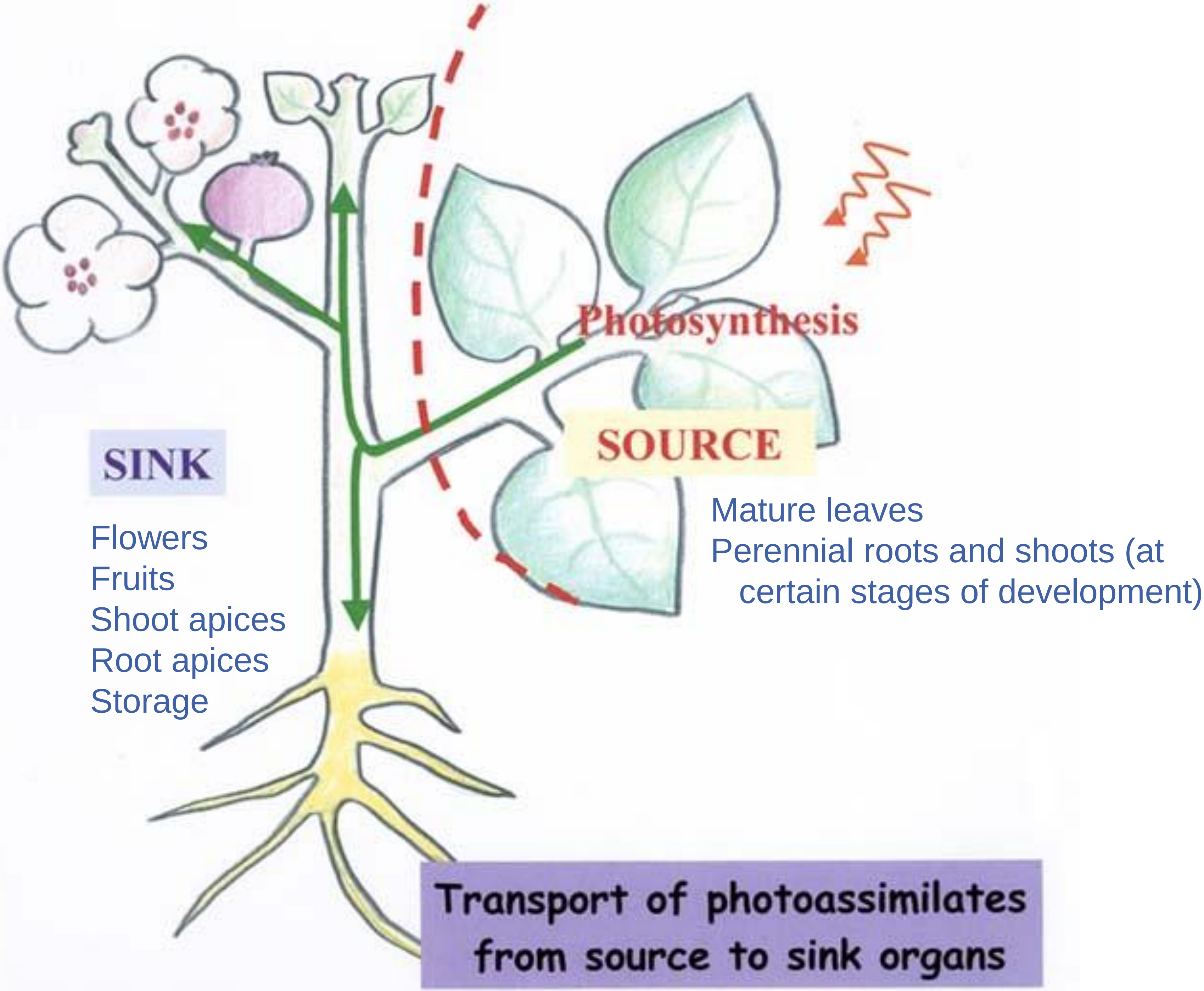
High light can also cause photo-oxidation, particularly in combination with decreased CO_2-fixation

N form effects on photosynthesis



From Claussen & Lenz, 1999

Source/sink relations


Photosynthesis
SOURCE
Mature leaves
Perennial roots and shoots (at certain stages of development)
SINK
Flowers
Fruits
Shoot apices
Root apices
Storage
Transport of photoassimilates from source to sink organs

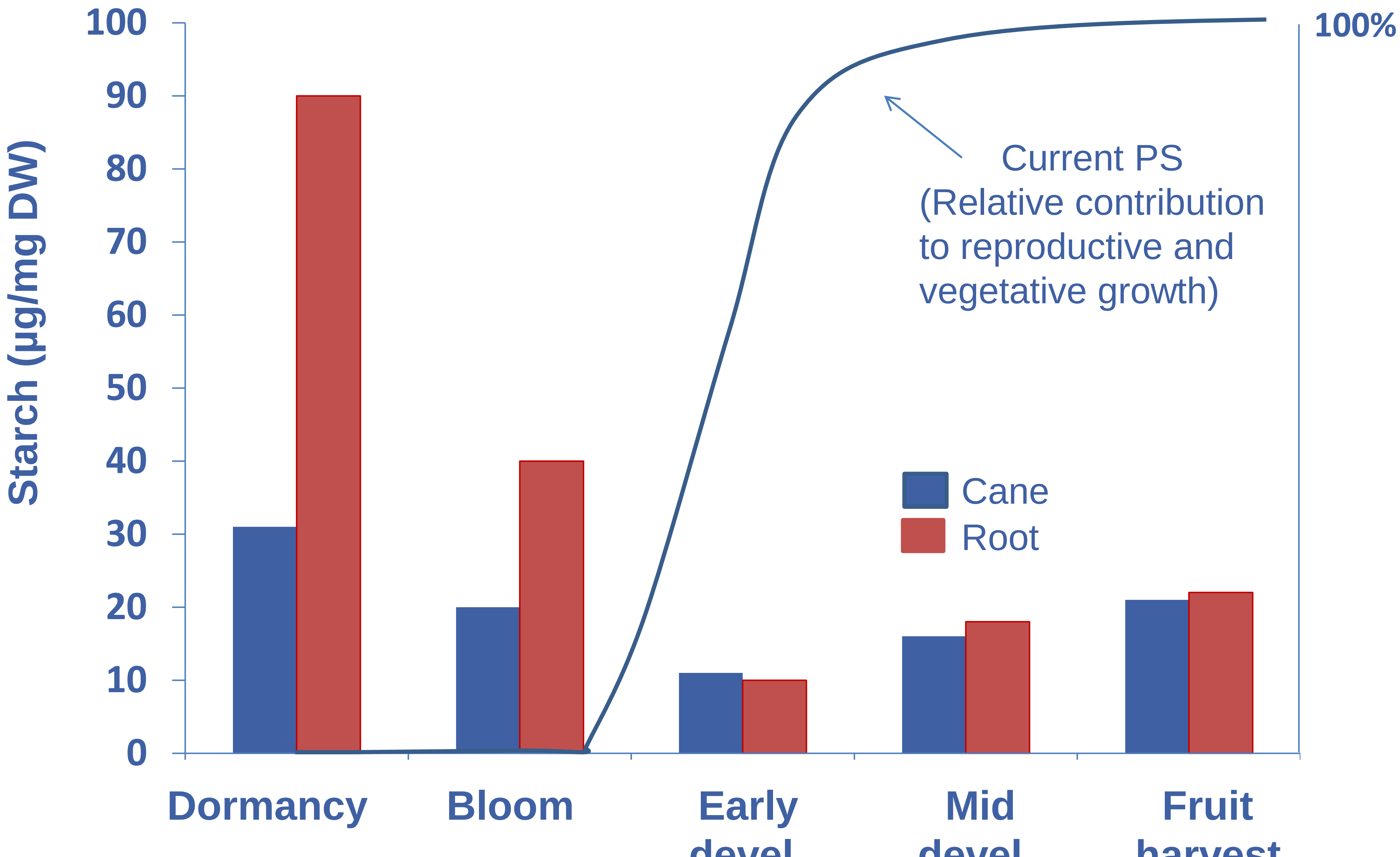
Source supply (photosynthates or stored assimilates) > Sink demand

Otherwise sink growth will be limited

- Source to sink translocation occurs in phloem
- Stronger sinks get more than weaker sinks
- Sink strength f(size x activity)

Seeds > Fruits > Flowers > Shoot/root apices > Storage

Source/sink (CHO) relations in blueberry during fruit development



Following fruit harvest, carbohydrate accumulation will increase in perennial parts (roots, canes, stems) to serve as sources during winter and spring

Carbohydrate partitioning also changes depending on fruiting status

Source/sink relations (dry weight partitioning) in strawberry

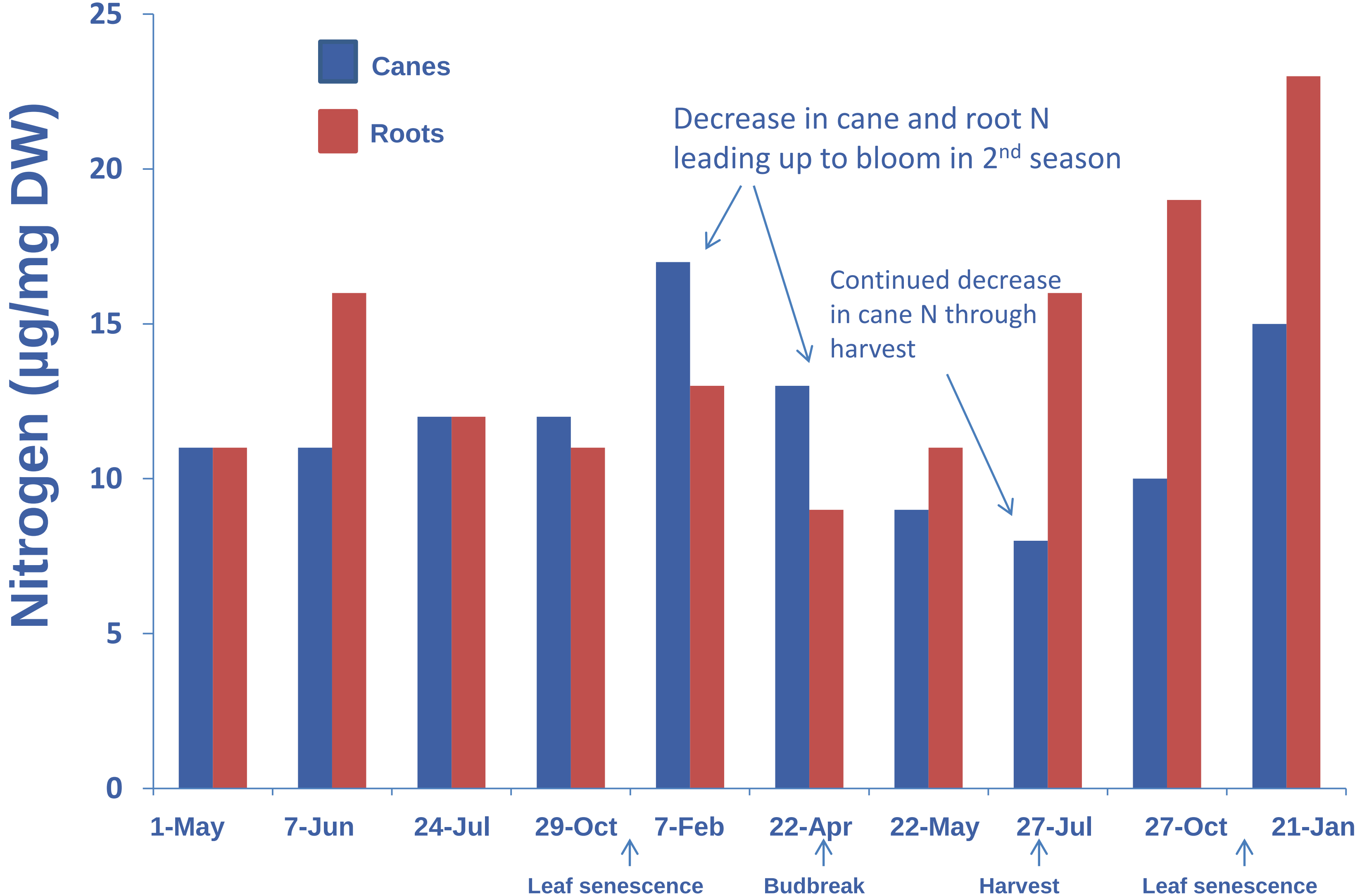
	Dry weight (g)	
Organ	Fruiting	Non-fruiting
Root	4.0	10.0
Crown	1.5	3.0
Leaves	18.0	30.0
Fruit	22.0	-
Total	45.5	43.0

From Forney and Breen, 1988

Importance of source/sink relations extends beyond carbohydrates:

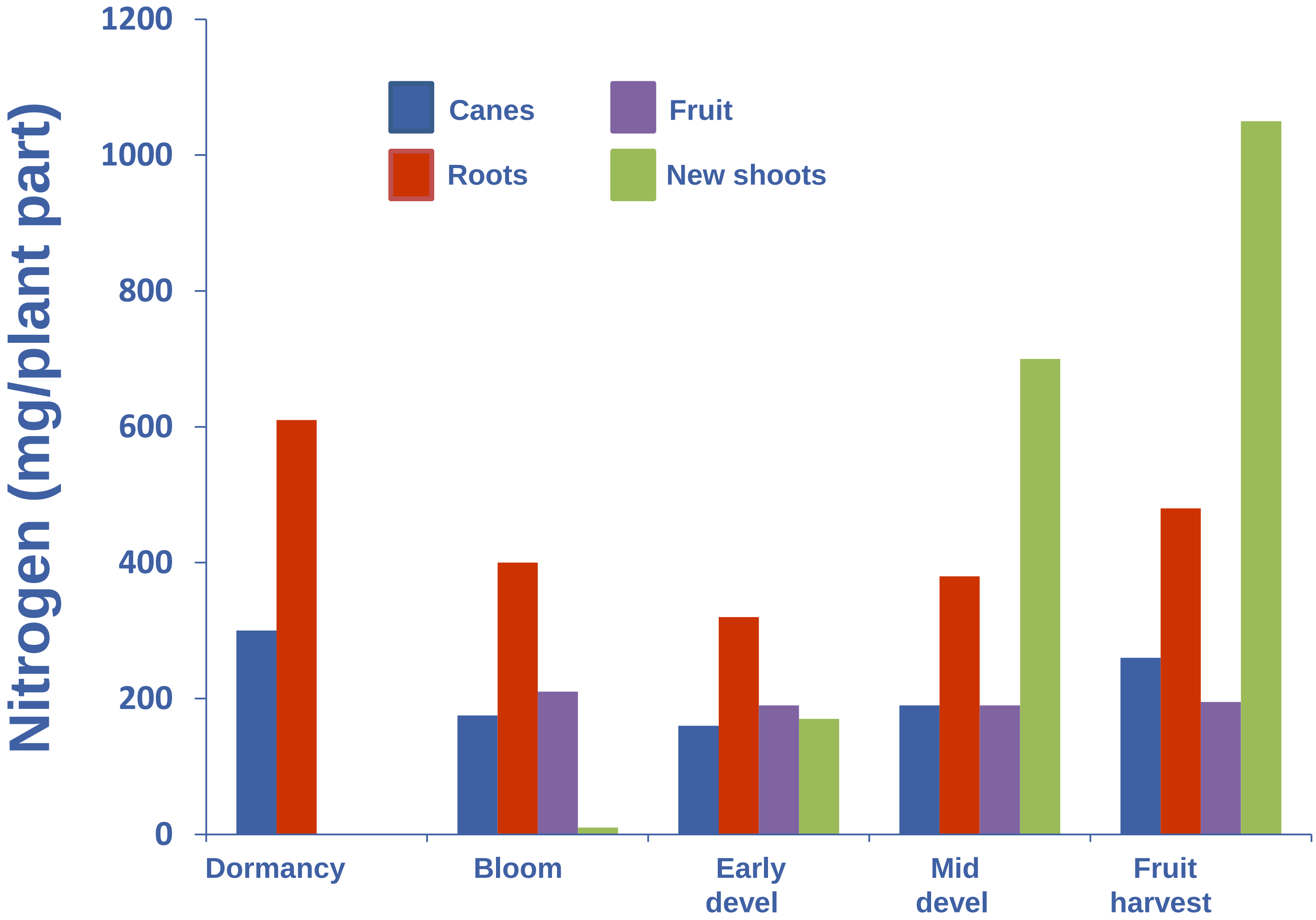
Nitrogen allocation

Seasonal N concentration in young blueberry

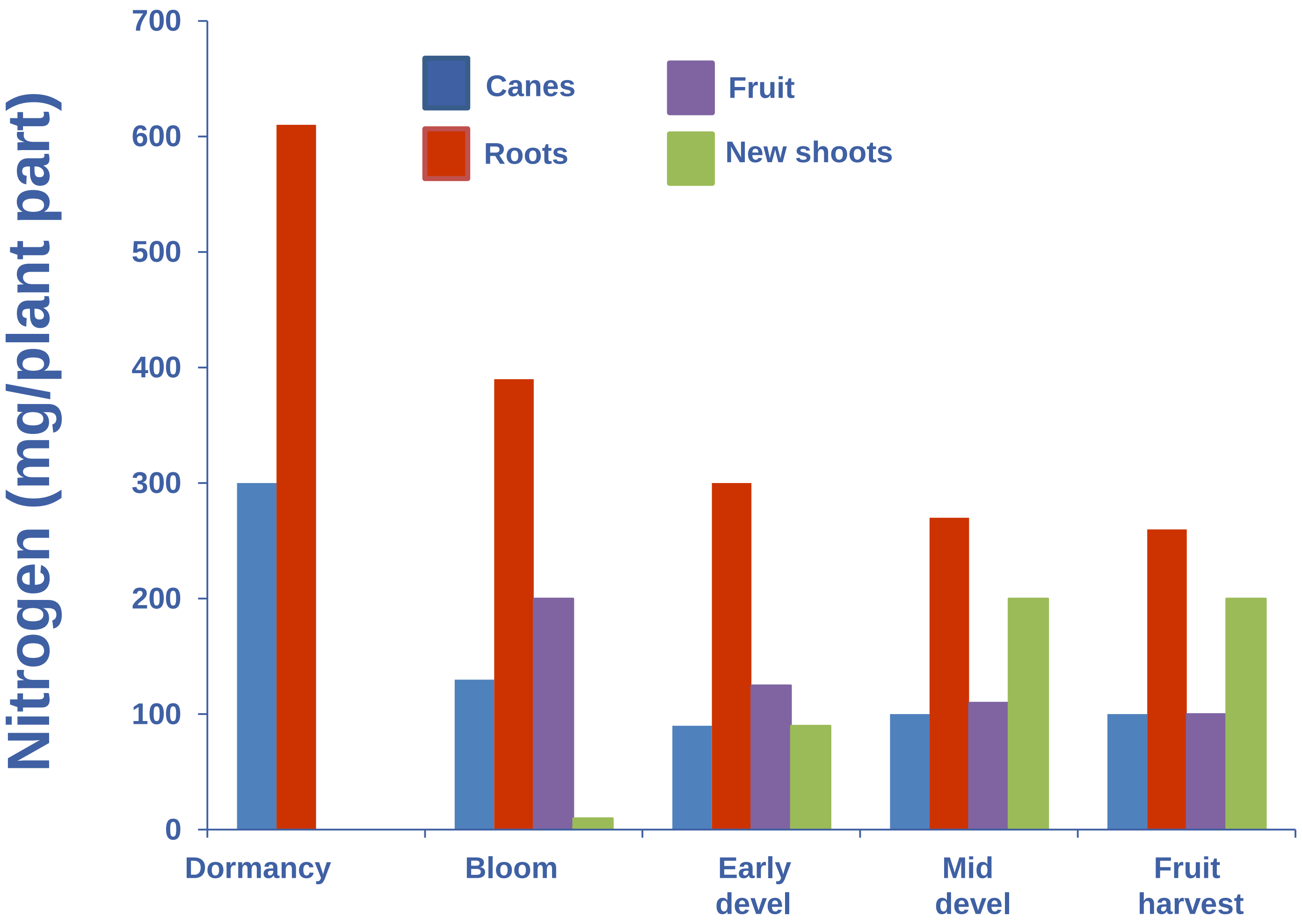


Modified from Banados et al., 2012

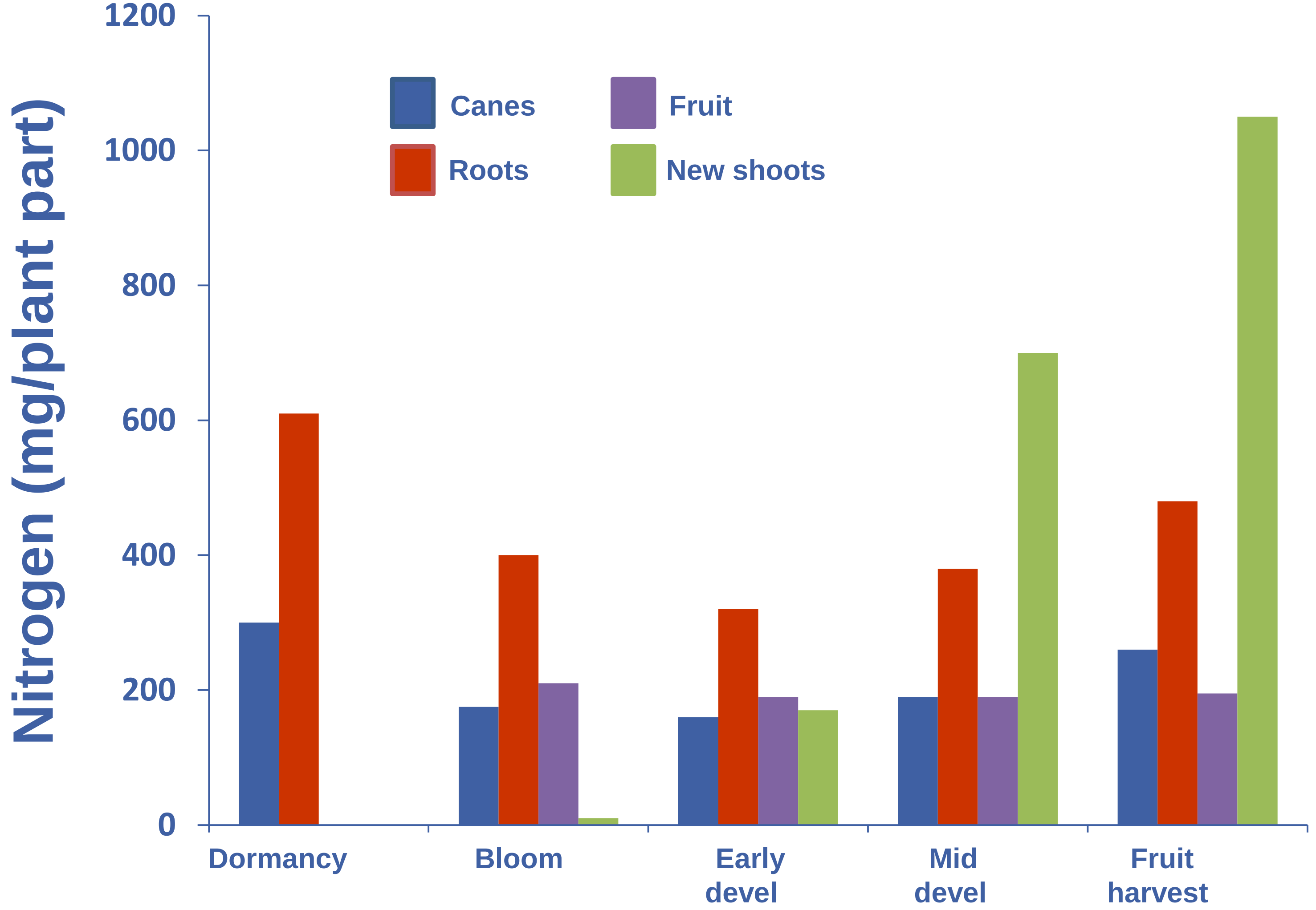
Nitrogen content in blueberry during fruiting



Storage nitrogen content in blueberry during fruiting



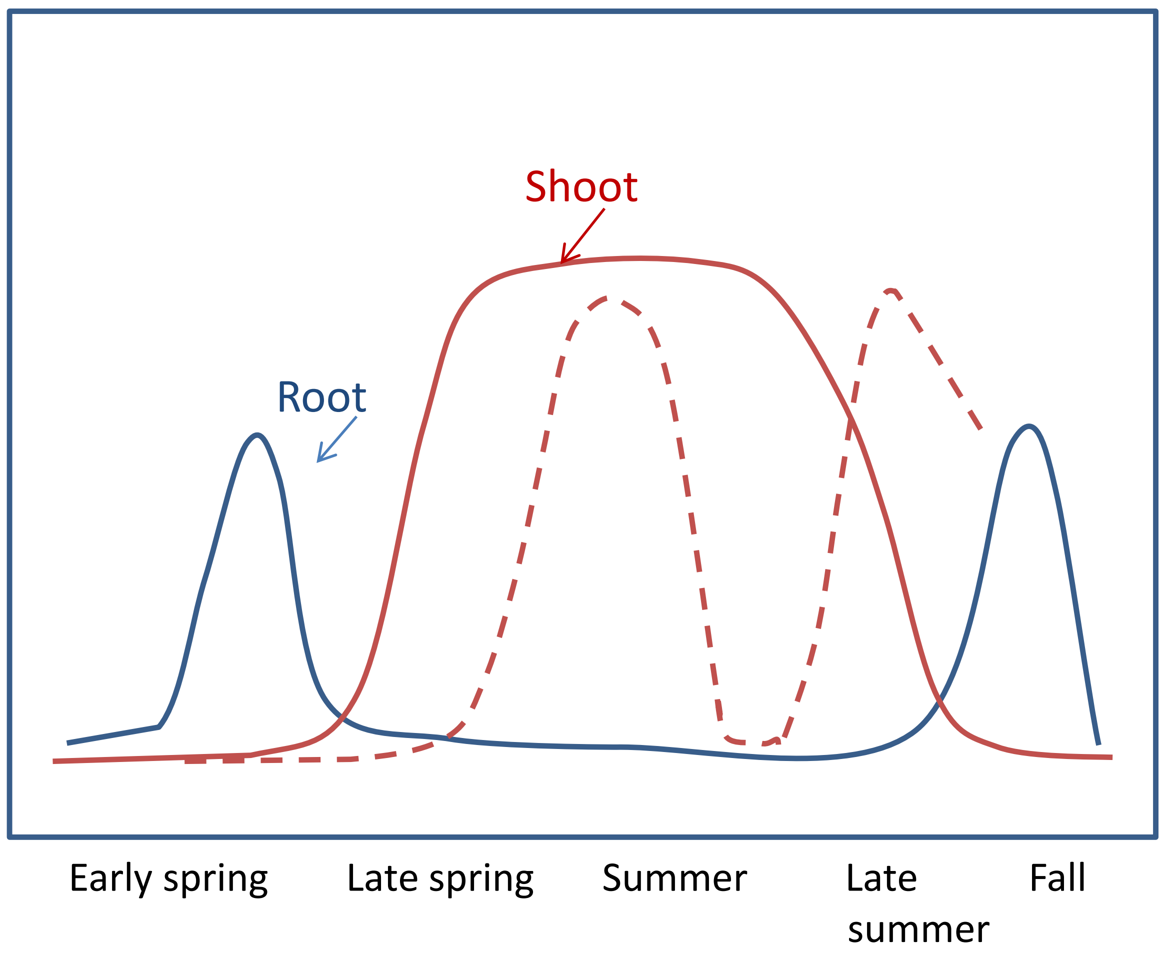
Nitrogen content in blueberry during fruiting



2. General growth and development

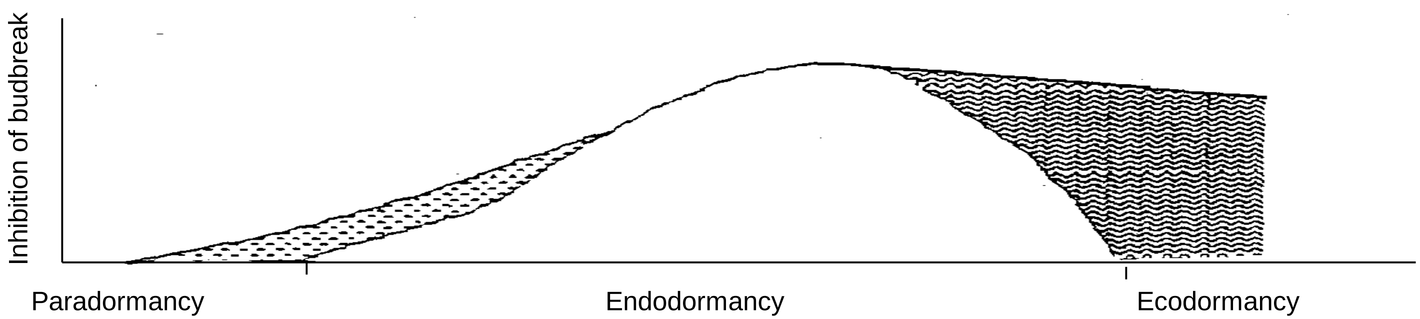
- Seasonal shoot/root growth
- Dormancy/chilling
- Heat units
- Flower bud initiation
- Pollination/fruit growth

Seasonal shoot and root growth



Dormancy

	Ecodormancy	Paradormancy	Endodormancy
	Regulated by environmental factors	Regulated by physiological factors outside affected structure	Regulated by physiological factors inside affected structure
Examples	Temp extremes Water stress	Apical dominance Leaf perception of short days (SD) in fall initiates bud dormancy	SD + cool temps SD alone

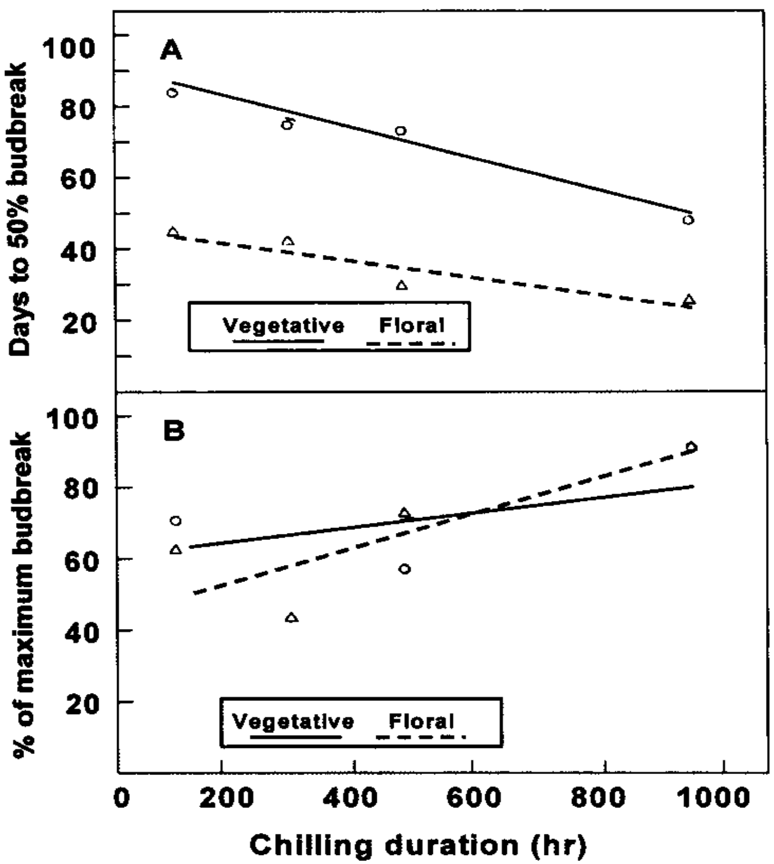


A schematic representation of inhibition of budbreak during dormancy. Dormancy begins with paradormancy and deepens during endodormancy. The depth and duration of ecodormancy is environment dependent.

Chilling requirement in hours below 7C of some deciduous fruit species

Species	Number of chill hours
Almonds	0-800
Peaches	100-1250
Blueberries	200-1200
Apples & Pears	200-1400
European plums	800-1500
Cherries	800-1700

Delayed, erratic budbreak on peach



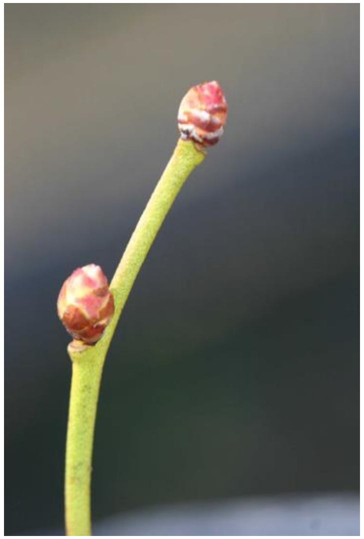
Days to 50% budbreak (A) and
% maximum budbreak (B) in blueberry
vegetative and floral buds exposed to
100, 300, 500, or 1000 h chilling at 7C.

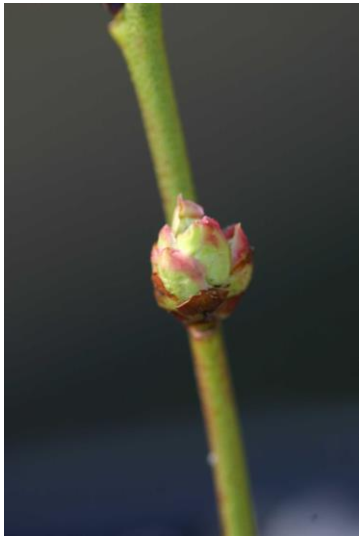
Insufficiently chilled vegetative buds in blueberry

Hydrogen cyanamide

Dormex®, BudPro®, Krop-Max®

- Stimulates earlier & stronger leafing on SHB blueberry in FL
- Often advances & concentrates harvest
- Apply 30 or more days prior to natural budbreak (apply only to fully dormant plants that have received some chilling)
- Can be phytotoxic





Credit J. Williamson


No Dormex
Dormex
Credit J. Olmstead

Heat units

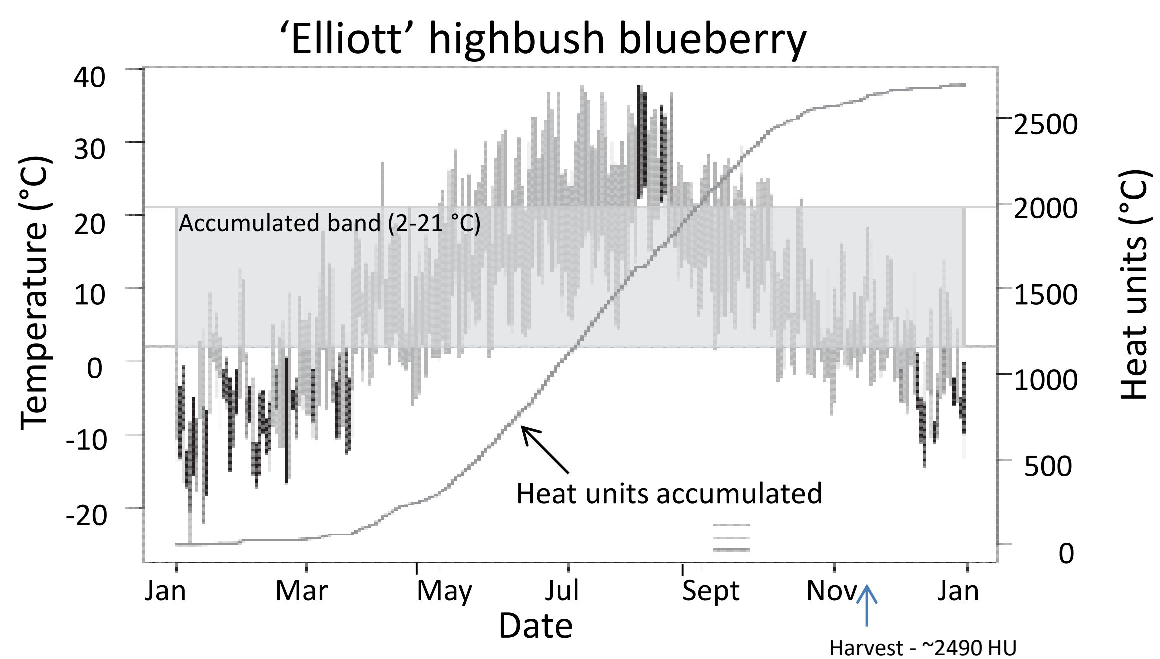
Required to break ecodormancy. Used to predict time to phenological stages.

Heat unit accumulation ranges for predicting blueberry harvest

Cultivar	T_{low} (°C)	T_{high} (°C)
Berkeley	-7	32
Bluecrop	7	27
Earliblue	4	21
Elliott	2	21
Jersey	-7	32

Modified from Carlson & Hancock, 1991 as used in Munoz et al., 2012

T_{low} and start date (1 Feb, 1 Mar, 1 Apr) for HU accumulation were most important variables for predicting harvest

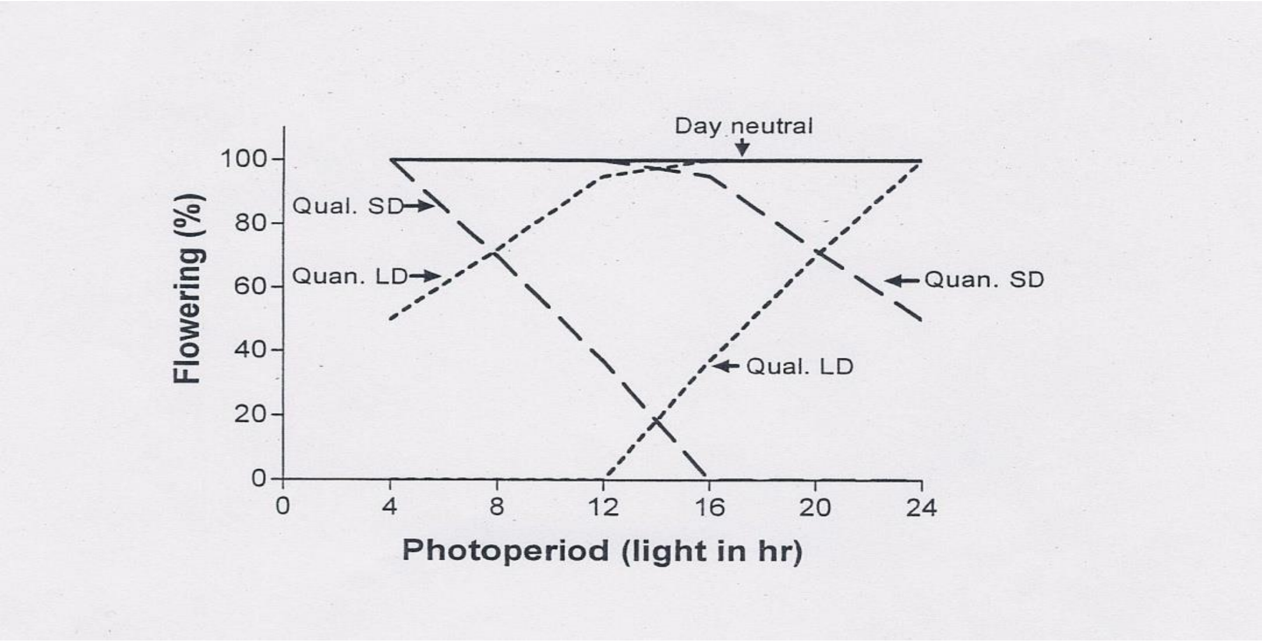


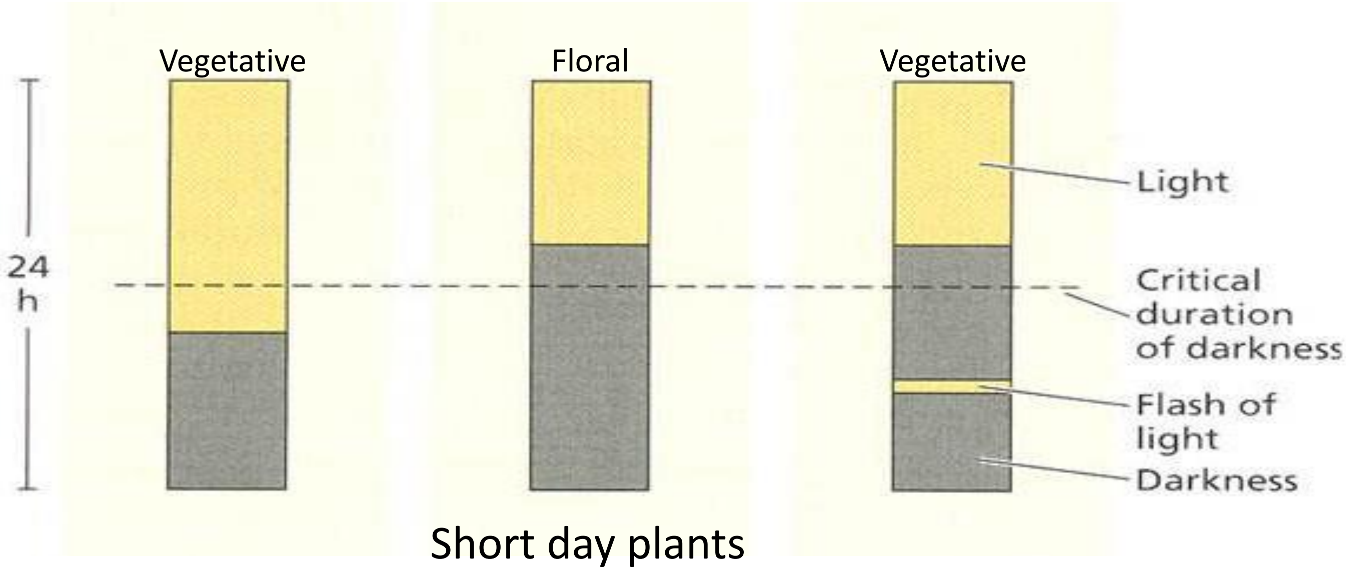
From Munoz et al., 2012

Reproductive development
Flower bud initiation

Photoperiodically sensitive – LD, SD
Day neutral – some other cue required

Flower bud initiation





Short day plants

Flower bud initiation under different daylengths in blueberry

Long days

Short days

Leaves are required for flower bud initiation in SDP – flower bud initiation on defoliated southern highbush blueberry

September

December

Photoperiod, temperature, and photoperiod duration effects on flower bud number in 'Misty' southern highbush blueberry

	Flower bud no./plant			
	21°C		28°C	
Photoperiod	4 wks	8 wks	4 wks	8 wks
SD	43.7	32.4	0.0	17.2
SD-NI	0.6	0.5	0.0	0.0

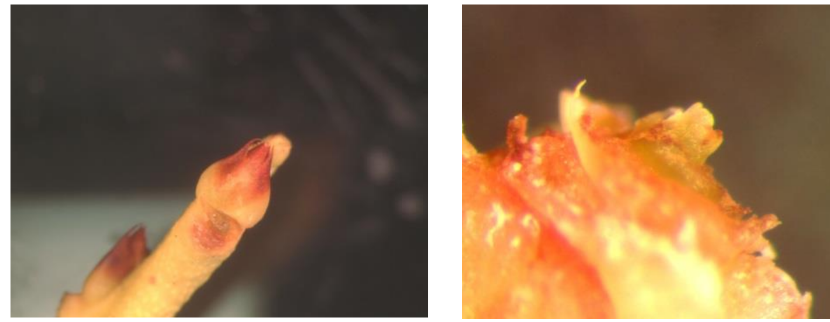
Photoperiod effects on organ dry weight of 'Misty' SHB

Photoperiod	Leaves	Old canes	New canes	Roots	Whole plant
SD	4.2	6.3	1.1	9.8	21.9
SD-NI	7.2*	9.2*	2.0*	12.2	30.6*

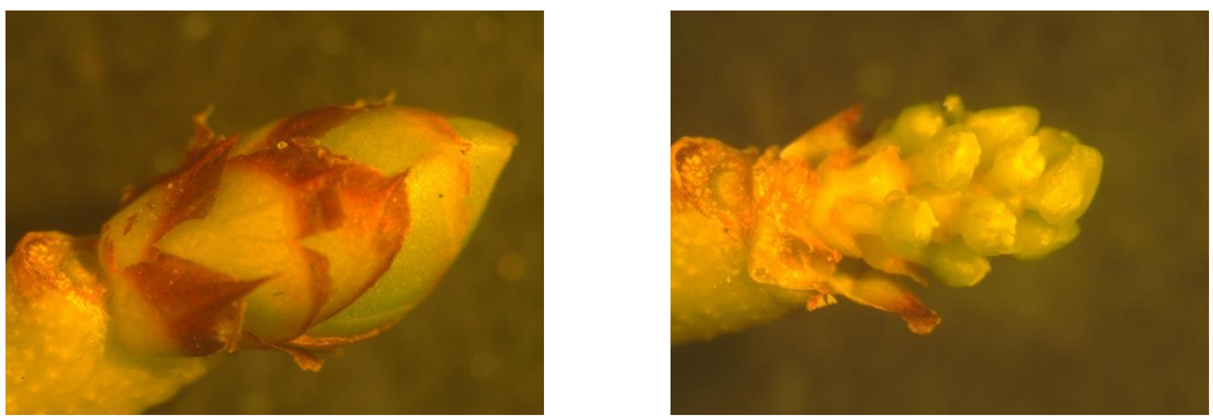
Increased DW under SD-NI may be source-sink effect

Flower bud initiation in ‘Emerald’ in Florida

Sept 20, 2011 – reproductive bud

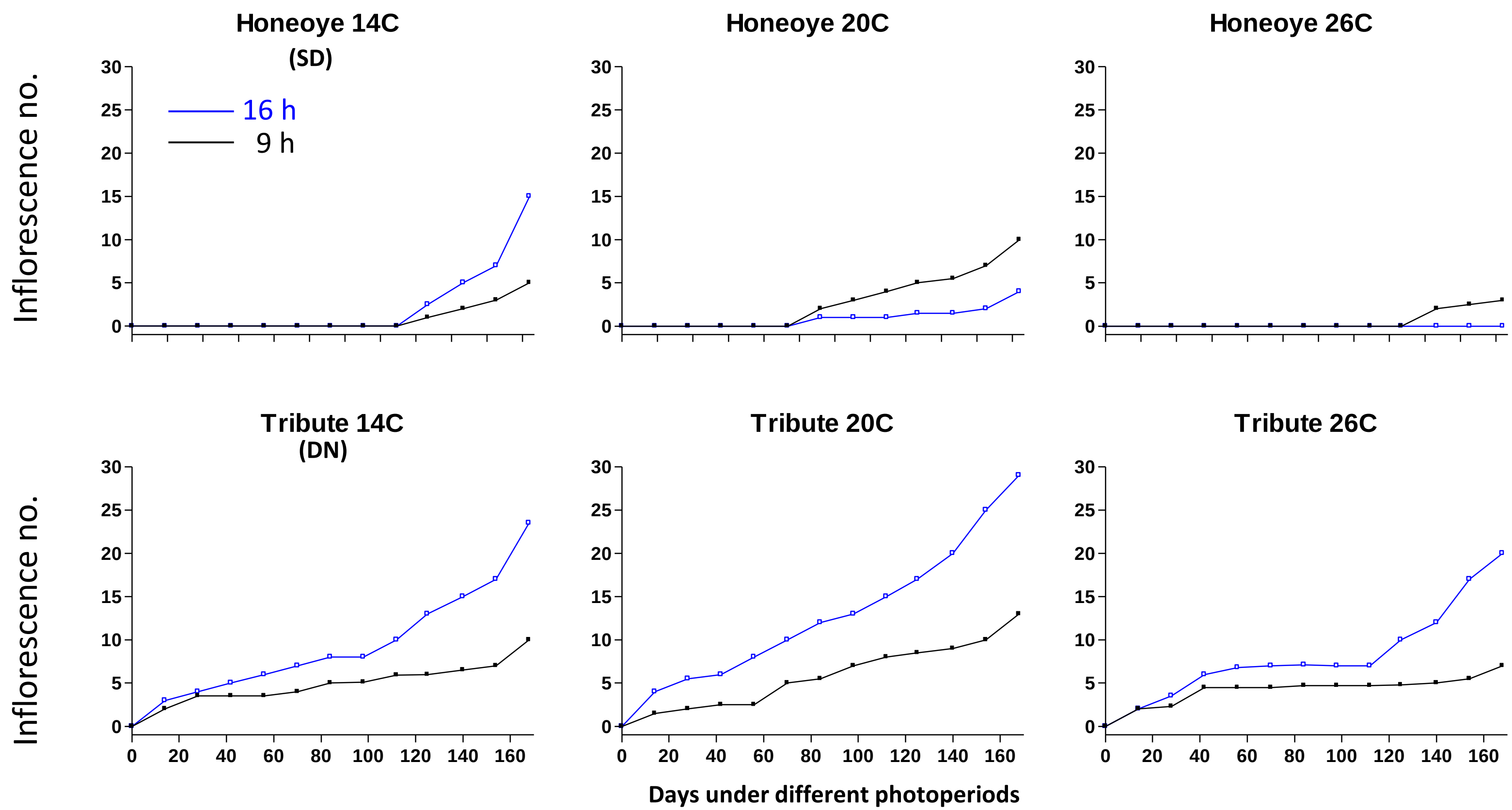


Sept 20, 2011 – vegetative bud

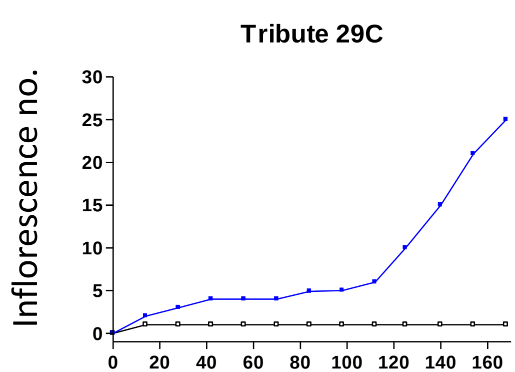


Oct 4, 2011 – reproductive bud

Flower bud initiation in ‘Honeoye’ and ‘Tribute’ strawberry



No. of inductive cycles ranges from 7 to 24. Generally increases with increased temperature

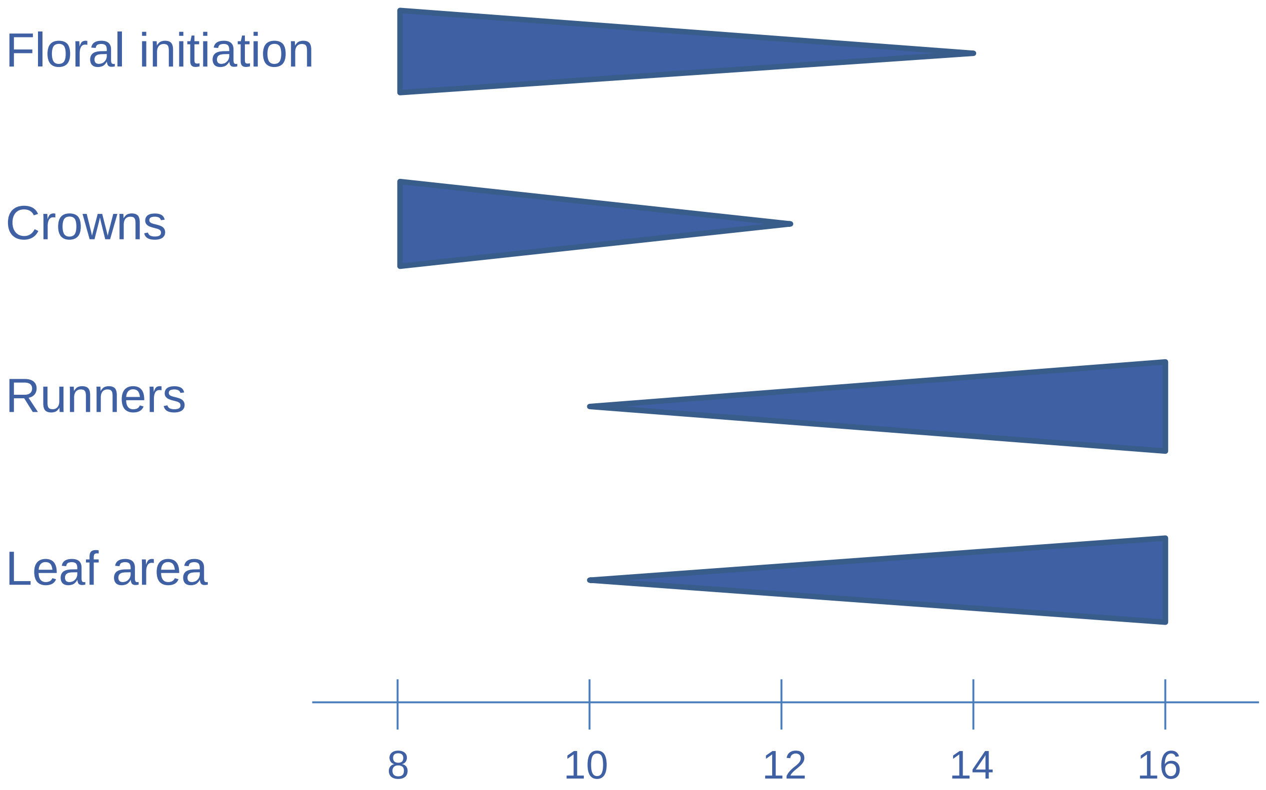


Bradford et al., 2010

Temperature x photoperiod on flower bud initiation in strawberry

	Temperature		
Photoperiod	10 – 15°C	15 – 25°C	>25°C
		Short day genotypes	
SD	+	+	-
LD	+	-	-
		Day neutral genotypes	
SD	+	+	-
LD	+	+	- (?)

Photoperiod effects on SD strawberry

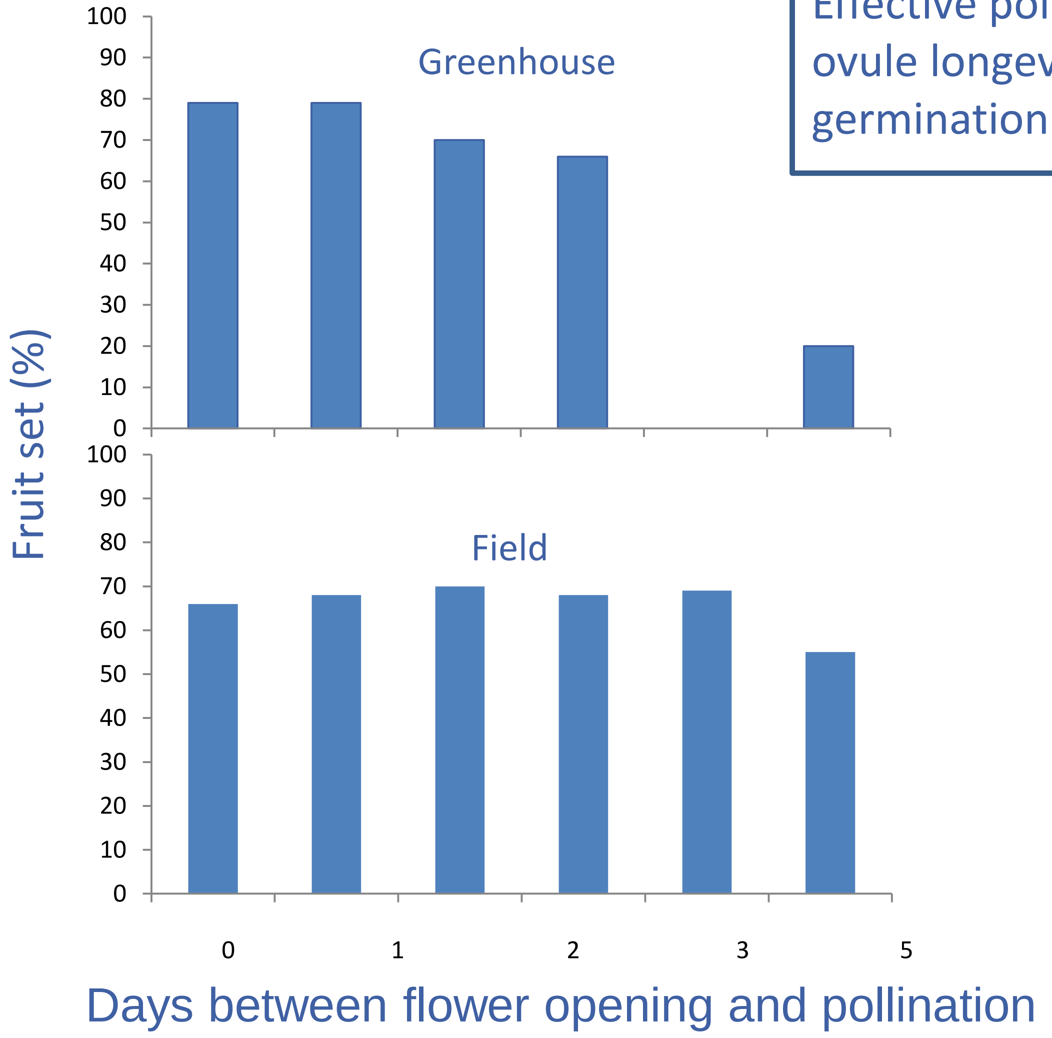


Photoperiod effects for crowns and runners likely Pfr mediated
Photoperiod effect on leaf area likely PS response

Pollination and fertilization

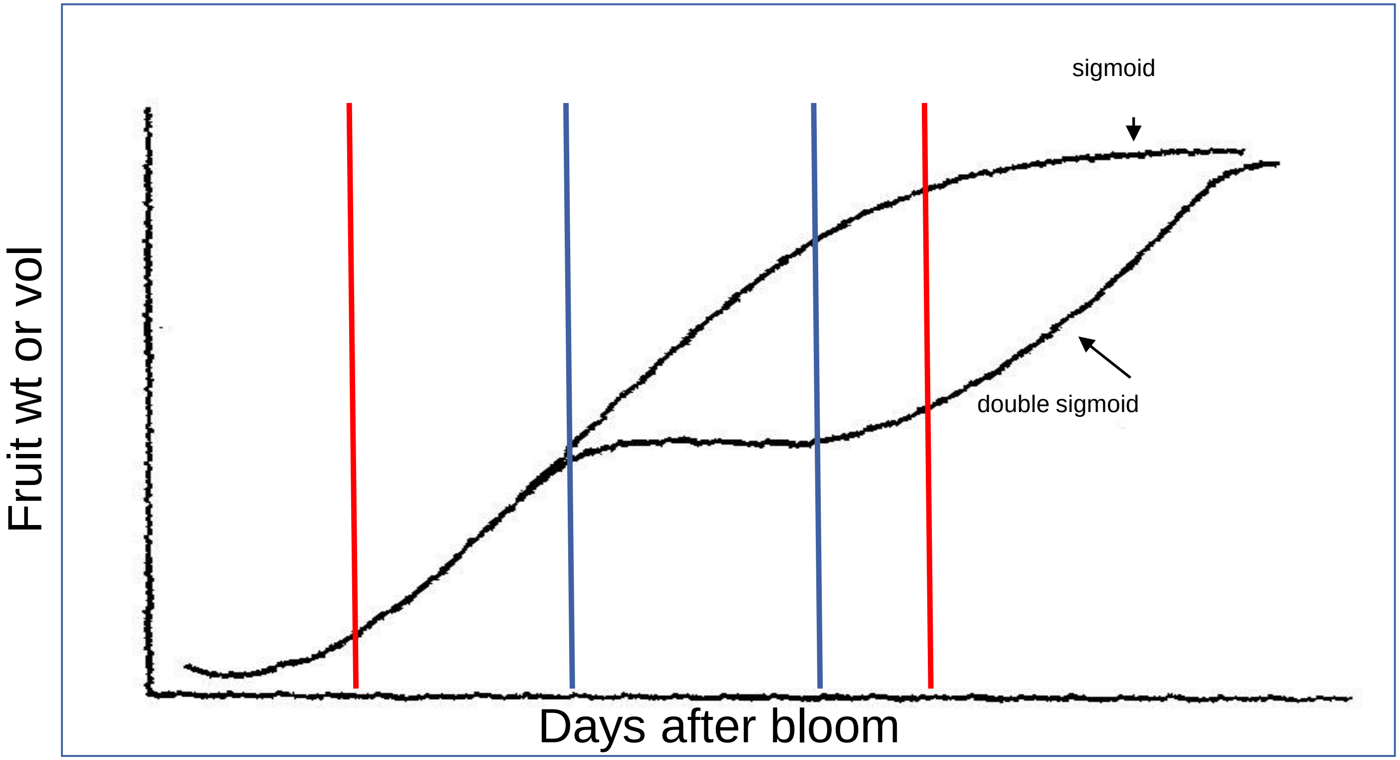
Northern highbush blueberry

Effective pollination period (EPP) = ovule longevity (d) – pollen germination & tube growth (d)



From Kirk and Isaacs, 2012

Fruit growth curves

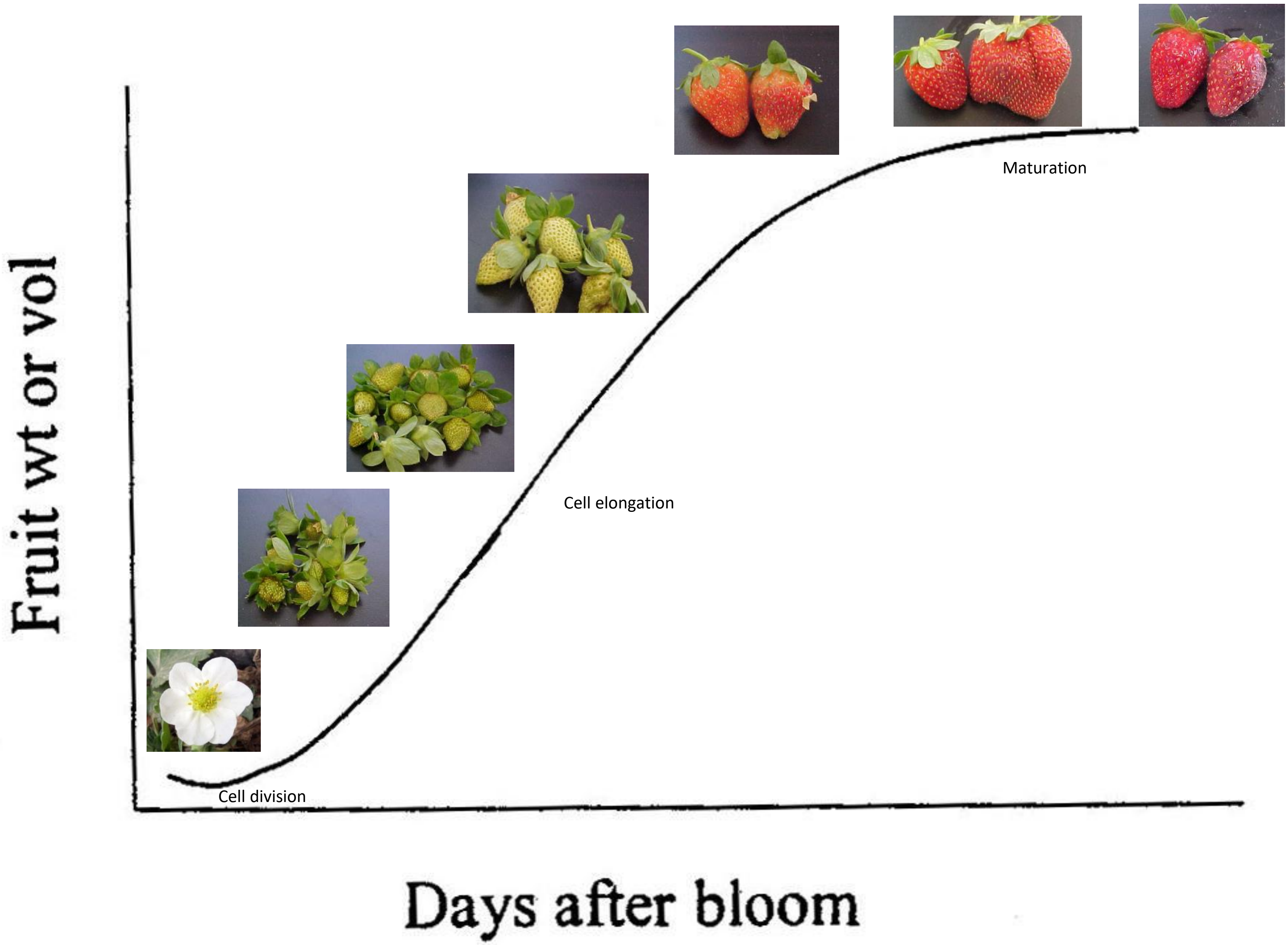


Stage I, II, and III for sigmoid

Stage I, II, and III for double sigmoid

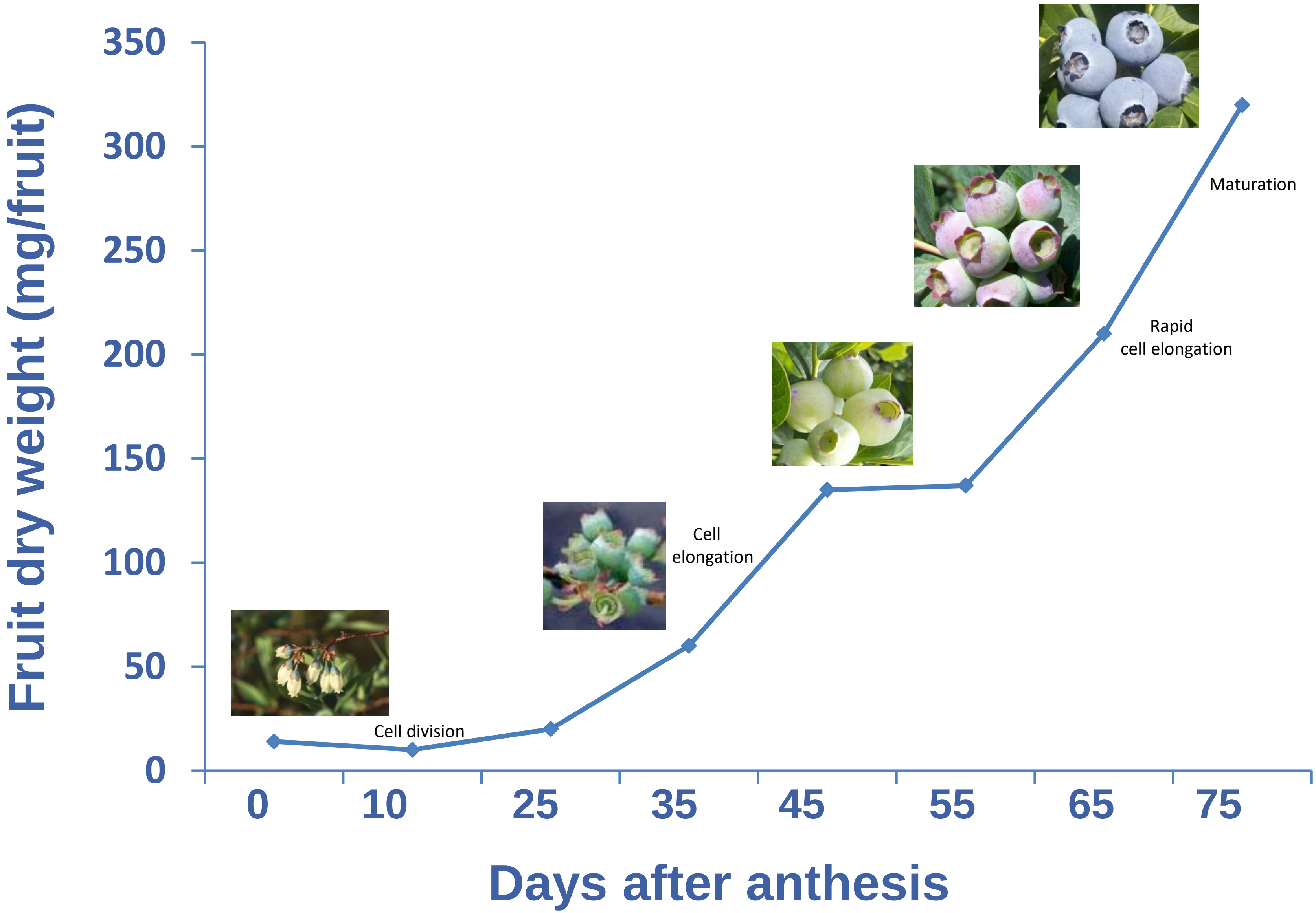
Strawberry fruit development

Sigmoid

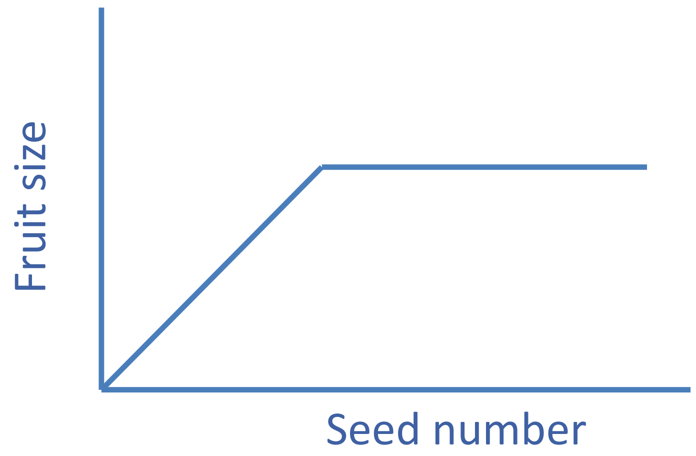


Blueberry fruit development

Double sigmoid



Fruit size and shape depends on seed number



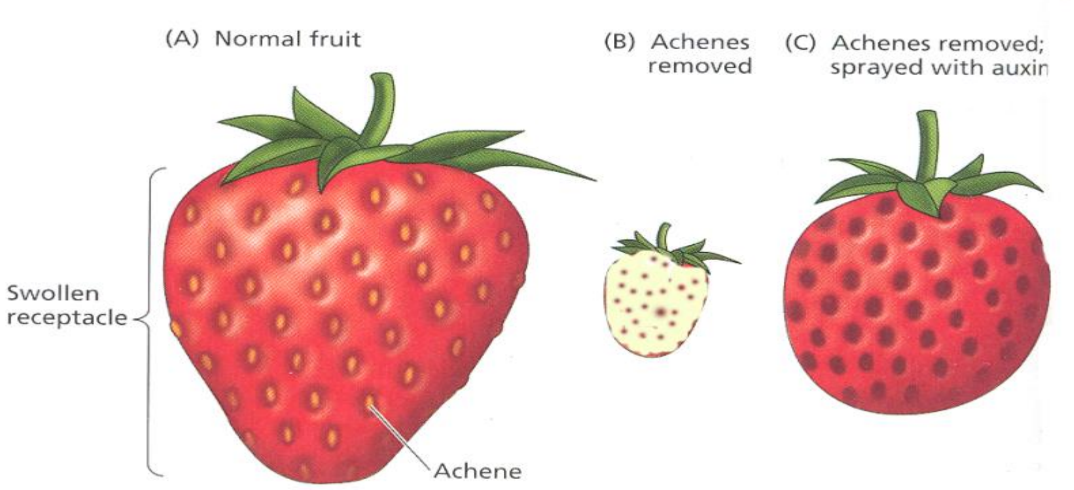


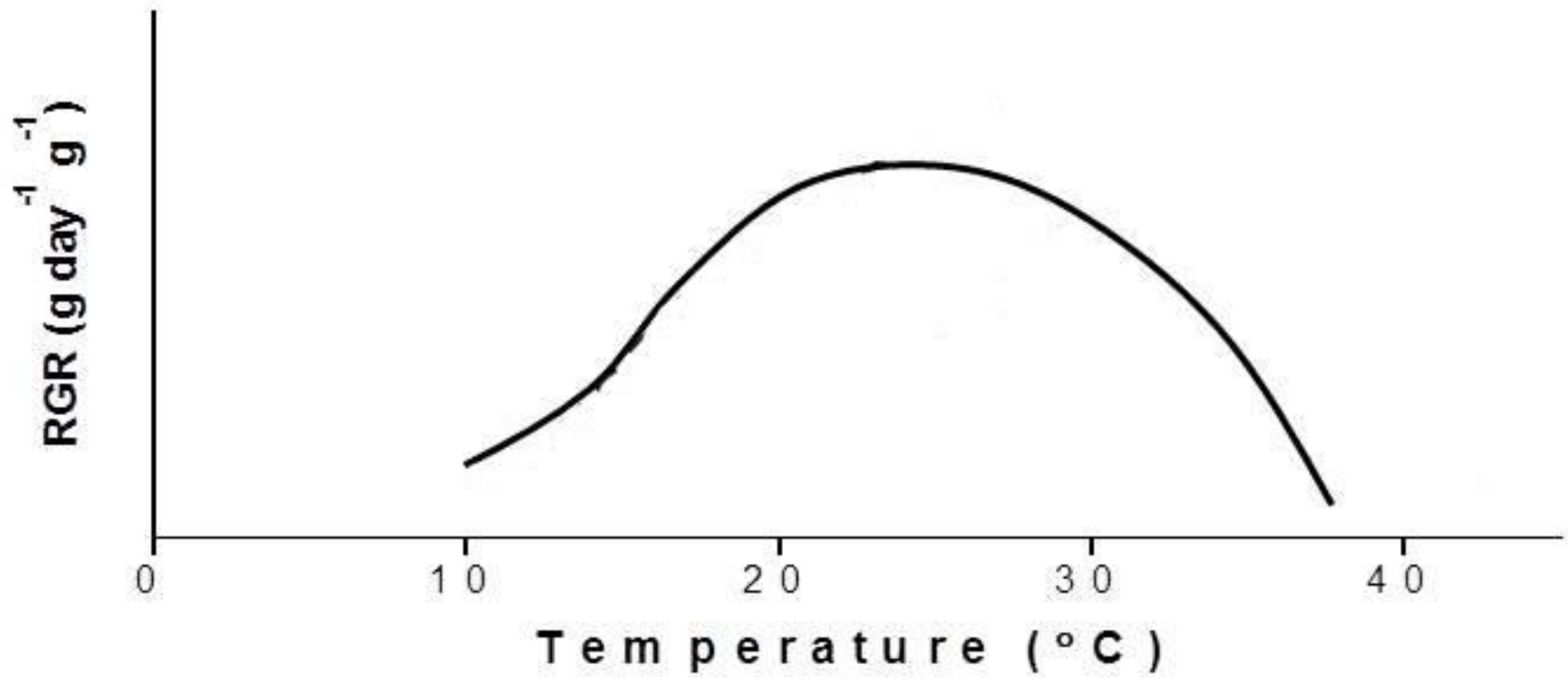
FIGURE 19.39 The strawberry "fruit" is actually a swollen receptacle whose growth is regulated by auxin produced by the "seeds," which are actually achenes, the true fruits. (A) When the achenes are present the receptacle enlarges and develops its characteristic flavor, sweetness, and red color. (B) When the achenes are removed, the receptacle fails to develop normally. (C) Spraying the receptacle minus its achenes with IAA restores normal growth and development. (After Galston 1994.)

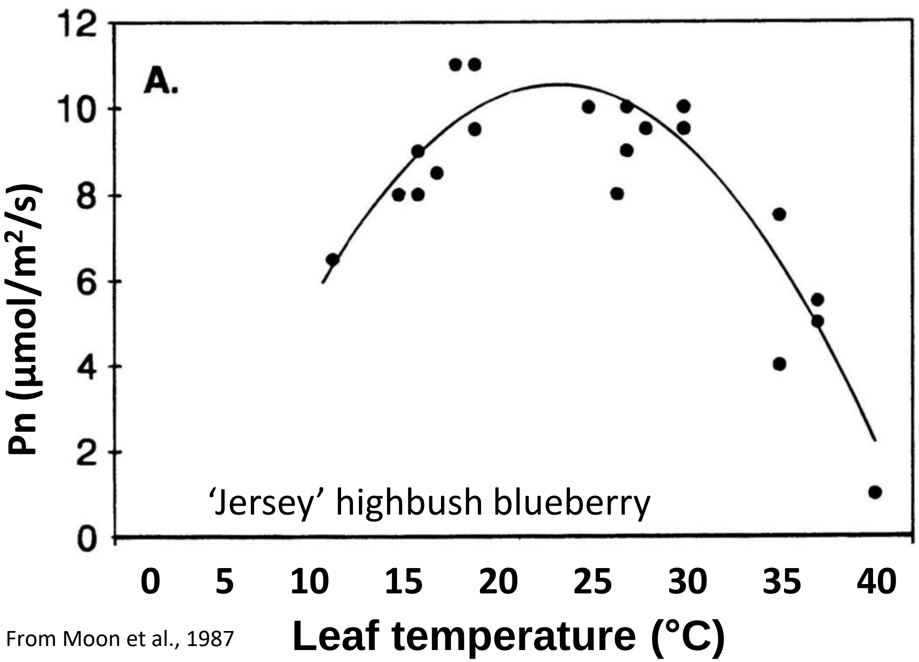
3. Environmental effects on growth and development

- Temperature
- Light
- Water
- Nitrogen nutrition

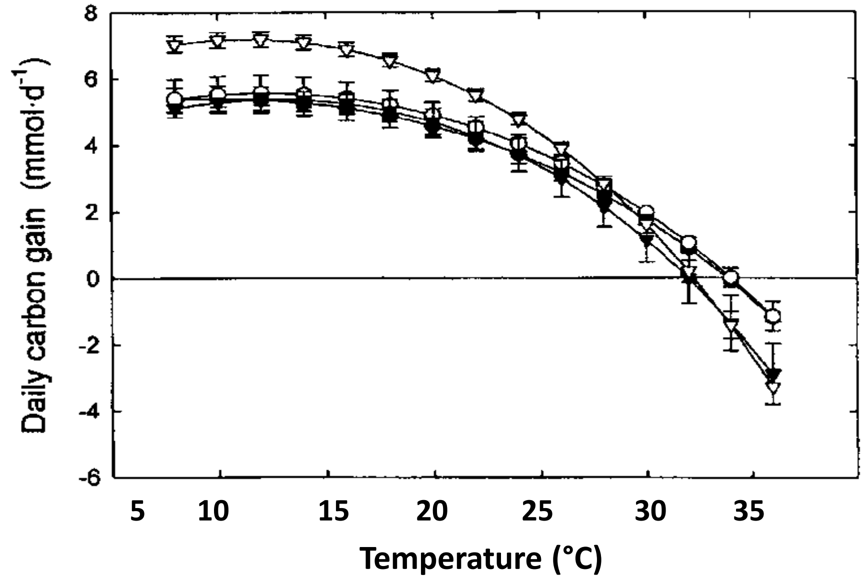
Temperature effects

Air temperature effects on RGR





From Moon et al., 1987



From van Iersel, 2003

Temperature effects on 'Misty' southern highbush

Organ	Dry weight (g) 21°C	Dry weight (g) 28°C
Root	11.2 a	9.2 a
Leaf	5.6 a	3.0 b
Old cane	9.8 a	5.6 b
New cane	1.7 a	0.7 b
Total plant	29.1 a	18.5 b

From Spann et al., 2004

Air temperature effects on pollination

Pollen viability in 'Toyonoka' strawberry flowers grown under two day/night temperatures regimes

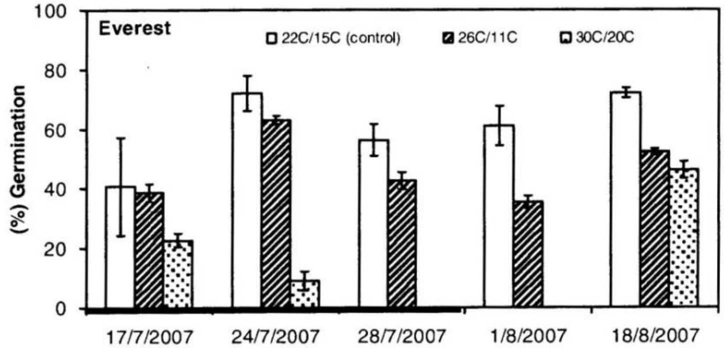
Temperature	Pollen viability (%)
23/18 °C	79.6a
30/25 °C	30.4b

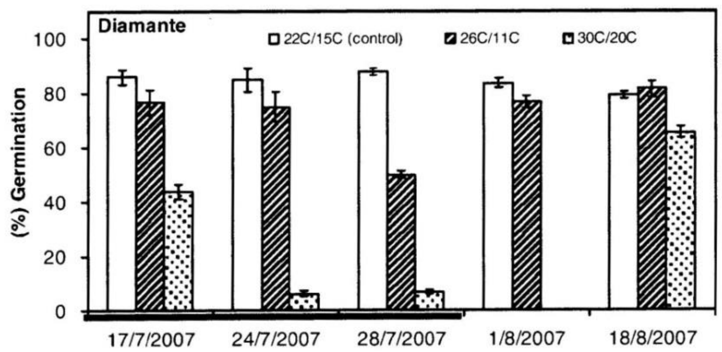
Pollen germination and tube growth in 'Toyonoka' strawberry flowers grown under two day/night temperature regimes and germinated at two temperatures

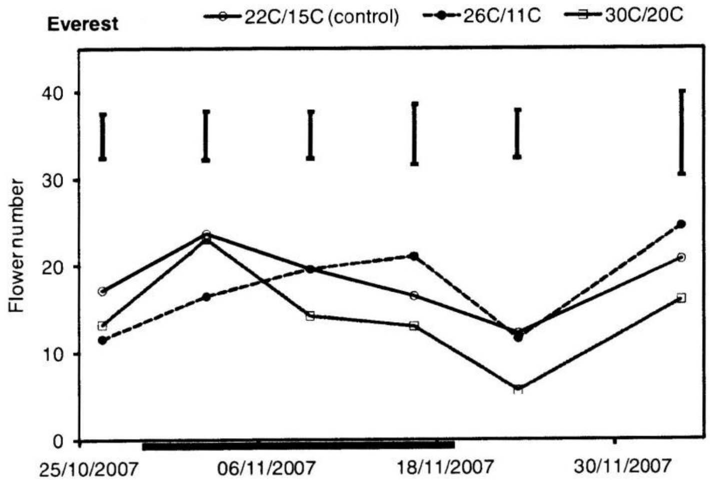
Growth temperature	Germination temperature	Pollen germination (%)	Tube length (mm)
23/18 °C	23 °C	55.6a	3.04a
23/18 °C	30 °C	28.2c	2.24b
30/25 °C	23 °C	38.6b	2.25b
30/25 °C	30 °C	18.4d	1.67c

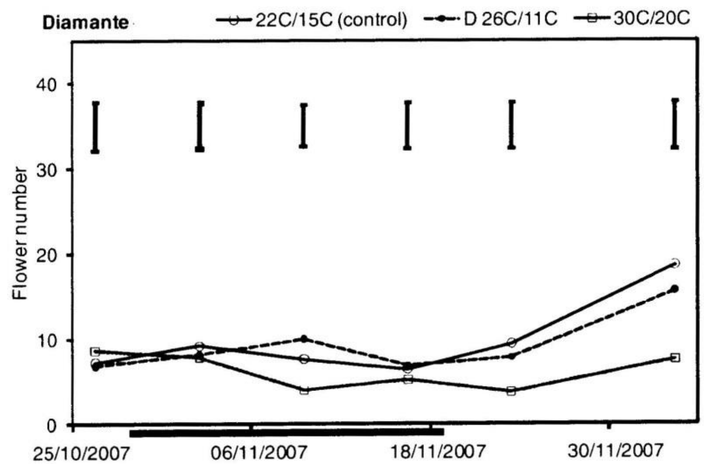
From Ledesma and Sugiyama, 2005

Air temperature effects on pollen germination and flower number in day-neutral strawberry









From Karapatzak et al., 2012

Air temperature effects on fruit set in strawberry

	Fruit set %	
Temp	Everest	Diamante
22/15°C	81.8	100
26/11°C	52.2	24.4
30/20°C	33.8	22.9

From Karapatzak et al., 2012

Air temperature effects on reproduction in southern highbush blueberry

Temperature (°C) Day/night	Fruit set (%)	Avg. fruit wt (g)	FDP (days)
26/21	63.9 b	1.5 b	85 b
26/10	83.2 a	1.7 a	88 ab
29/10	71.4 ab	1.4 b	90 a

High root temperature effects

Excessively high root temperatures:

1. Decrease root growth
2. Decrease nutrient uptake
3. Decrease water uptake

- Decrease photosynthesis & growth,
  even when air temperatures are optimum.
- Critical in shallow rooted species

Influence of root temperature on growth of southern highbush blueberry (air temperatures 16-18 °C)

Root temp (°C)	Shoot dw (g)	Root dw (g)	Total dw (g)	Root length (cm)	Shoot vigor[a]	Root vigor
16	4.8	15.2	20.0	22.8	3.5	4.0
27	3.2	9.7	12.9	20.4	2.5	2.5
38	1.5	7.3	8.8	14.7	1.1	1.4

[a]Visual rating from 0=dead; 1= worst, but living; 5=best

From Spiers, 1995

The majority of roots are located in the top 10 to 15 cm of soil profile.

- Avg soil temperature at 10 cm in SE US is 28-31°C in summer without mulch

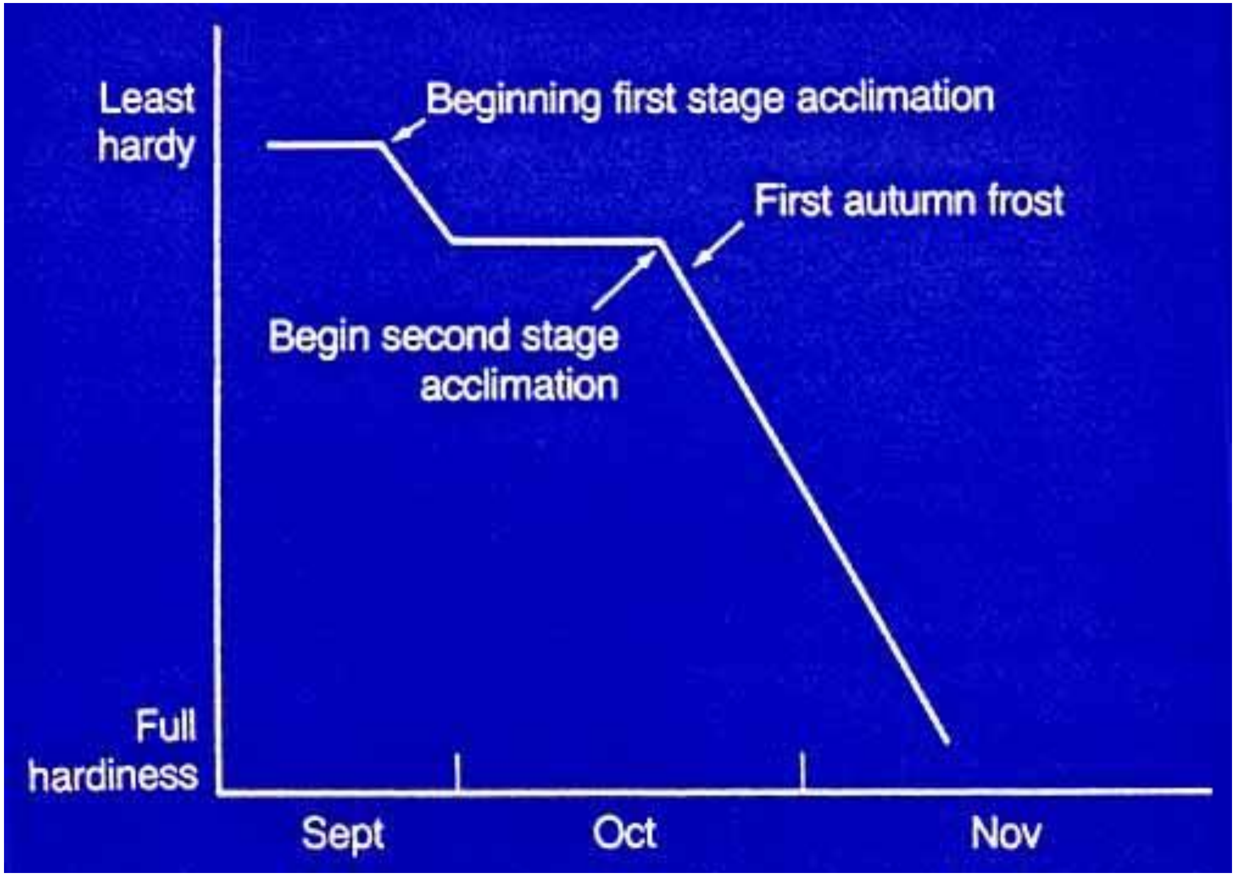
Credit J. Williamson

Influence of root temperature on strawberry growth (air temperatures 8-24 °C)

Root temp (°C)	Leaf DW (g)	Root DW (g)	Crown DW (g)	Total DW (g)
10	1.36	2.04	1.40	4.80
17	2.79	2.43	1.71	6.93
25	4.54	2.50	1.86	8.90
32	1.73	1.03	1.16	3.92

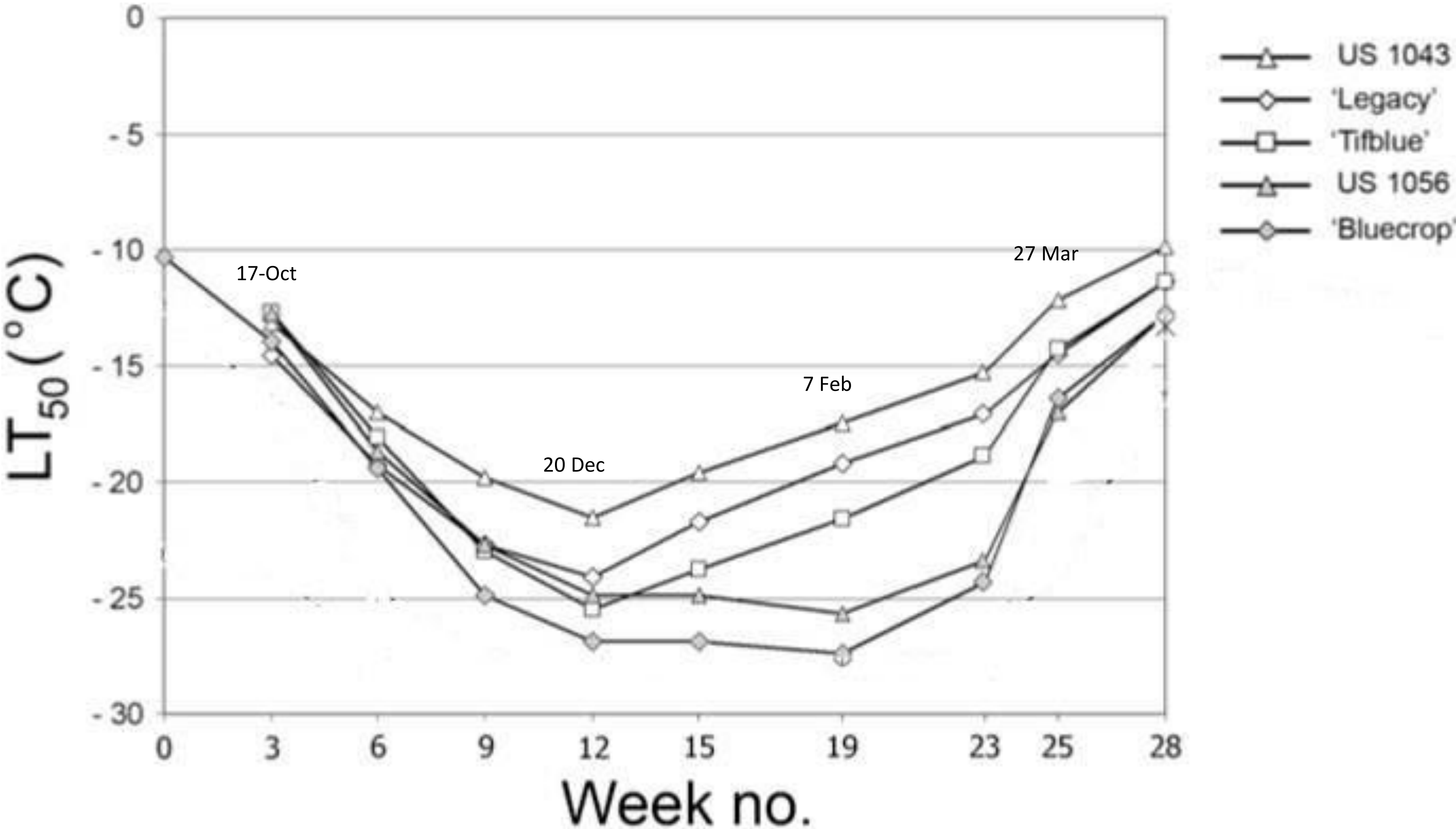
From Ganmore-Neumann and Kafkafi, 1983

Dormant Season Temperatures
Cold Acclimation



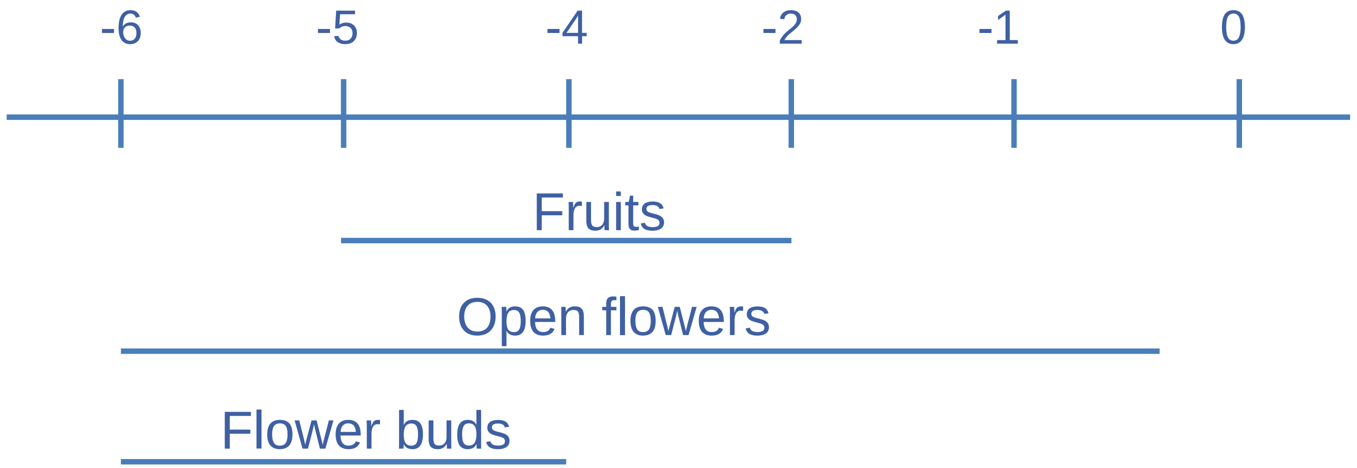
Cold acclimation (hardiness) acquisition

Cold acclimation in blueberry

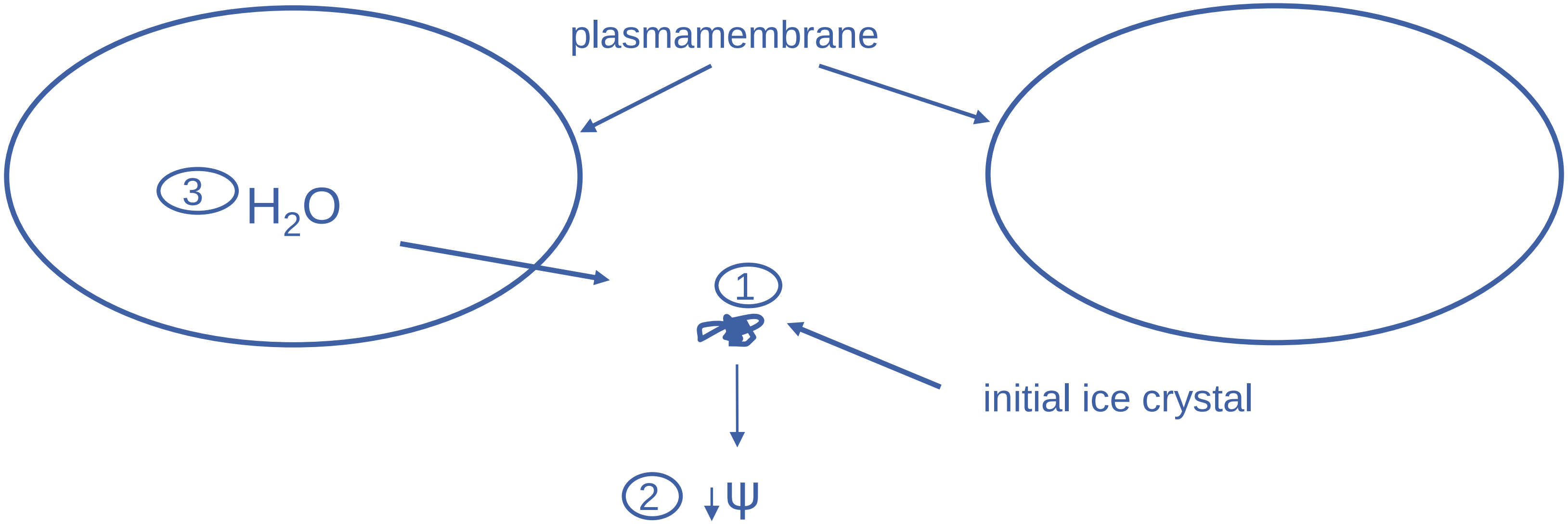


From Ehlenfeldt et al., 2012

Cold acclimation of strawberry reproductive structures (°C)



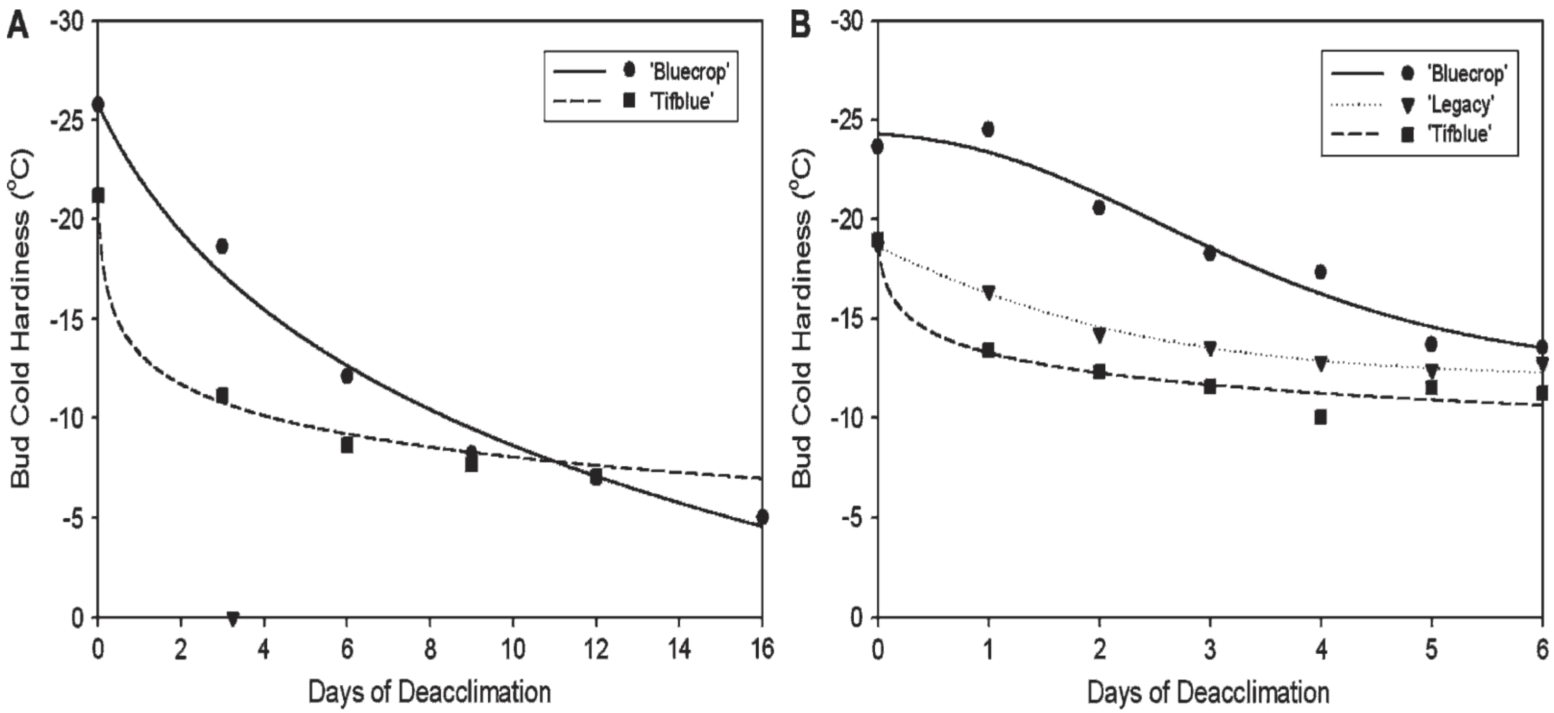
Freezing Stress – 2 ways plants survive



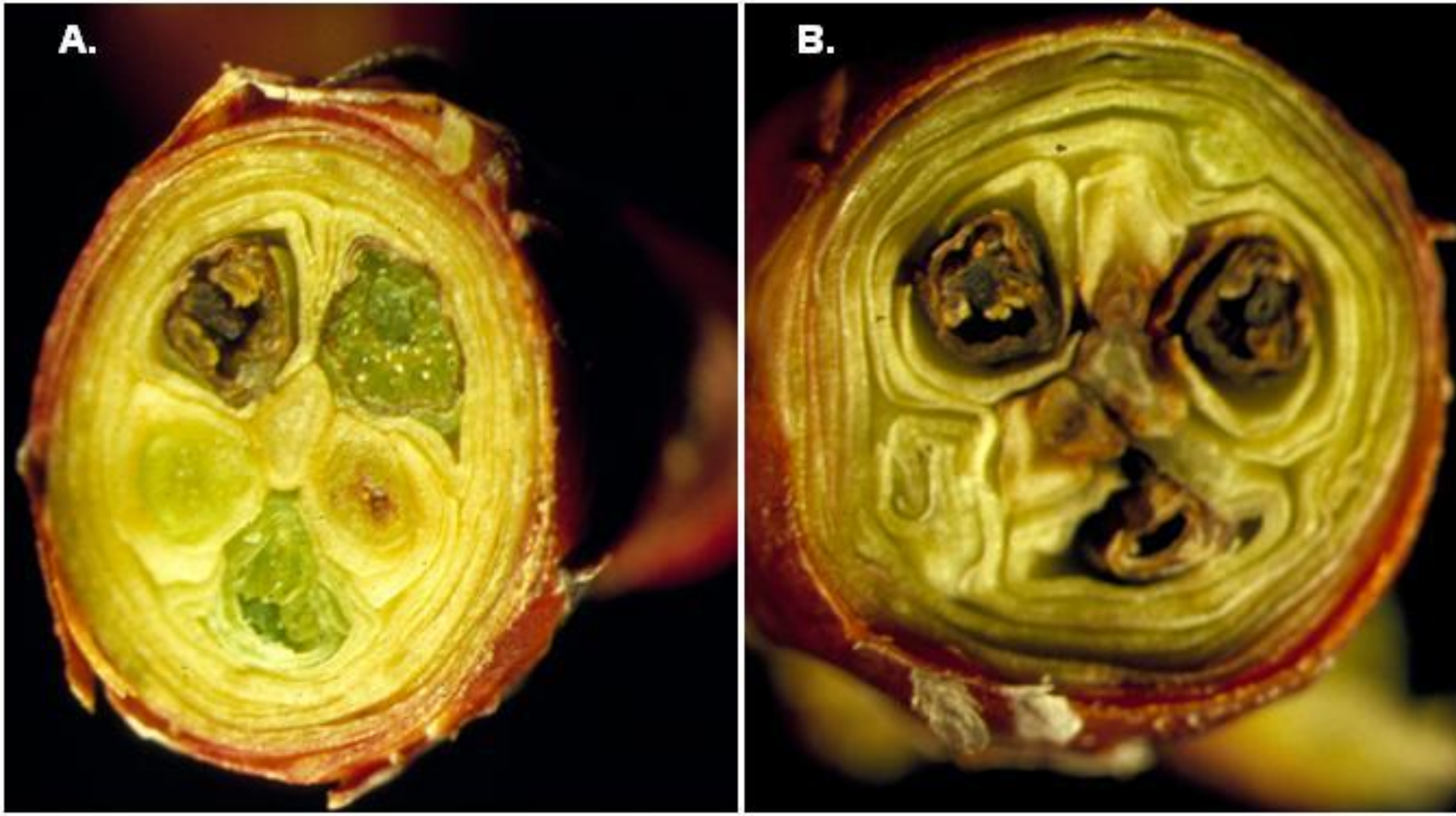
Thus, freezing stress is really dehydration stress

Supercooling

Deacclimation occurs rapidly in response to warm temperatures in winter and buds can start to initiate growth



From Rowland et al., 2008



Cold injured highbush blueberry flower buds

Photograph credit to Nick Vorsa

Freeze protection

Overhead irrigation

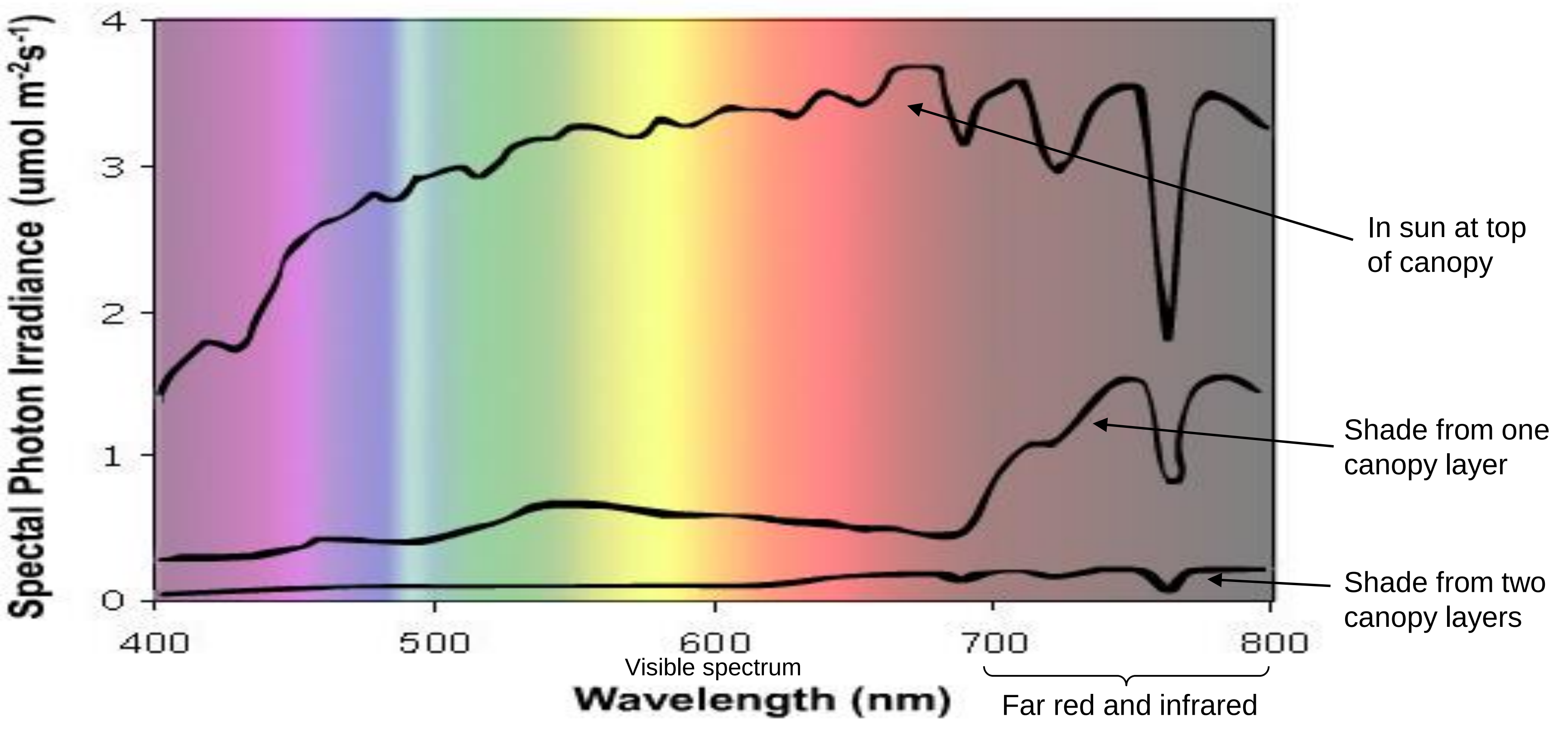
High tunnels

Row covers

Snow/
straw mulch

Light effects

Light relations in canopy



Light intensity & light quality

Phytochrome – photoreceptor senses light quality

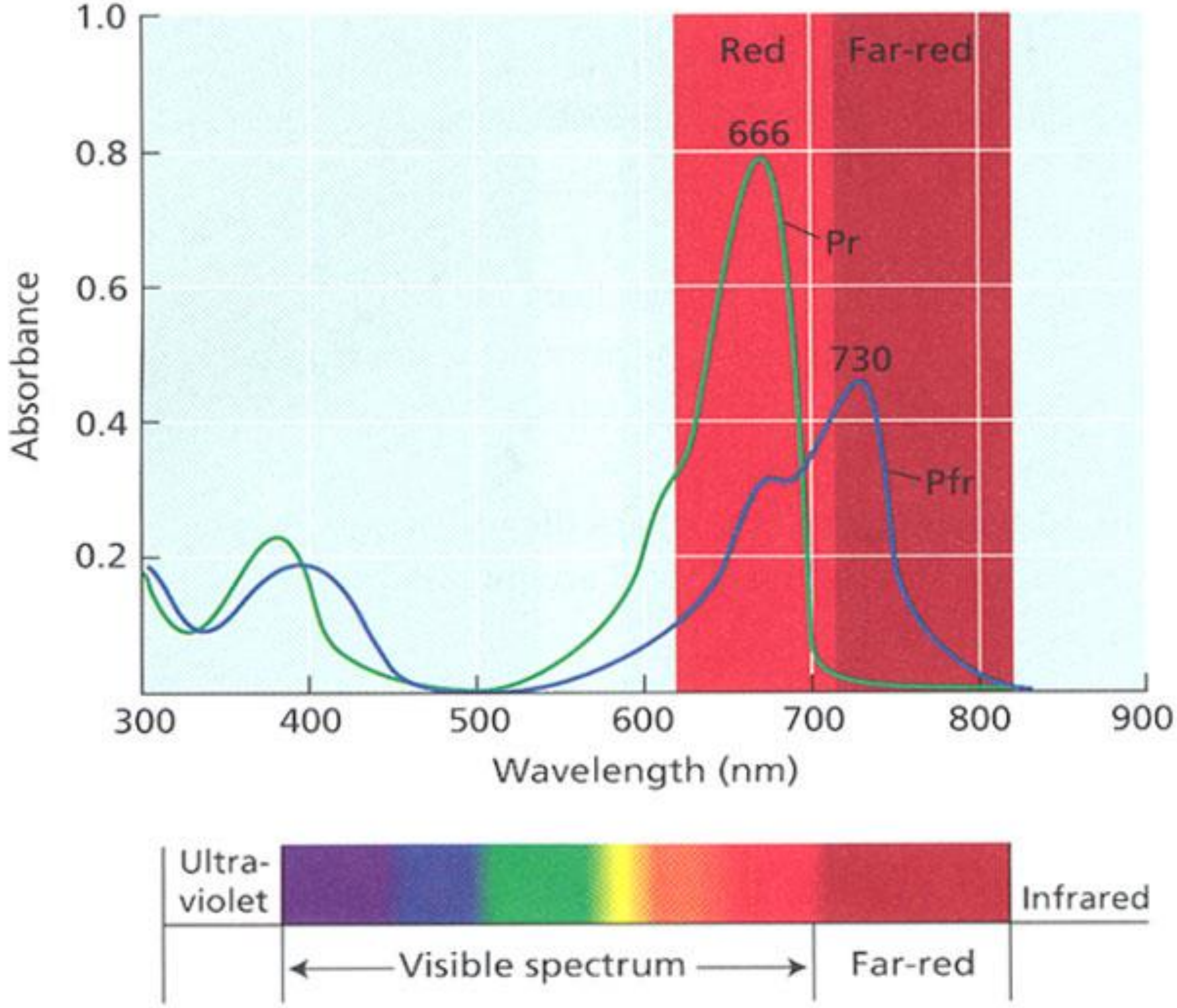
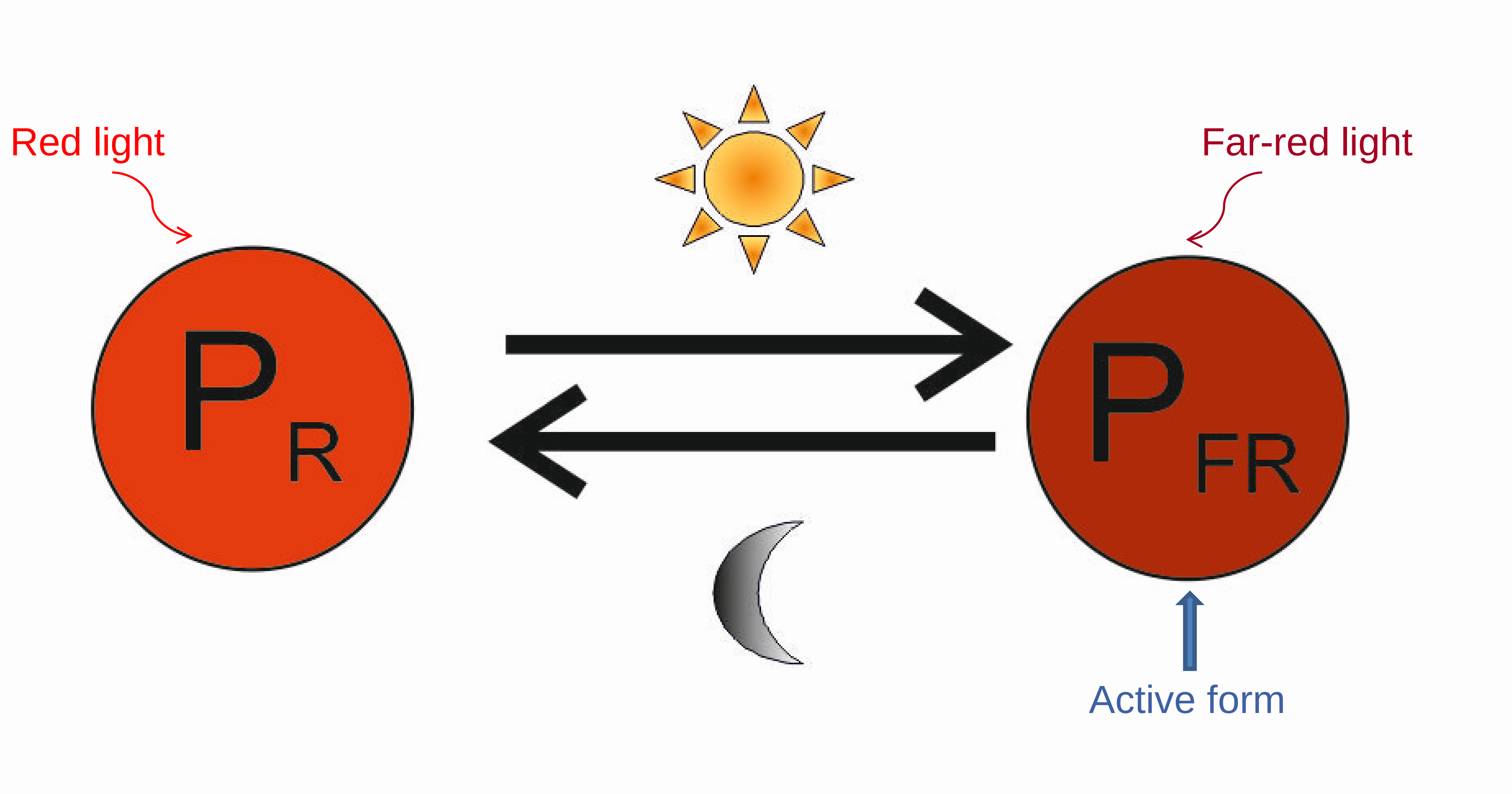


FIGURE 17.3 Absorption spectra of purified oat phytochrome in the Pr (green line) and Pfr (blue line) forms overlap. (After Vierstra and Quail 1983.)

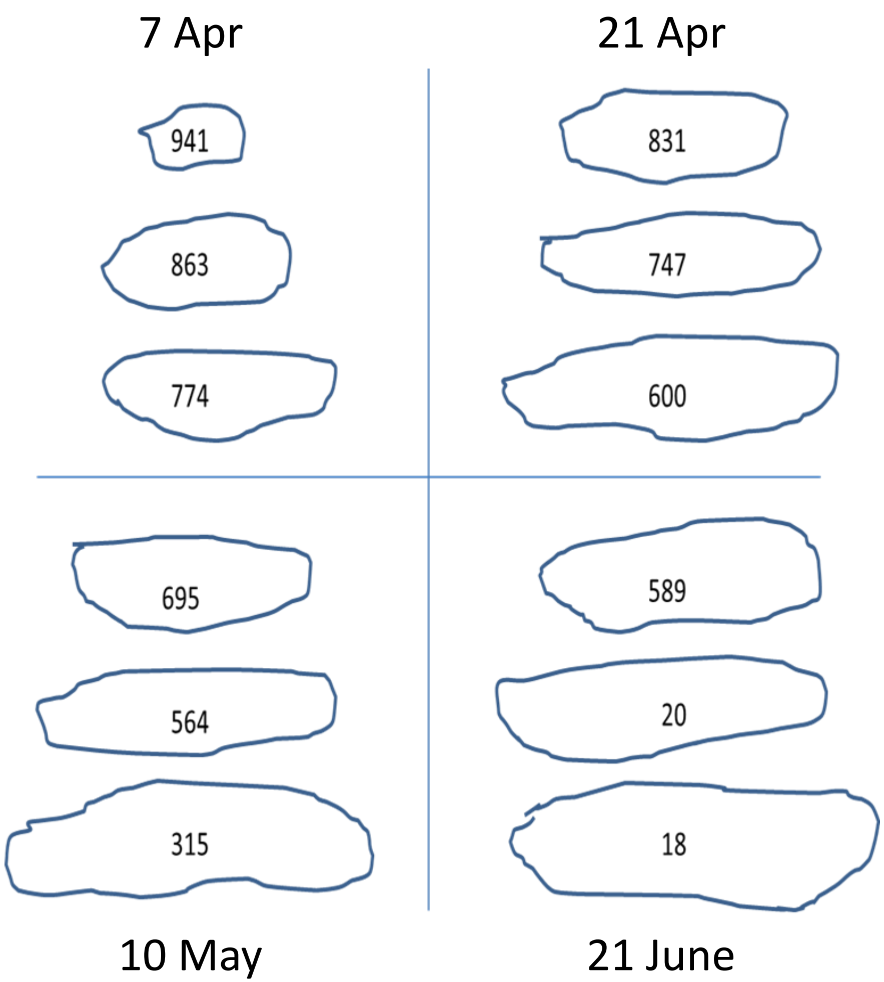


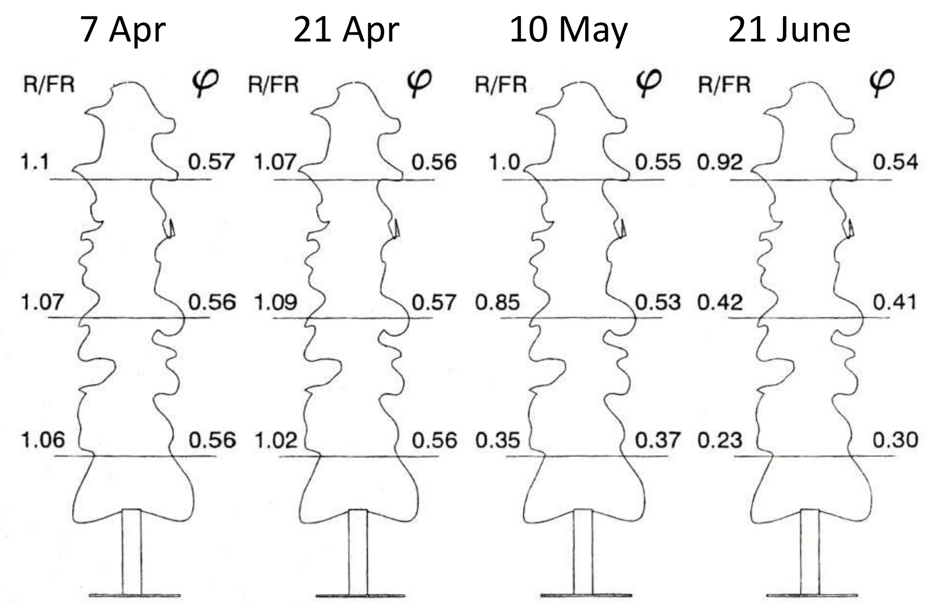
P_{FR}: Promotes seed germination, anthocyanin synthesis, branching. Inhibits stem elongation. *Affects* flower bud initiation.

Estimated values of R/FR for canopy filtered light

Canopy	R/FR
wheat	0.5
maize	0.2
oak woodland	0.12-0.17
maple woodland	0.14-0.28
spruce forest	0.15-0.33

Light intensity (PPF) and R/FR light ratios (P_{FR}/P_{TOT}) in peach canopy





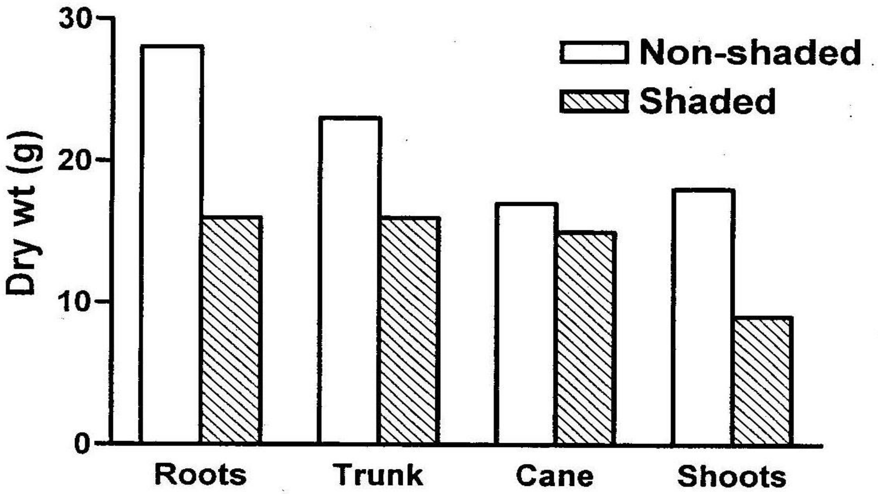
Shade effects on growth of 'Bluecrop' blueberry

Shade (%)	Shoot no.	Shoot length (cm)	Leaf area (cm^2)	Flower bud no.	Fruit set (%)	Yield (g/plant)
31	16.8 a	16.9 b	9.1 d	7.7 a	100.0 a	73.3 a
60	15.0 b	20.7 ab	13.0 c	5.2 b	89.0 b	42.4 b
73	11.3 c	21.5 a	18.9 b	3.5 bc	83.5 b	19.7 c
83	8.8 d	31.0 a	22.4 a	2.3 c	28.8 c	1.2 d

Primarily light intensity response decreasing Pn

From Kim et al., 2011

Shade one season affects the next season's growth



Effect of 85% shading from bloom until fruit harvest the previous season on dry weight of current season's growth in grapevine

Light intensity response decreasing Pn and accumulation of CHO reserves

From McArtney and Ferree, 1999

Internode elongation, flower density and percentage of lateral shoots developed in year-old twigs in the three layers of the peach canopy

	Internode length (cm)	Flower (m^{-1})	Lateral shoots (%)
Top	1.7 c	40.1 a	22.0 a
Middle	1.9 b	29.5 b	12.2 b
Bottom	2.1 c	20.5 c	10.0 c

Primarily a light quality response due to decreased P_{FR}

From Baraldi et al., 1994

In SDP, red light (which increases Pfr) inhibits flower bud initiation

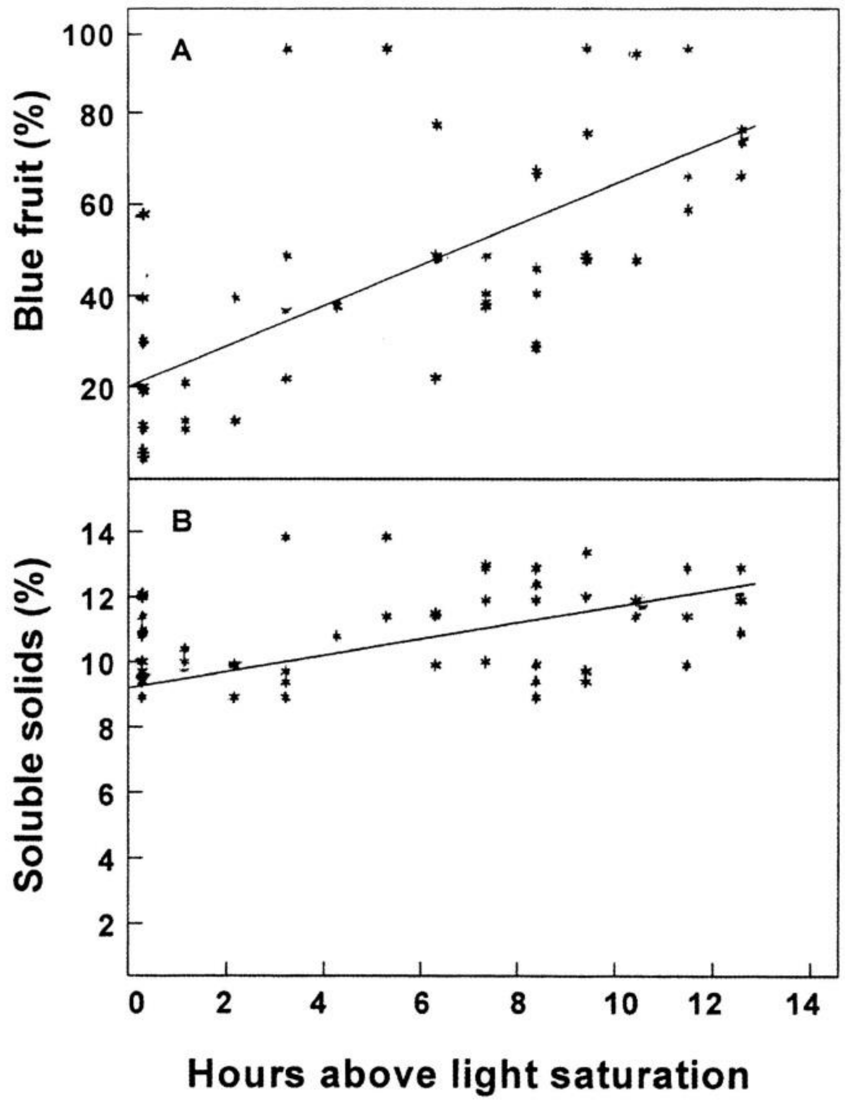
Effect of red light-emitting diodes on flower bud initiation in 'Strawberry Festival' grown at high density under long days

	Flowering plants (%)			
Treatment	3 Oct.	24 Oct.	27 Nov.	17 Dec.
Control	70.3	83.0	95.7	95.7
Red light	37.3*	45.7*	58.3*	62.3*

In control, leaf cover eliminated red light, allowing far red light to penetrate to crown → decreasing P_{FR} and activating gene expression changes that led to flower bud initiation

From Takeda et al., 2008

Shade decreases fruit color (anthocyanin) and quality



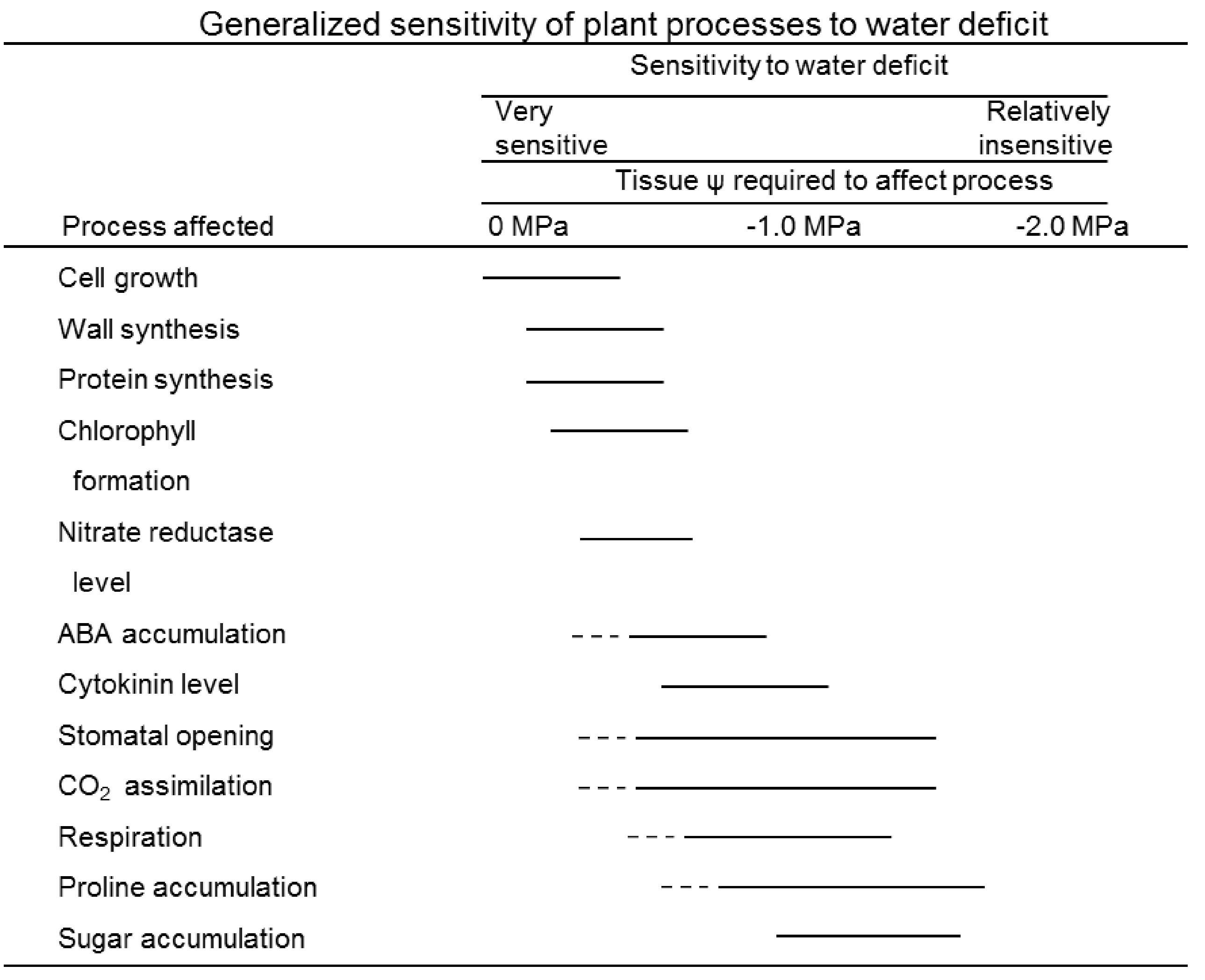
Anthocyanin production is an HIR response induced by high intensity red light for long durations.

Light intensity and quality response

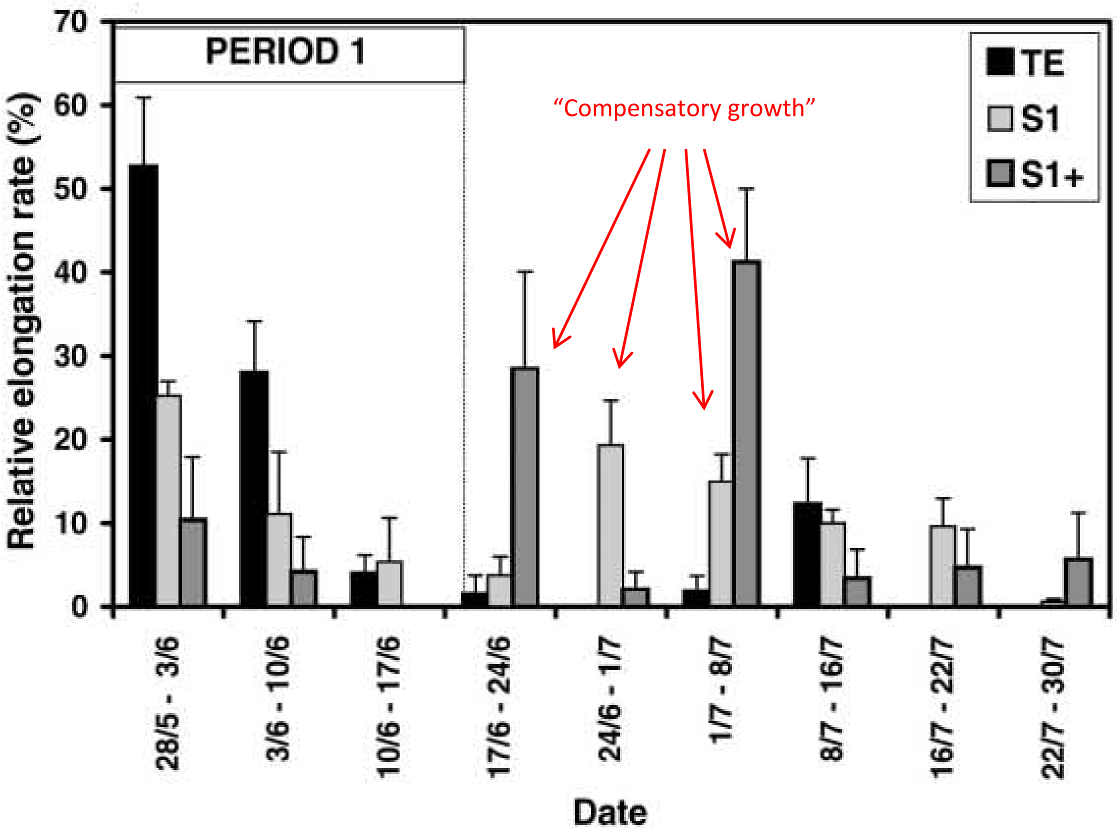
From Patten and Neuendorff, 1989

Water deficit effects

Water deficit



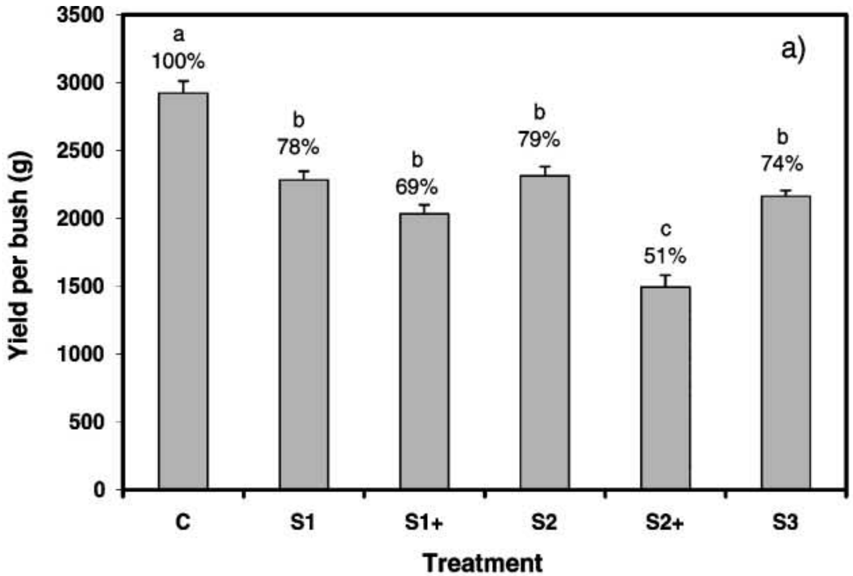
Drought effects on shoot growth in 'Bluecrop'

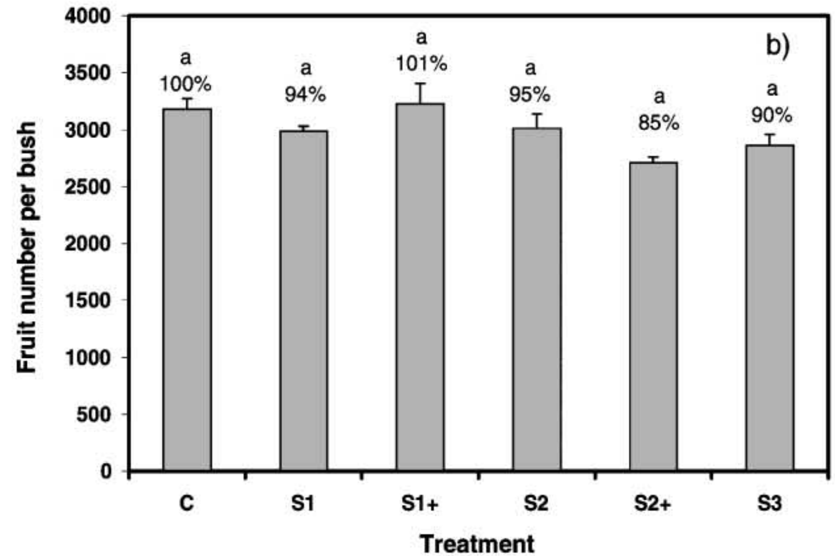


TE=control (no water stress)
S1=65% replacement-fruit growth (28 May-16 June)
S1+=35% replacement-fruit growth

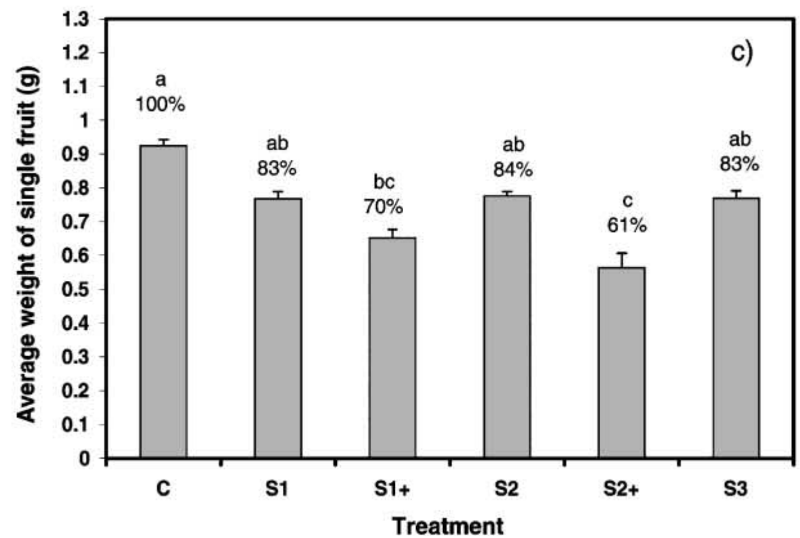
From Mingeau et al., 2001

Drought effects on yield in 'Bluecrop'



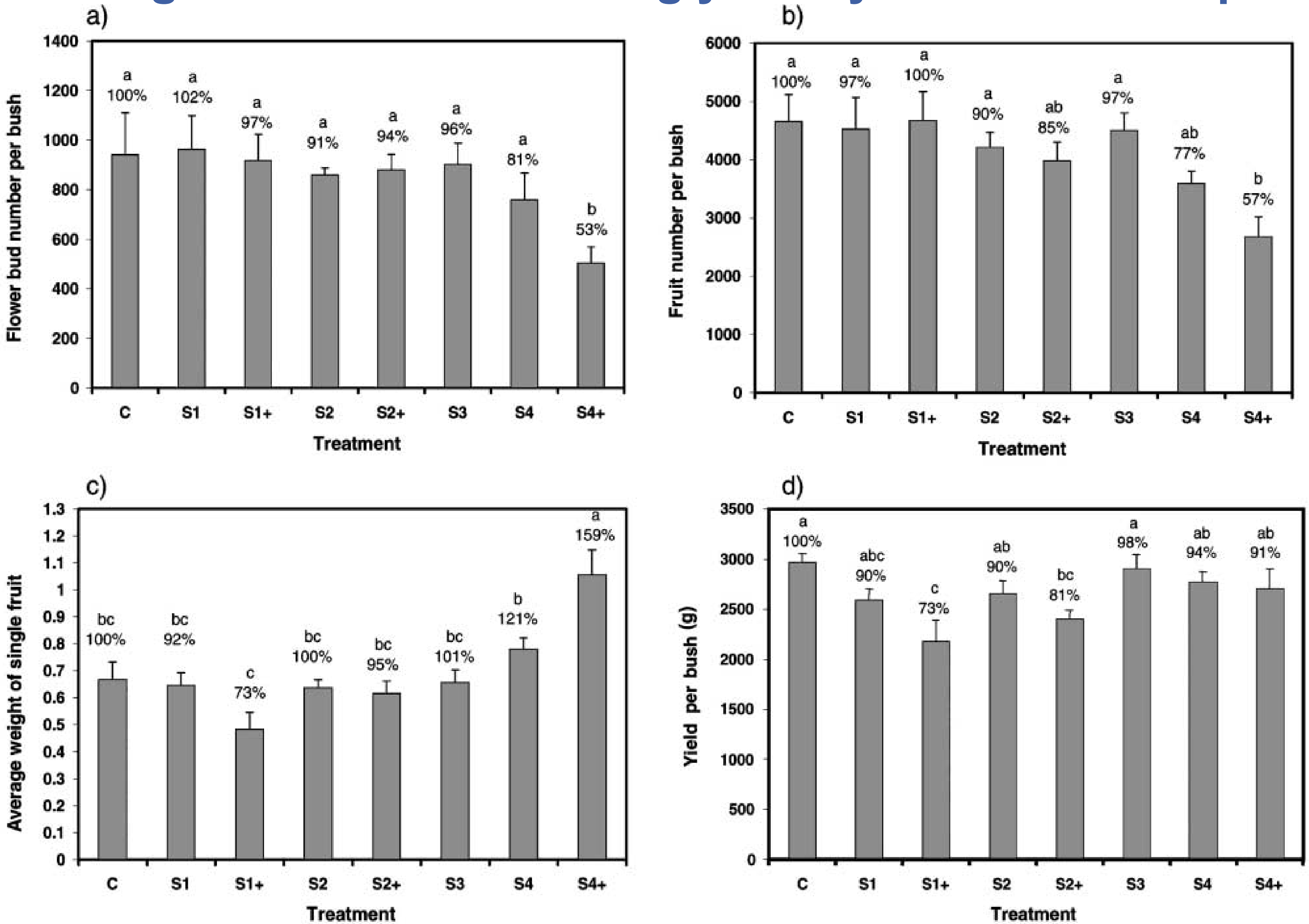


S1=65% replacement-fruit growth (28 May-16 June)
S1+=35% replacement-fruit growth
S2=65% replacement-fruit ripening (18 June-7 July)
S2+=35% replacement-fruit ripening
S3=65% replacement-fruit harvest (10-29 July)



From Mingeau et al., 2001

Drought effects on following year's yield in 'Bluecrop'

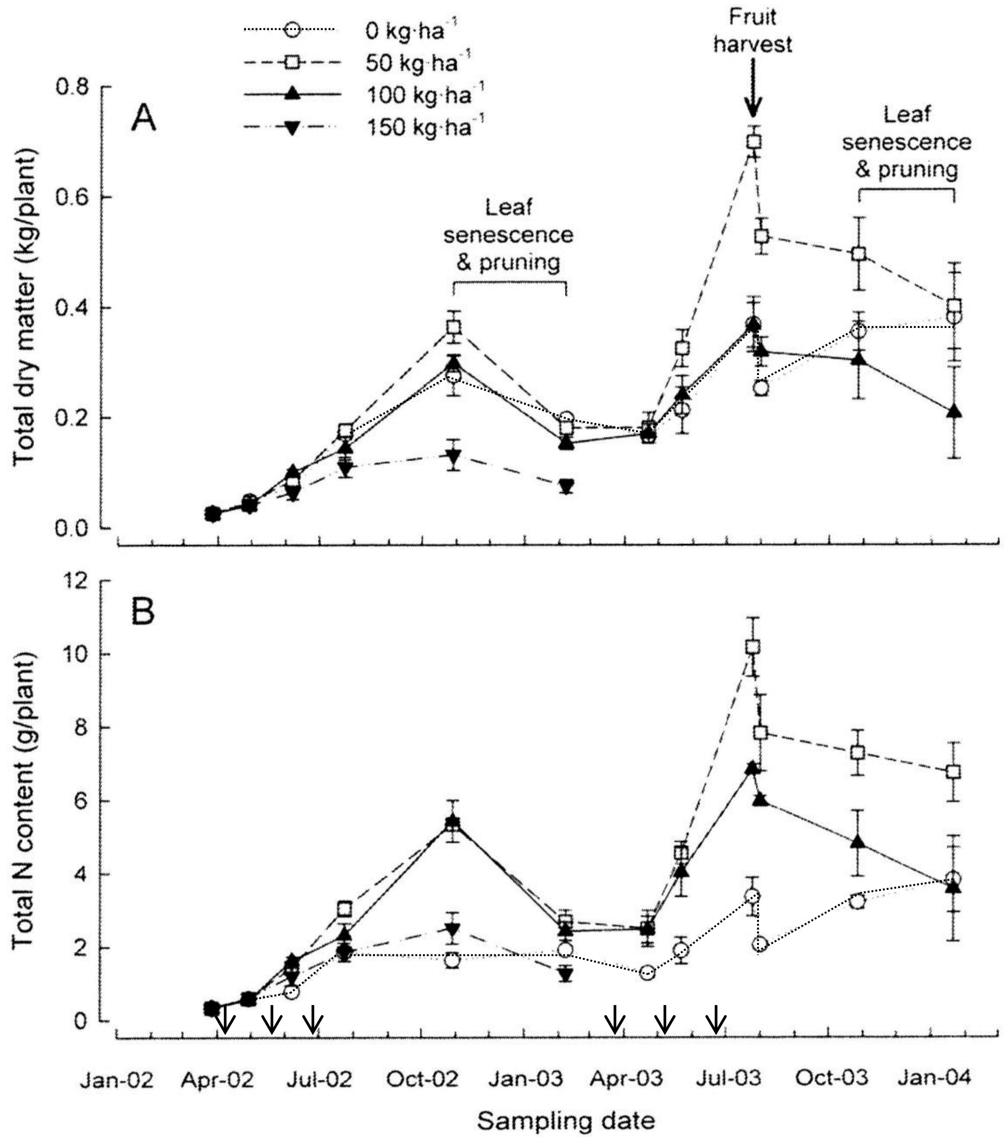


S1=65% replacement-fruit growth (28 May-16 June); S1+=35% replacement-fruit growth;
S2=65% replacement-fruit ripening (18 June-7 July); S2+=35% replacement-fruit ripening
S3=65% replacement-fruit harvest (10-29 July); S4=65% replacement-post harvest (10-30 Aug); S4+=35% replacement-post harvest (10-30 Aug)

Nitrogen nutrition

- N concentration
- N form

Nitrogen concentration effects on dry matter and N content in young 'Bluecrop' blueberry



From Banados et al., 2012

For all berry crops:

N concentration required will depend on

- Plant age
- Production practices – plant density, soil system, irrigation/fertigation

N absorption most rapid during active growth – between bloom and fruit maturity

N applications should be split over the growing season to maintain sufficient soil/substrate N during this time

Nitrogen form (NO_3 vs NH_4) effects on growth

Total dry weight (g; shoot + root) of strawberry, raspberry, and highbush blueberry grown in quartz sand supplied with nitrate or ammonium nitrogen

Species	Nitrate	Ammonium
Strawberry	168.0*	53.1
Raspberry	82.1	81.0
Blueberry	32.0	81.4*

From Claussen and Lenz, 1999

Effect of NO_3/NH_4 ratio on dry weight of strawberry plants after 8 weeks

NO_3	NH_4	Root	Crown	Leaves	Total
mmol/L		g/plant			
7.0	0.0	2.2	1.4	2.6	6.2
5.0	2.0	1.9	1.4	3.0	6.3
3.5	3.5	2.5	1.9	4.5	8.9
2.0	5.0	1.0	1.2	1.4	3.6
0.0	7.0	1.0	1.1	1.8	3.9

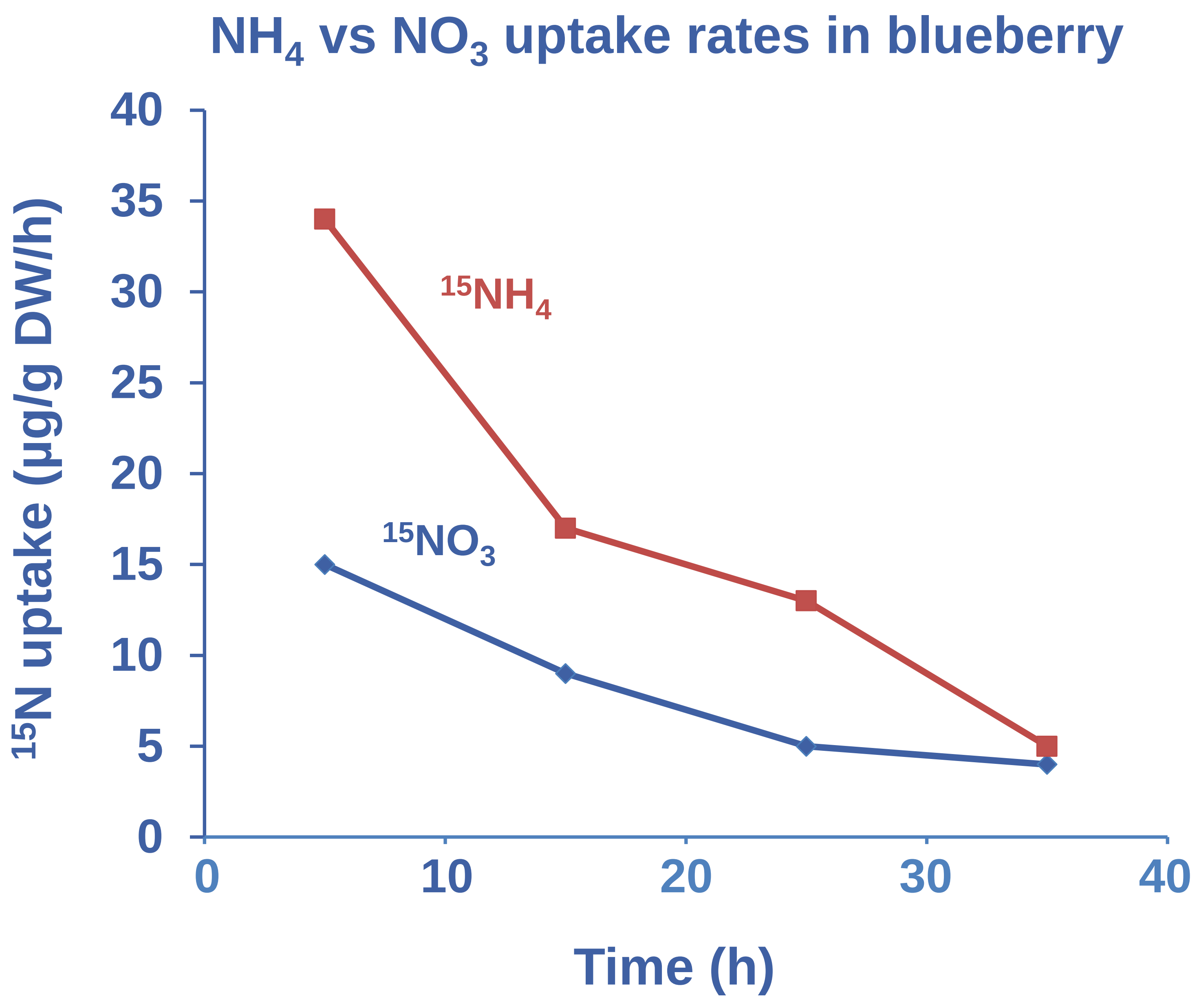
From Ganmore-Neumann and Kafakfi, 1983

Dry weight (g) of 'Sharpblue' SHB grown with NH_4 vs NO_3

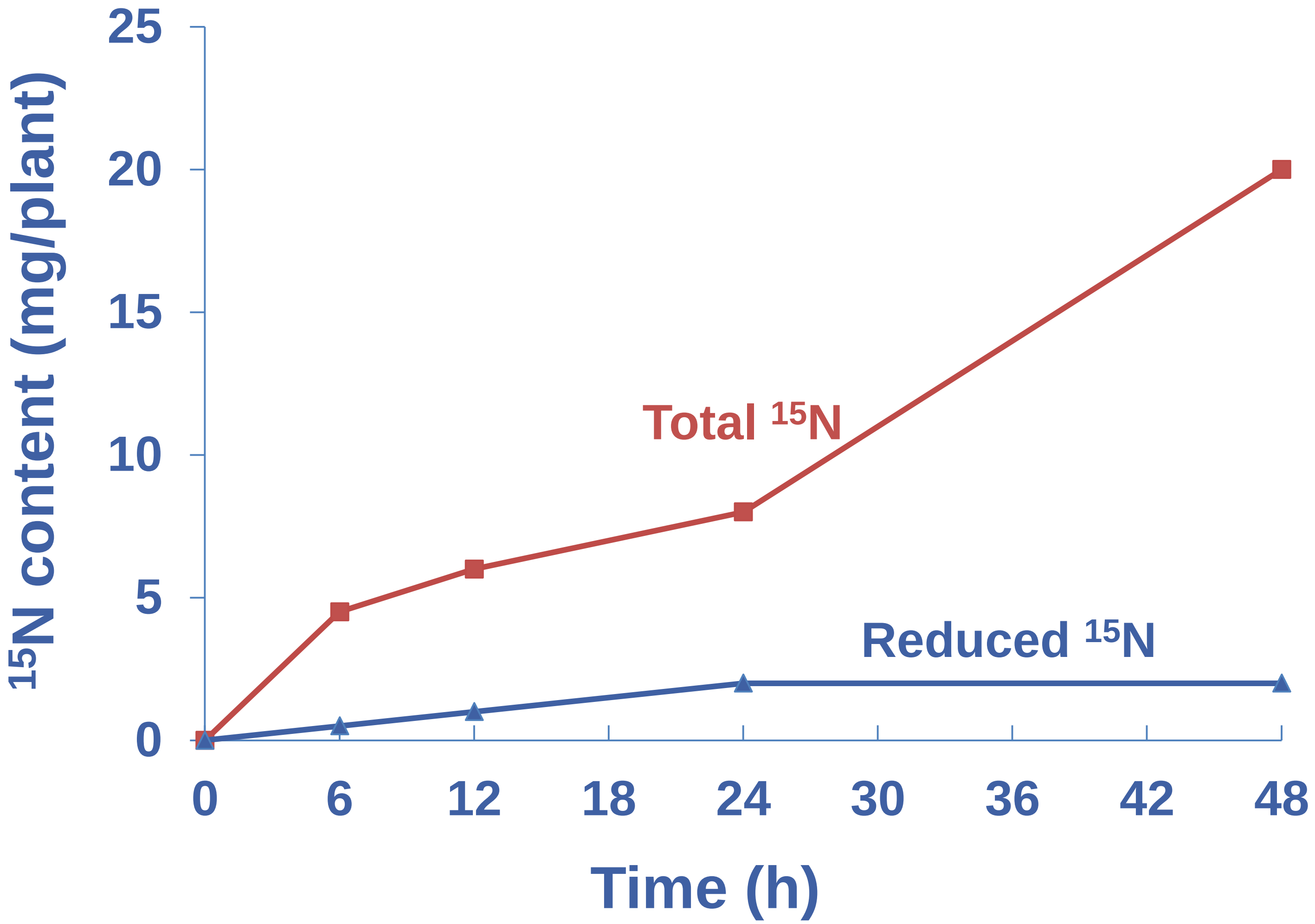
	Plant	New shoot	Leaf	Stem	Root
NH_4	226.3*	9.0	66.6*	83.4*	67.2
NO_3	167.2	9.4	36.4	64.2	52.2

NH_4

NO_3


NH4 vs NO3 uptake rates in blueberry
15N uptake (µg/g DW/h)
40
35
30
25
20
15
10
5
0
15NH4
15NO3
0
10
20
30
40
Time (h)

NO_3 reduction limited in blueberry



Species	NRA (nmol/g FW/h) Root	Leaf
HB blueberry	50-200	0
Strawberry	250-400	300
Raspberry	80	990
Apple	300	1810
Peach	200-400	2000
Calamondin	370	1000

4. Manipulations to Blueberry Growth & Development

- Pruning
- Soil adaptation
- Evergreen Production
- Tunnel Production

Pruning blueberries

- Aids in young plant establishment
- Aids in development of desirable architecture & facilitates cultural practices such as harvesting
- Increases plant vigor; promotes growth of new fruiting wood
- Reduces diseases incidence and spread
- Prevents over-fruiting and increases fruit size
- Improves light penetration into canopy

Pruning during establishment

Credit J. Williamson

Goal – encourage canopy Establishment and develop properly shaped plants

Remove weak, twiggy growth
Remove all flower buds

Failure to remove flower buds on young plants reduces vegetative canopy establishment and results in overbearing and high mortality in some SHB cultivars

Young ‘Misty’ plant with heavy fruit set and few leaves will probably die from blueberry stem blight before the end of the growing Season.

Young blueberry plant with blueberry stem blight caused by stress associated with fruit set without leaves.

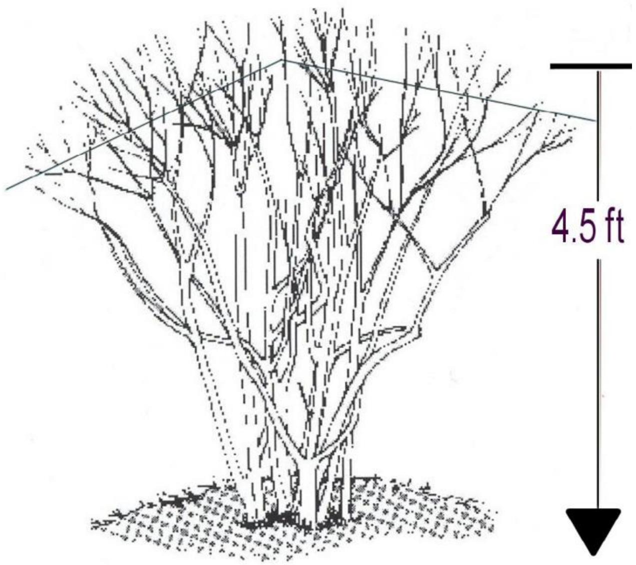
Credits J. Williamson

Dormant pruning mature plants

- Should be done annually in mature plants to prevent overbearing, maintain vigor, enhance fruit quality
- Cane renewal of older canes required to maintain vigor and productivity
- Head back vigorous vegetative shoots to encourage branching

Credits J. Williamson

Summer pruning – major pruning time in FL



Summer topping post-harvest stimulates new vegetative growth with leaves that remain healthy longer into the season

Regrowth will contain many of the flower buds for next year's crop

Industry standard ~30% removal

Summer pruning encourages leaf retention Into fall when FBI occurs

Credit J. Williamson

Hedging results in denser crowns over time, requiring cane renewal in older plants

Credits J. Williamson

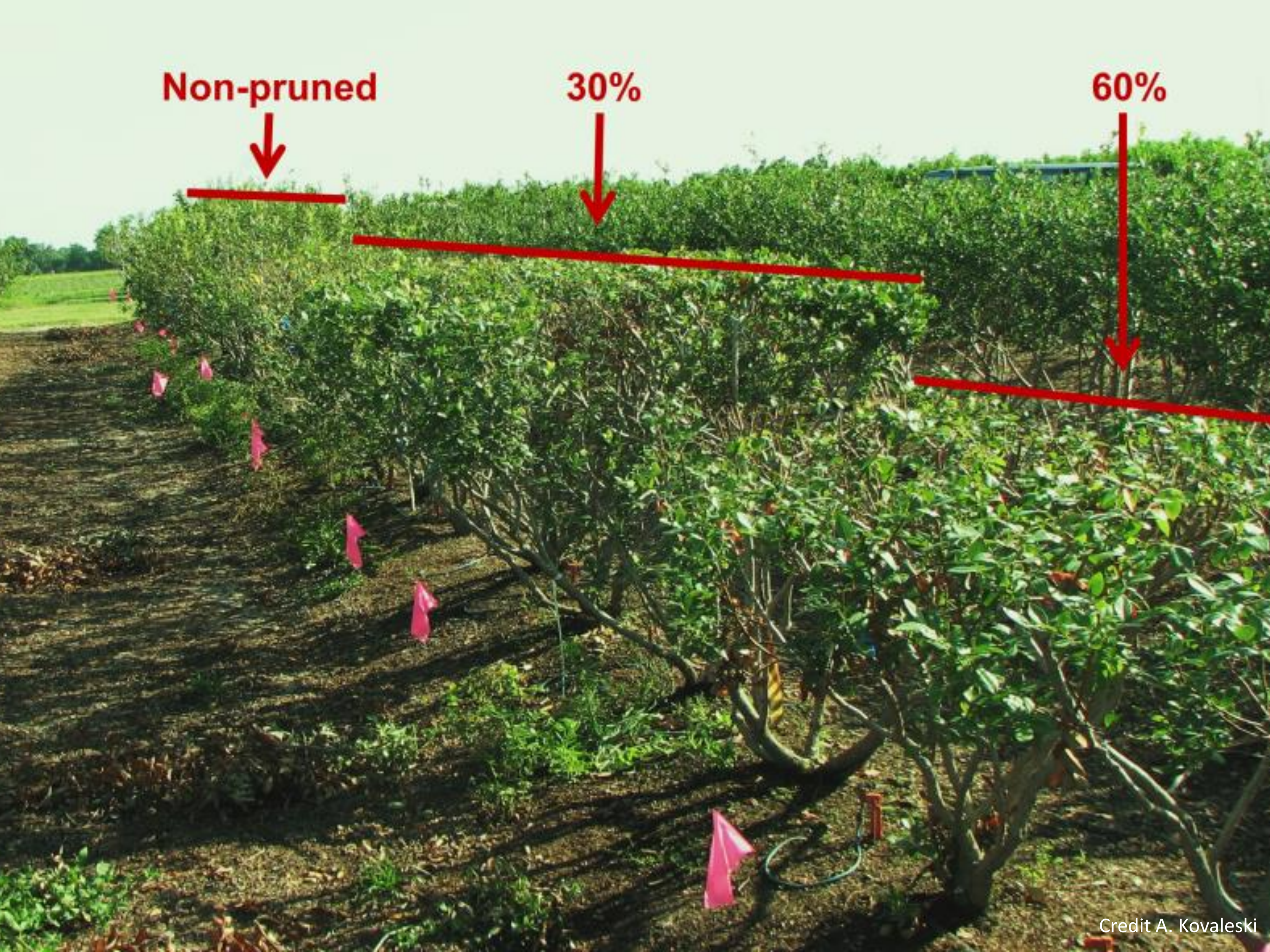
How severe should summer pruning be?

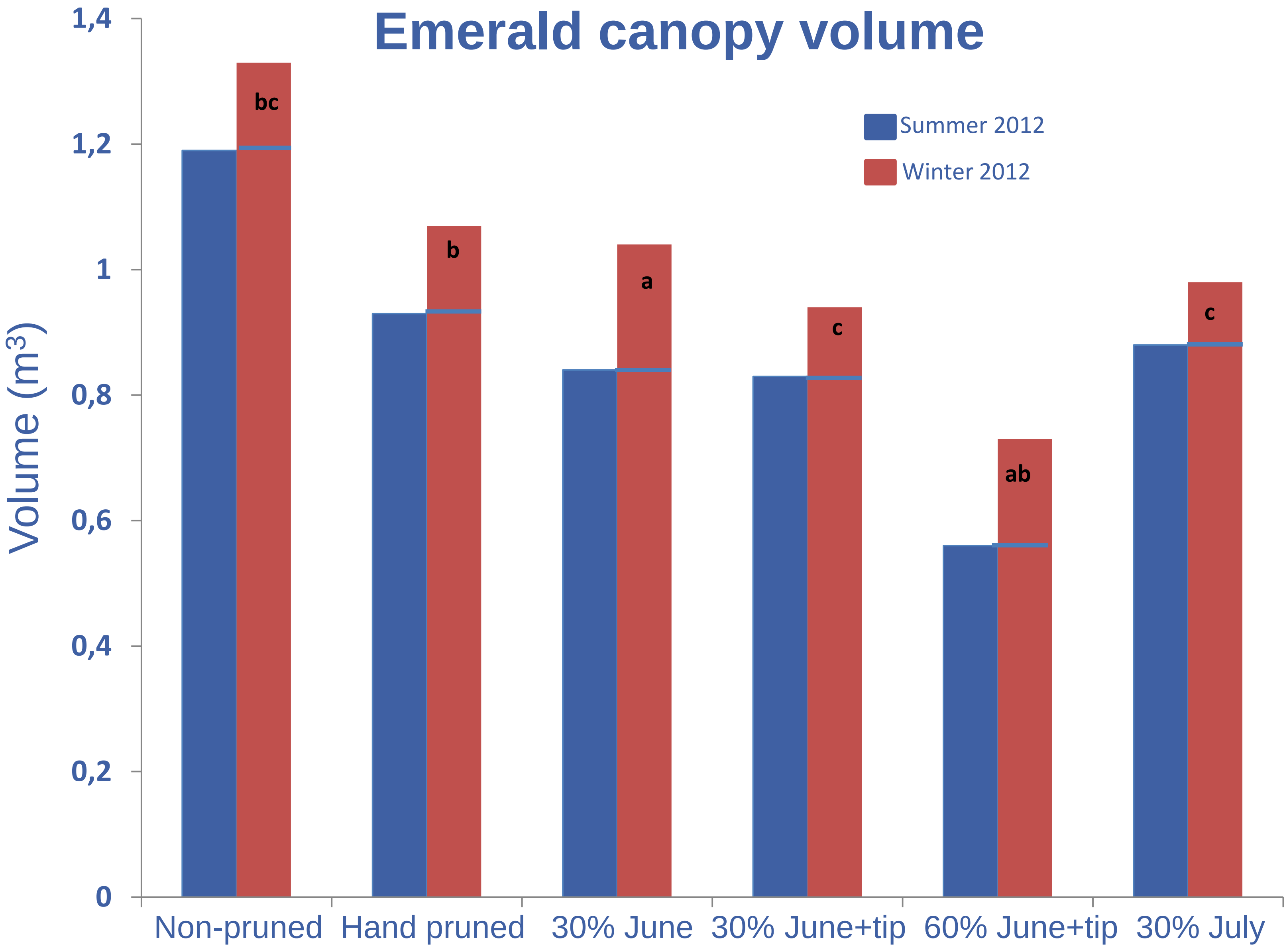
When is the best time to summer prune?

Mature (6-yr old) plants of 'Jewel' and 'Emerald'

Treatments (2011 & 2012):

- Non-pruned
- Hand pruned
- 30% canopy removal early June
- 30% June + shoot tipping mid-July
- 60% June + tip
- 30% July

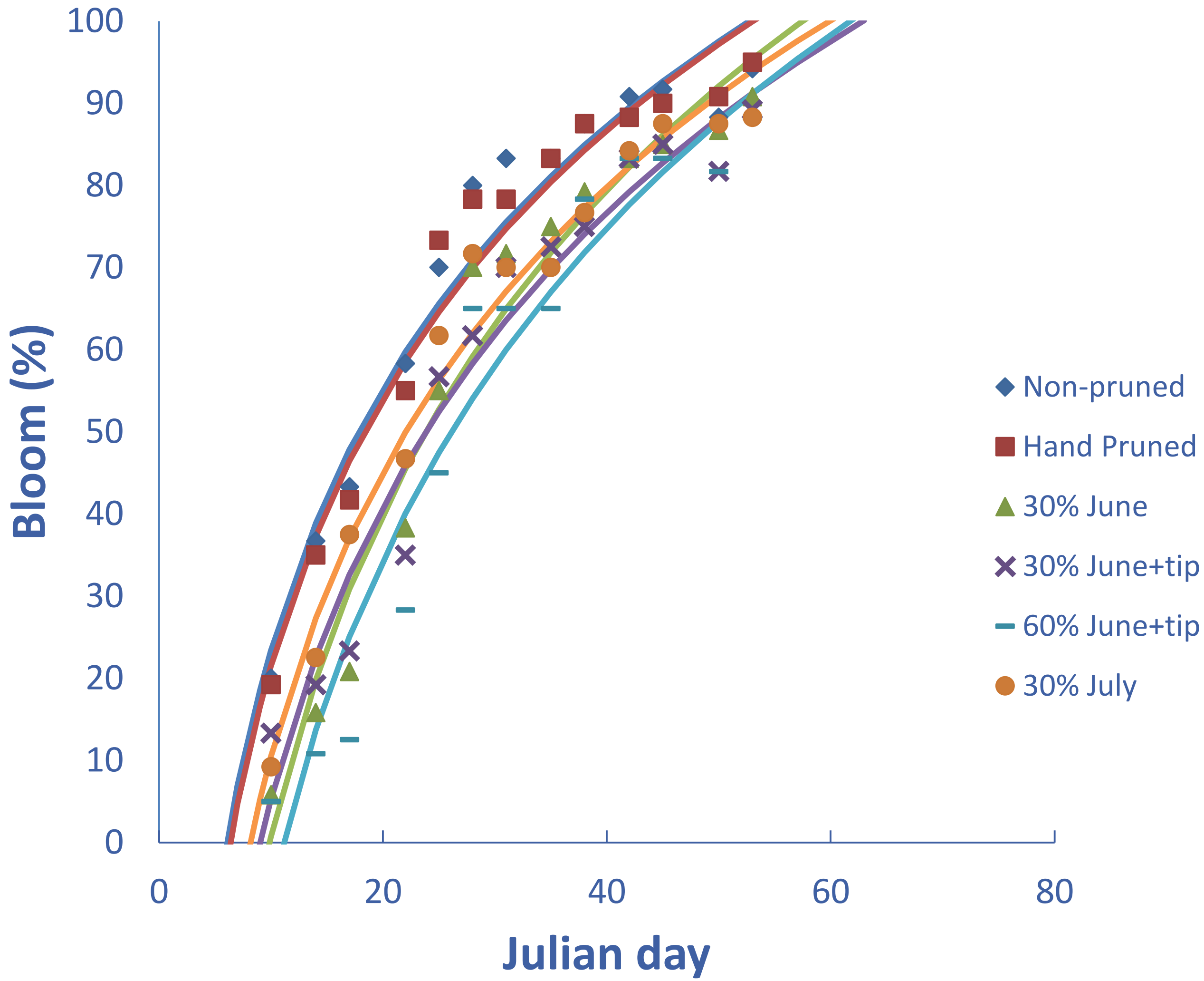

Non-pruned
30%
60%
Credit A. Kovaleski


Emerald canopy volume
Summer 2012
Winter 2012
Volume (m3)
1,4
1,2
1
0,8
0,6
0,4
0,2
0
bc
b
a
c
ab
c
Non-pruned
Hand pruned
30% June
30% June+tip
60% June+tip
30% July

Shoot regrowth and flower bud number in summer pruned SHB

	Avg shoot regrowth length (cm)		Avg flower bud number per shoot		Flower bud density (buds·cm^{-1})	
Treatment	Jewel	Emerald	Jewel	Emerald	Jewel	Emerald
Hand pruned	32.4 b	26.5 c	7.3 bc	6.5 bc	0.22 bc	0.28 b
30% June	34.2 b	33.3 bc	8.2 b	7.7 ab	0.23 b	0.28 b
30% June+tip	34.7 b	24.9 c	6.8 bc	6.8 bc	0.19 cd	0.30 b
60% June+tip	48.2 a	36.3 a	10.3 a	8.5 a	0.20 c	0.26 b
30% July	19.4 c	15.9 d	5.5 c	5.5 c	0.28 a	0.44 a

Bloom progression in ‘Emerald’ - 2012

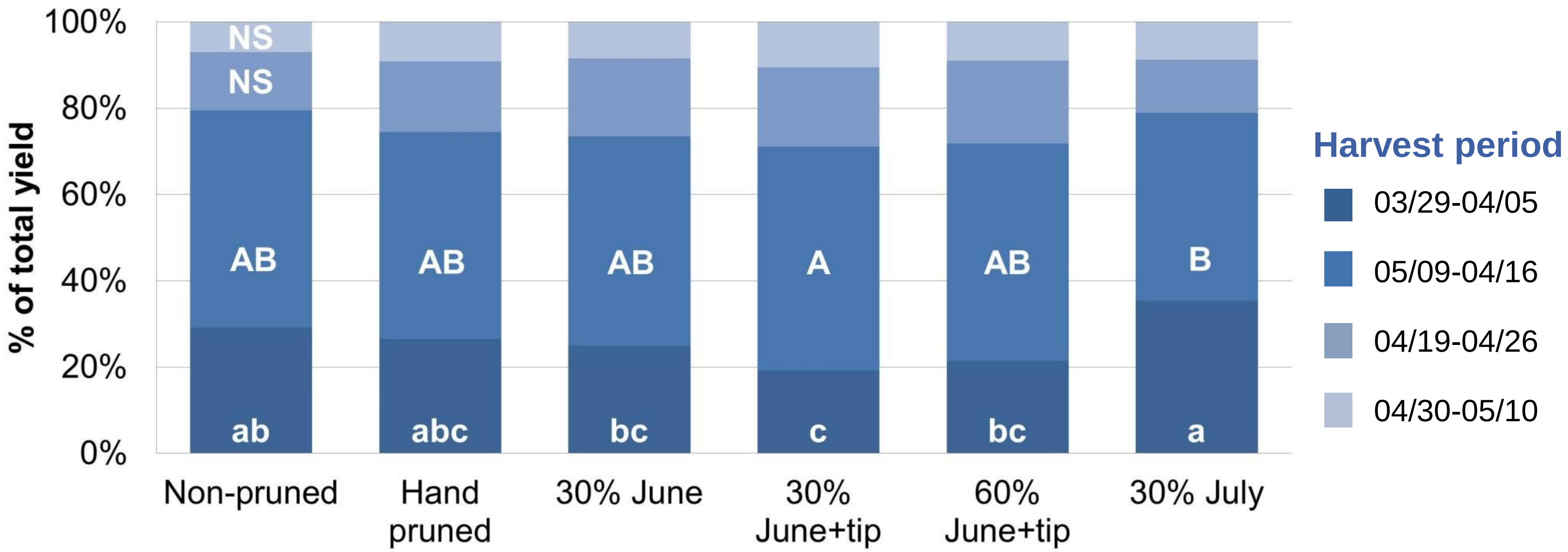


Bloom started earlier in non-pruned and hand pruned compared with 30 and 60% June pruned, and bloom period was shorter (47 vs 52 days)

No effect of pruning treatment on total 2012 yields in either cultivar

	Jewel		Emerald	
Treatment	Total yield (g)	Avg berry weight (g)	Total yield (g)	Avg berry weight (g)
Non-pruned	3270.0	1.43 c	4582.7	1.32
Hand pruned	3014.4	1.68 ab	4078.0	1.49
30% June	3681.4	1.54 bc	4127.1	1.39
30% June+tip	4423.3	1.59 bc	4948.6	1.53
60% June+tip	3157.3	1.77 a	4185.0	1.53
30% July	3542.7	1.65 ab	4393.0	1.47

Pruning effects on 2012 yield distribution in 'Jewel'




Jewel
30% pruning
Jewel
60% pruning

Soil adaptation

Blueberry soils

- Acidic
- High om - amended
- NH_4

Mineral soils

- pH>6.0
- Low om
- Accumulate NO_3 over NH_4

Most FL soils require amendments to be suitable for crop production

Bark beds

Bark incorporated into soil

Incorporated bark with ground cloth

Addition of soil amendments greatly increases establishment costs of SHB planting in Florida ($20,000-$25,000 per acre exclusive of land)

Pine bark can decrease air temperatures by 5°C on calm, cold, low RH winter nights (interferes with heat transfer from soil to air)

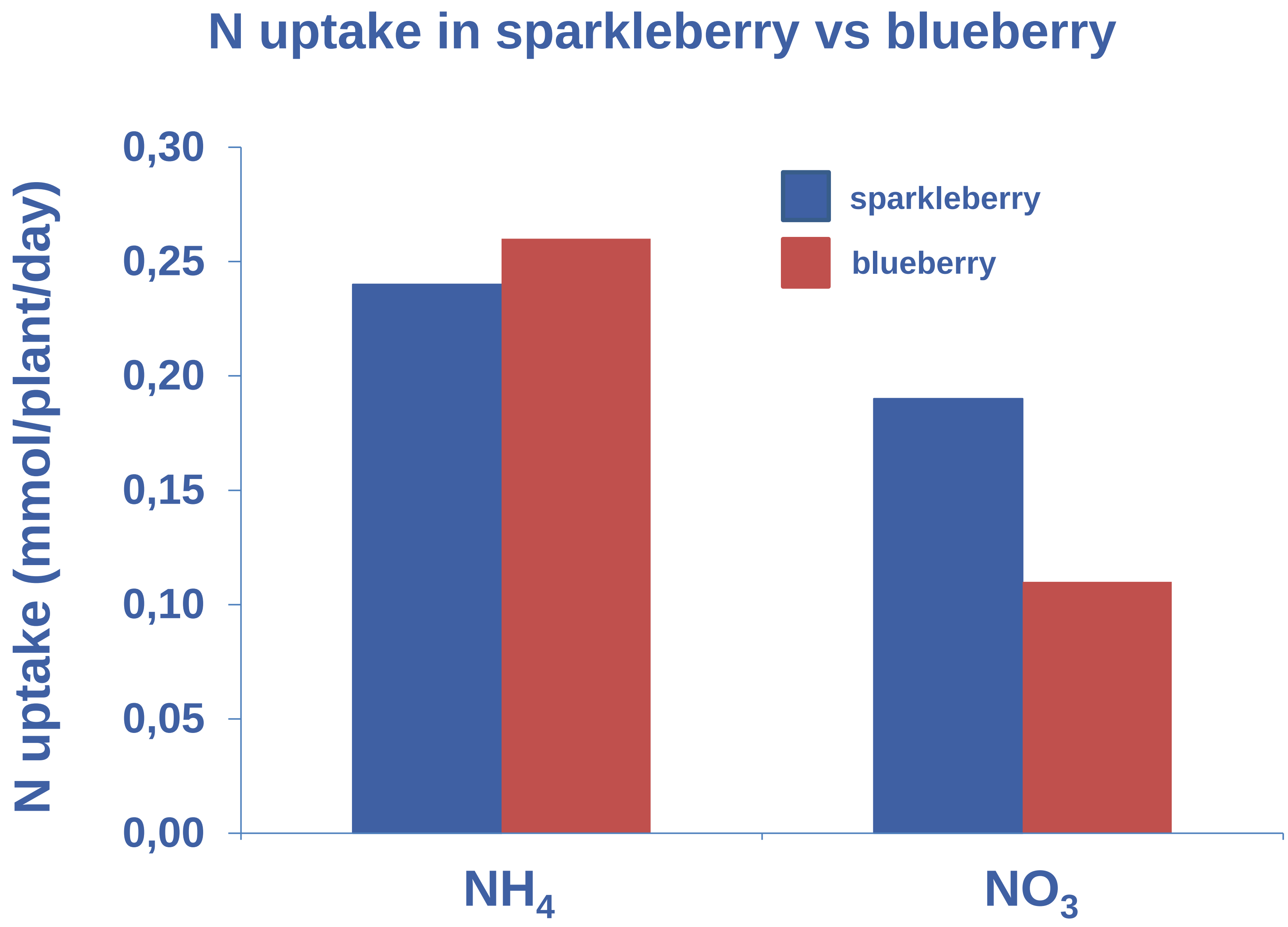
Pine bark also limits an already shallow root system

Are there *Vaccinium* species native to higher pH (nitrate predominant N form), low om soils, where amendments wouldn’t be needed?

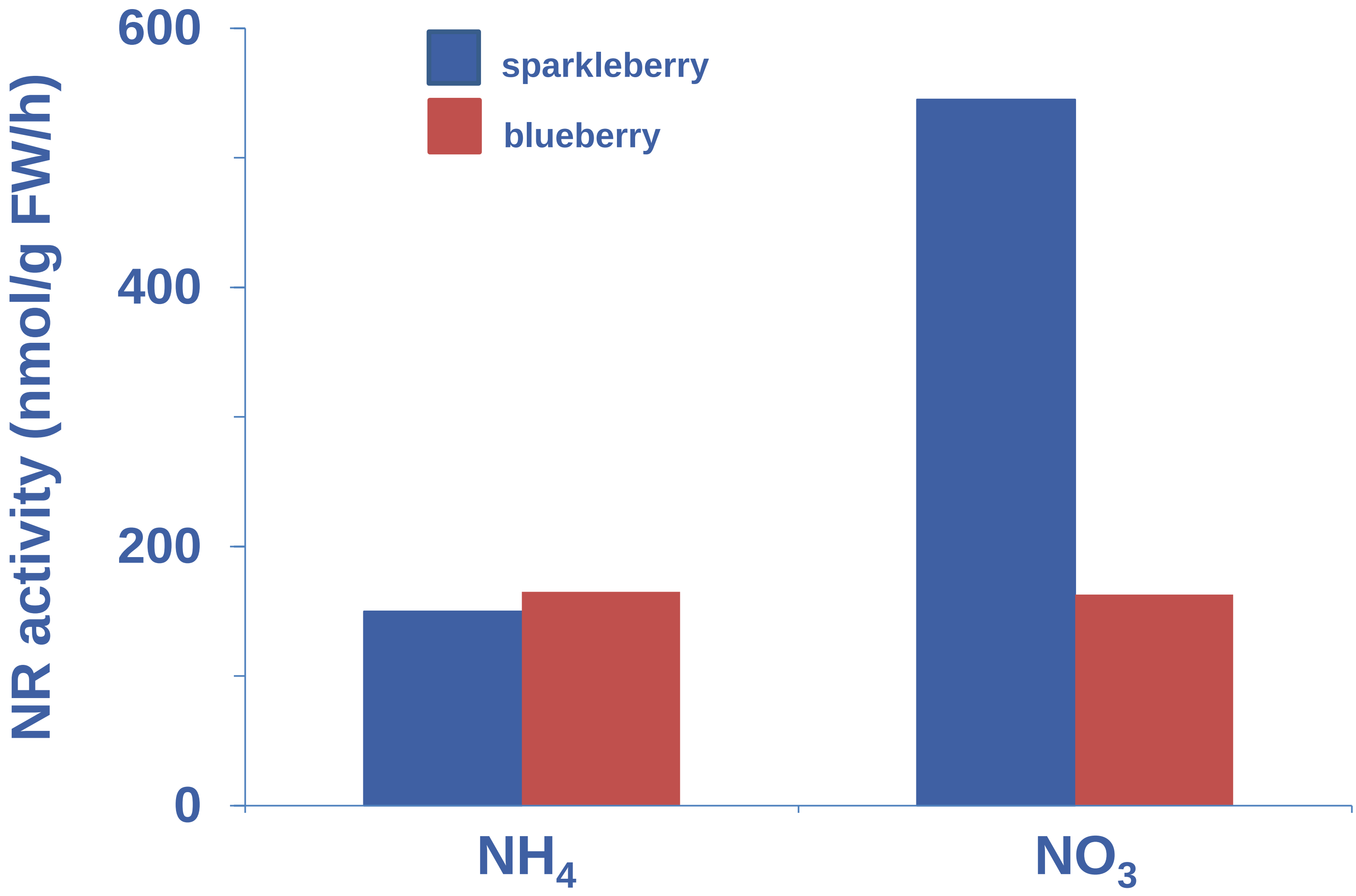
Vaccinium arboreum

"Sparkleberry"





N uptake in sparkleberry vs blueberry
N uptake (mmol/plant/day)
0,30
0,25
0,20
0,15
0,10
0,05
0,00
sparkleberry
blueberry
NH_4
NO_3

Nitrate reduction in sparkleberry vs blueberry



Nitrogen

- NO_3 uptake in sparkleberry is greater than in blueberry
- Differences in NO_3 uptake are reflected in differences in NR activity

Can we use sparkleberry to increase adaptation of blueberry to more mineral soils?
And increase mechanical harvesting potential?

Grafted vs Own-rooted

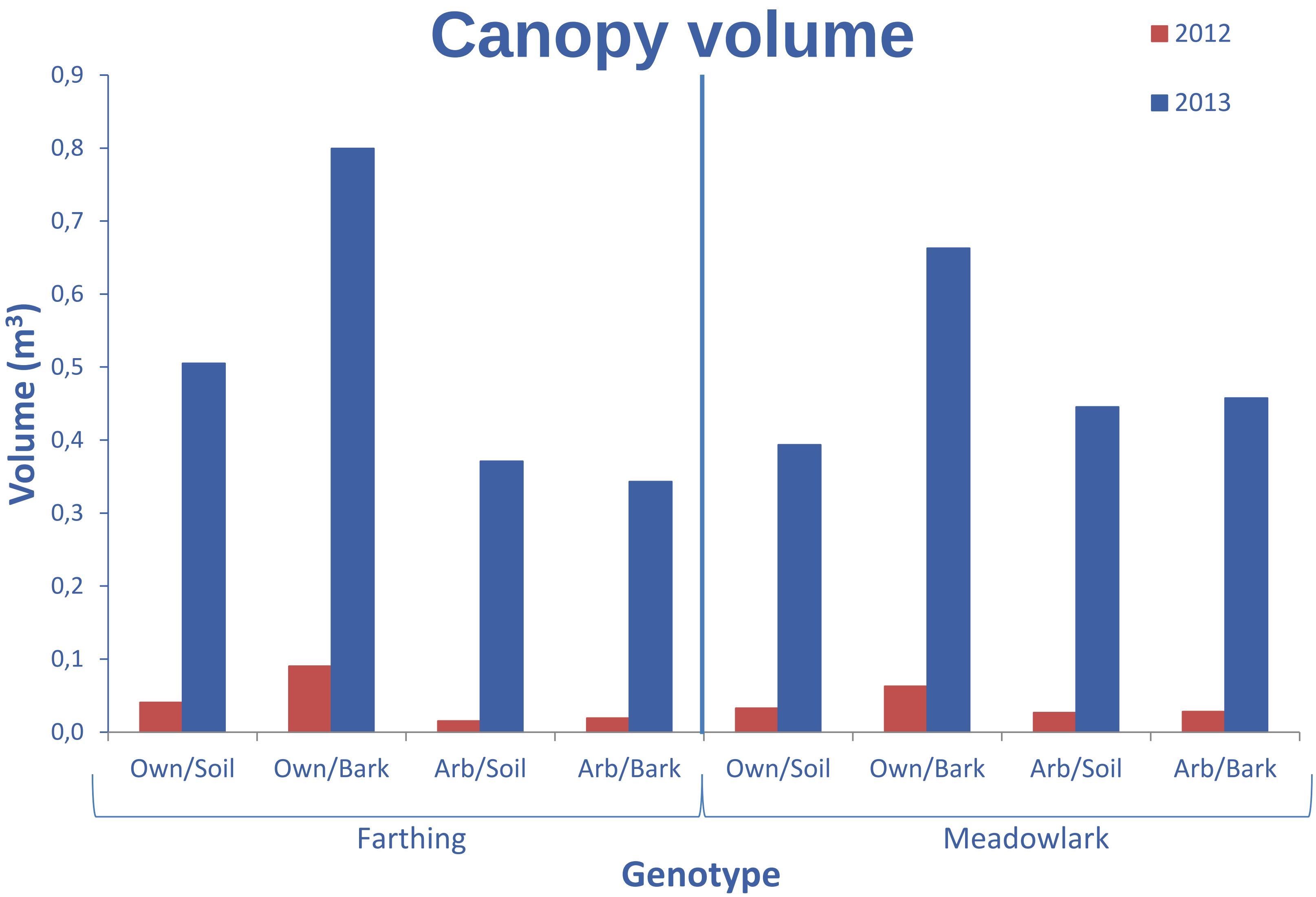
↓

Pine bark amended vs non-amended soil

2-yr-old ‘Meadowlark’ SHB

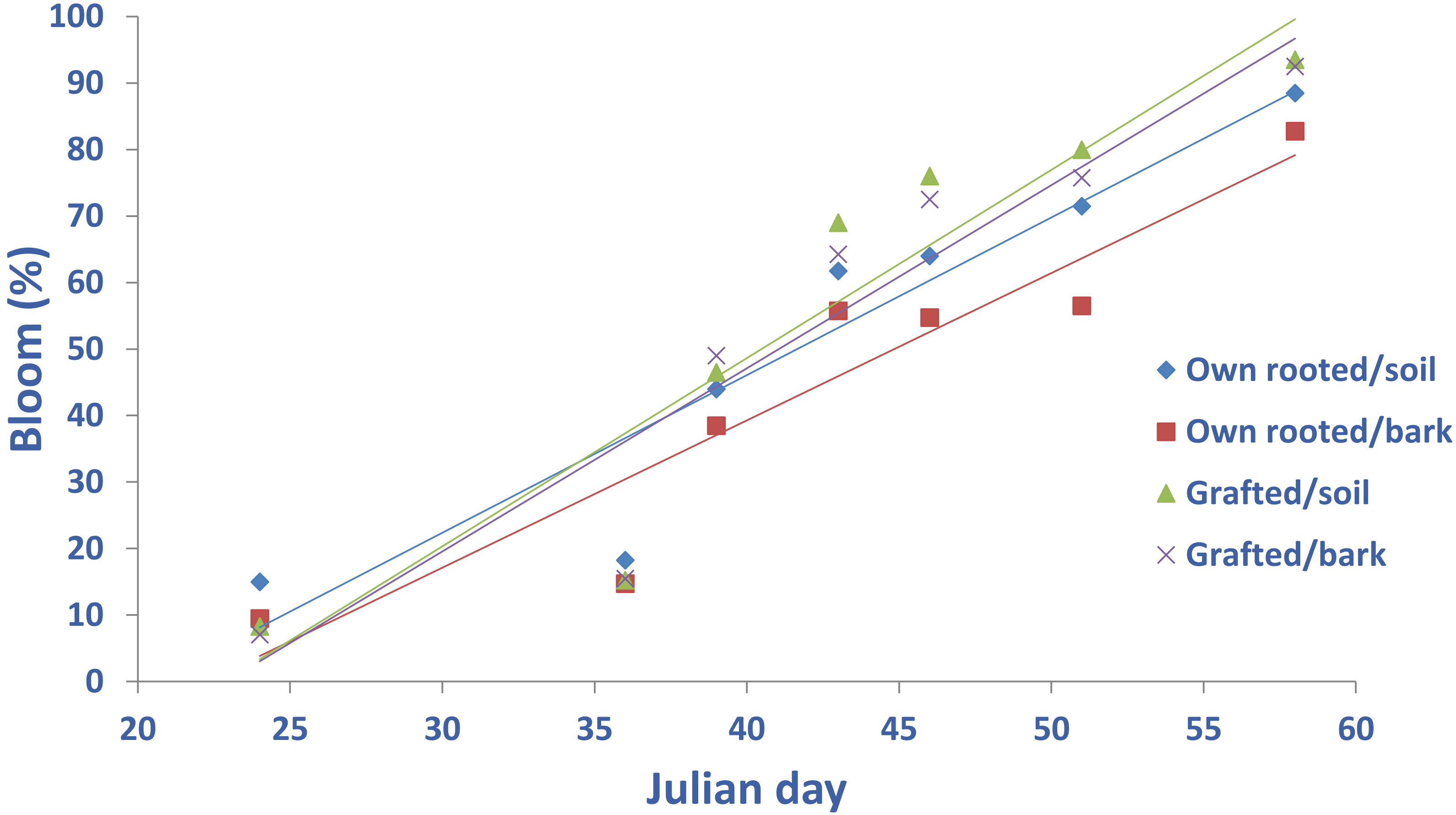
Grafted

Own-rooted



Canopy volume
2012
2013
Volume (m3)
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
Own/Soil
Own/Bark
Arb/Soil
Arb/Bark
Own/Soil
Own/Bark
Arb/Soil
Arb/Bark
Farthing
Meadowlark
Genotype

Bloom progression in 'Farthing' - 2013



Bloom period averaged 7 days shorter in grafted compared with own-rooted 'Farthing'

- **Fruit harvest period**
- **Yield**
- **Mechanical harvest ability**

Dormant vs evergreen blueberry production

Evergreen system

- Maintained with constant fertilization and water
- Plants retain most leaves during winter
- Dormancy is avoided; therefore chilling not an issue

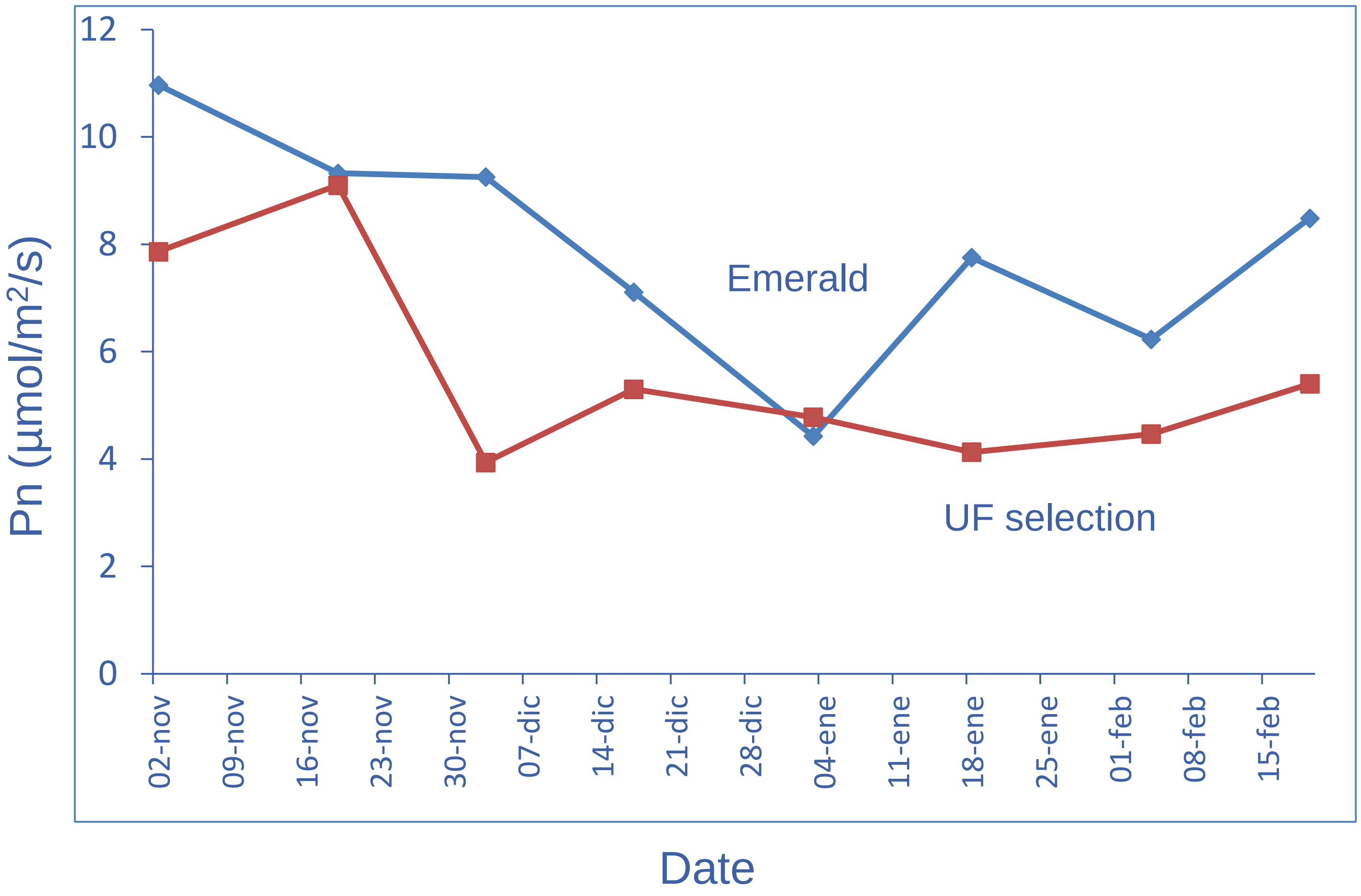
Evergreen → Nondormant → Dormant

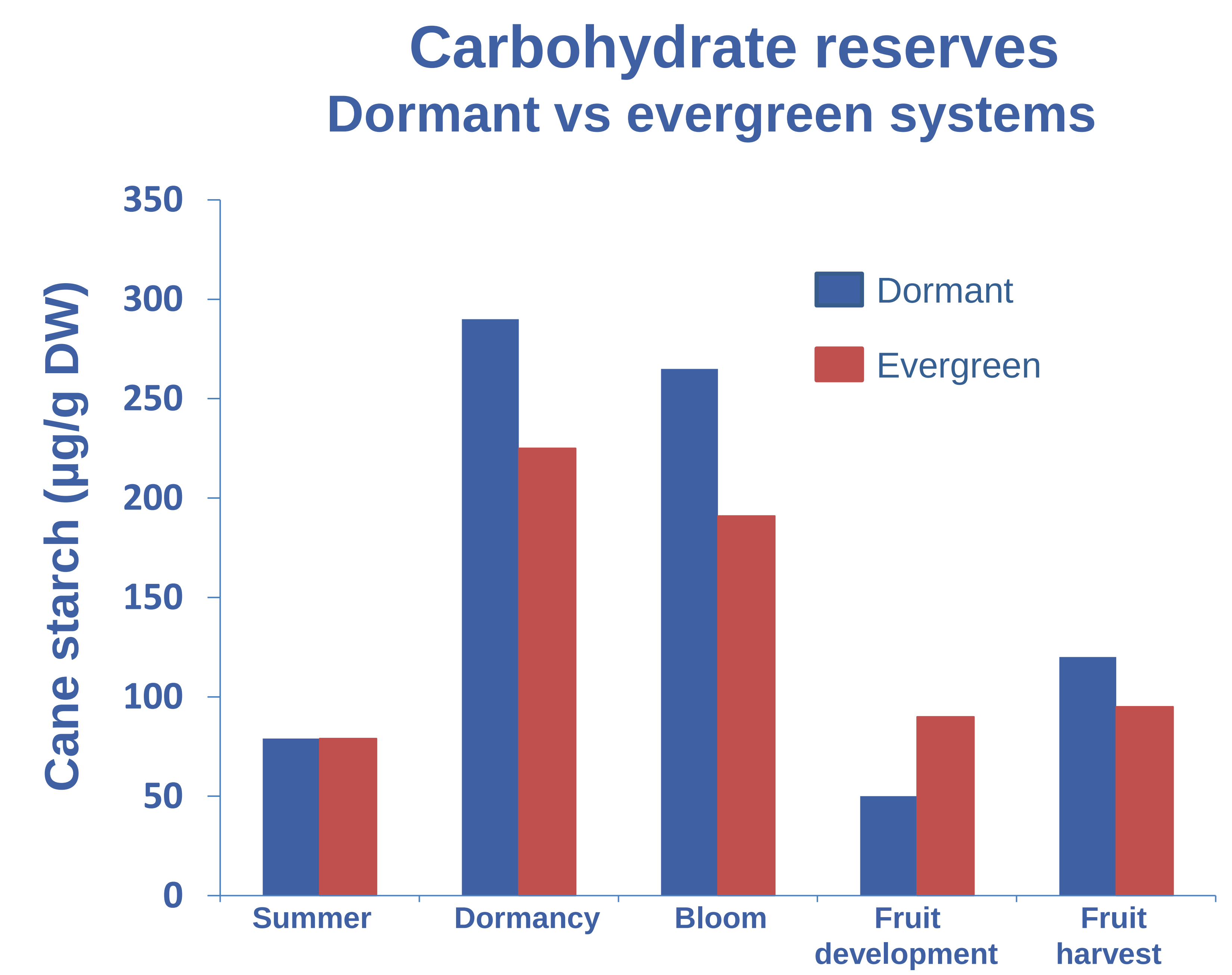
UF selection

Emerald

Chickadee

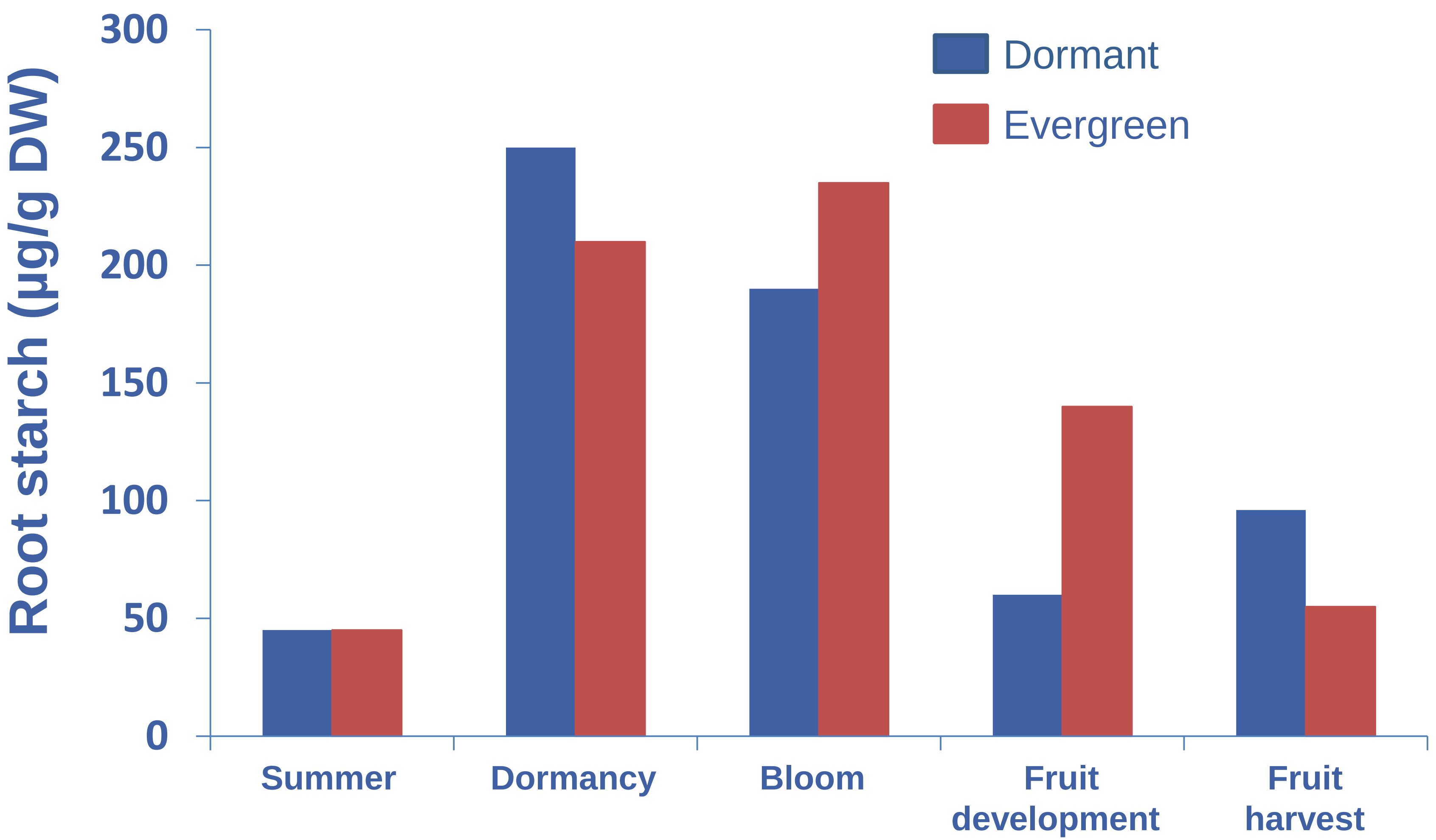
Photosynthetic rates of evergreen genotypes





Carbohydrate reserves
Dormant vs evergreen systems
Cane starch (µg/g DW)
350
300
250
200
150
100
50
0
Dormant
Evergreen
Summer
Dormancy
Bloom
Fruit development
Fruit harvest

Carbohydrate reserves
Dormant vs evergreen systems



Fruit Production

	Dormant	Evergreen
Flower Bud (No.)	238.6 b	297.4 a
Fruit No./plant	453.9 b	608.3 a
Fruit FW/plant (g)	572.7 b	709.1 a
Average Fruit FW (g)	1.45 a	1.19 b

Dormant vs Evergreen System

Both depend on CHO reserves for flowering and early fruit development

But Evergreen:

- -Increases CHO accumulation
- -Increases flower bud no. & total fruit yield
- -Decreases fruit size
- -Earlier (?), more protracted bloom
- -Earlier (?), more protracted harvest

Tunnel production of blueberries

Advantages of tunnel production

- Earlier production
- Higher yields
- Cleaner, higher quality fruit
- More efficient water and fertilizer use
- Decreased weed/pest pressure?

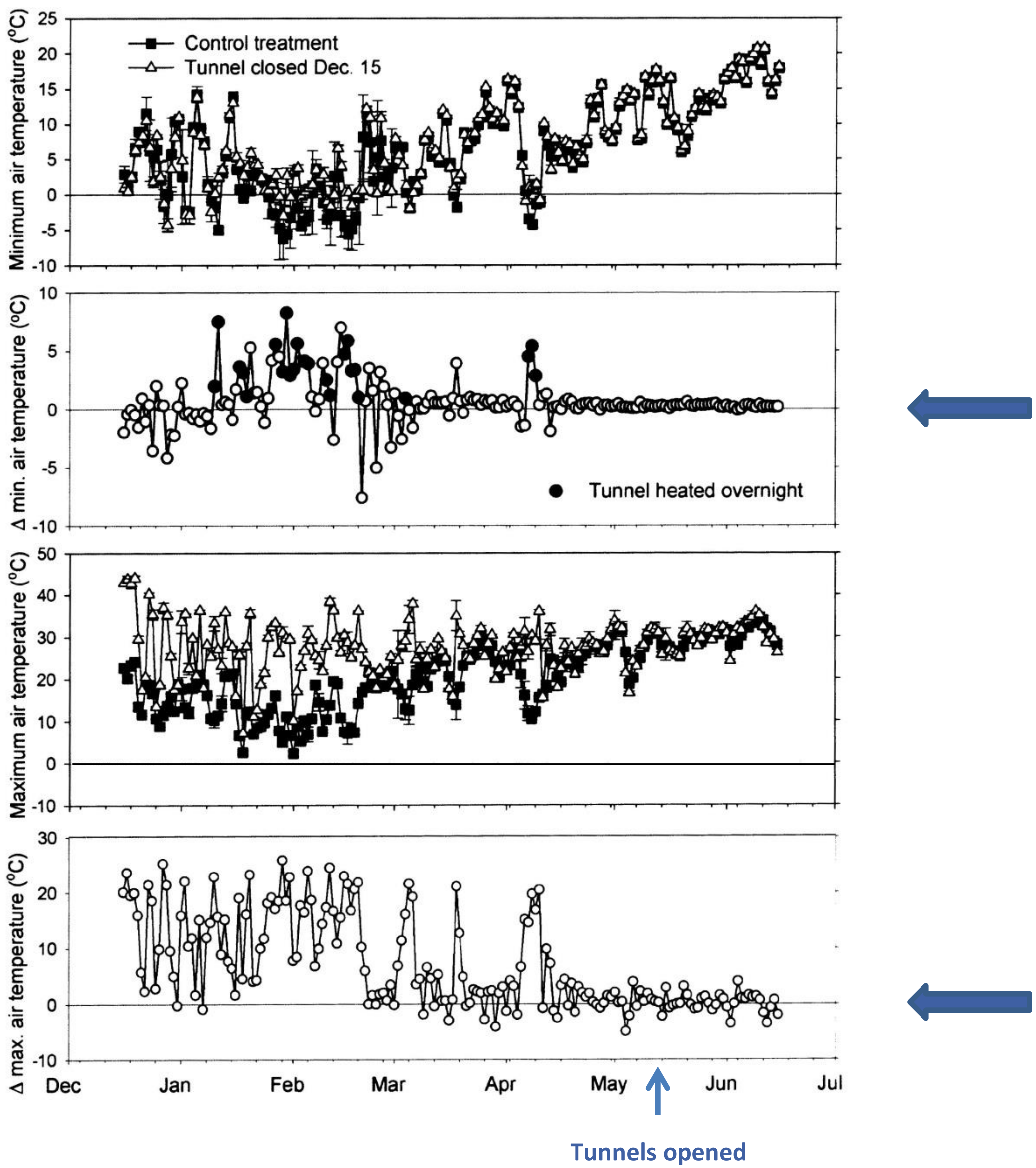
Dormant vs evergreen tunnel production

Dormant tunnel production of SHB

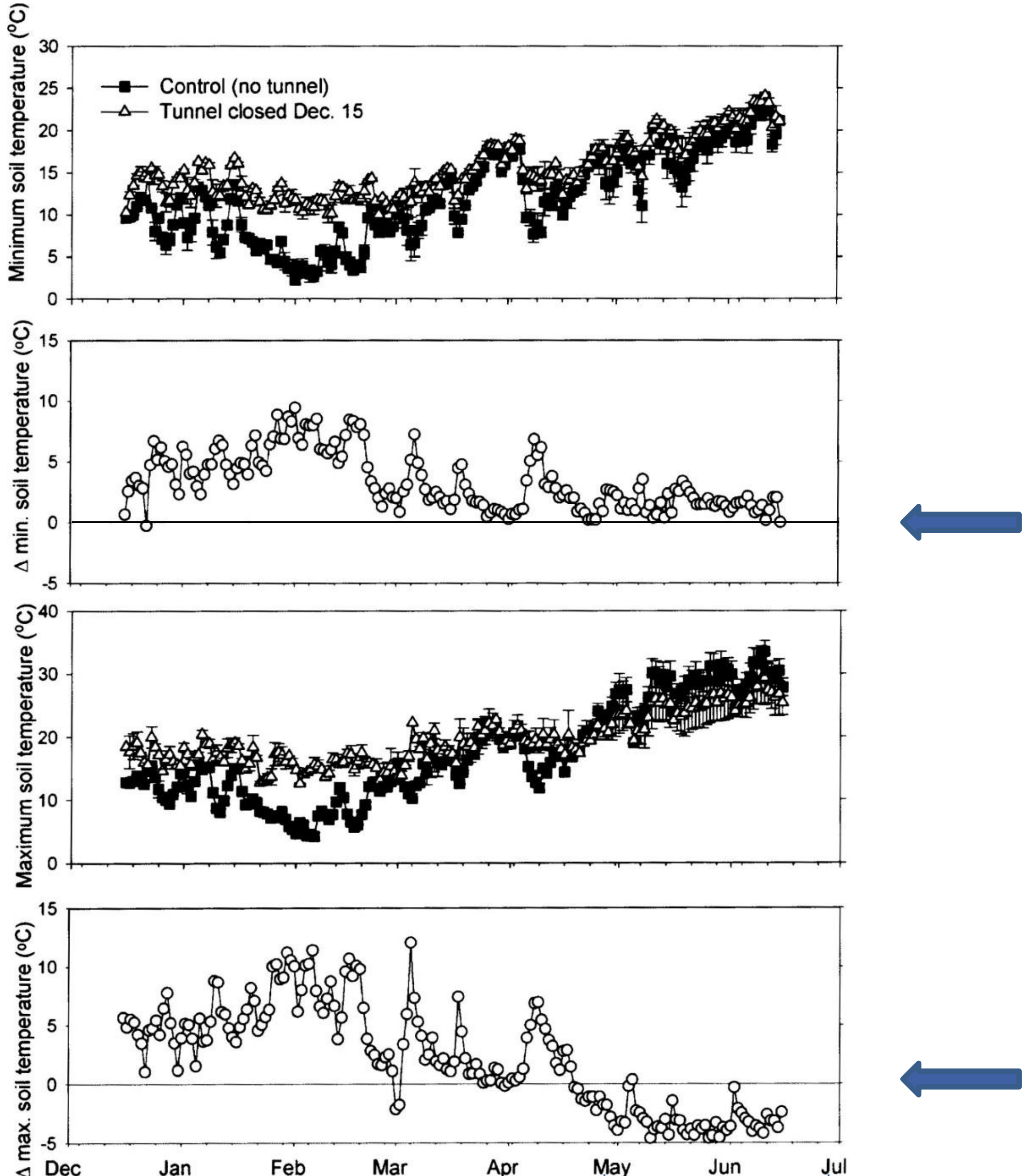
From Ogden and van Iersel, 2009

- Polyethylene high tunnels in Georgia
- 2-year-old ‘Emerald’ and ‘Jewel’ SHB in pine bark beds
- Spacing – 1 m within row and 0.75 m between staggered rows
- Irrigation with microjet sprinklers
- Granular fertilizer applied 5 times during growing season
- (467 kg N/ha/year)
- Tunnel closure dates: 15 Dec., 2 Jan., 16 Jan.
- Tunnel sidewalls manually opened when $T_o \geq 16°C$
- Bumblebee colonies in tunnels
- Tunnel sidewalls removed 15 May

Air temperatures inside vs outside tunnel

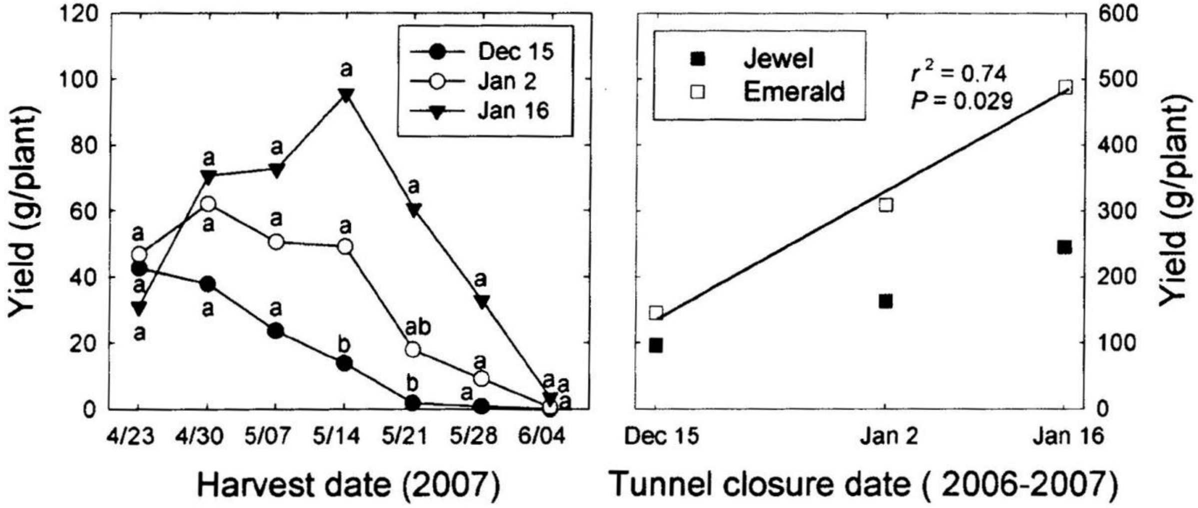


Soil temperatures inside vs outside tunnel



Note lower soil temperatures in tunnel compared to outside

Fruit yield in tunnels



No data for control (outside) plants due to freezes

Dormant production in tunnels

Temperature effects of tunnels:

- Increased maximum air temperatures by 3-15°C
- Decreased minimum air temps on cold nights
- Increased minimum soil temps by 2-8°C
- In summer, decreased soil temps by 2-5°C

Biological effects of temperature differences:

- Warmer air and soil temps initiated earlier flower and fruit development
- Reduction in summer soil temps beneficial to water and nutrient uptake
- Did not provide freeze protection – polyethylene allowed long-wave radiation transmission. Pine bark beds also decreased air temperatures
- No data on yield effects compared with control

Evergreen tunnel production - Florida

- Polyethylene tunnels (5.5 m high x 7.6 m wide x 183 m long) (35% light reduction [~1300 PPF])
- Pine bark beds with black groundcover
- ‘Snowchaser’, ‘Springhigh’, ‘Emerald’, ‘Sweetcrisp’, ‘Flicker’, ‘Kestrel’, plus UF selections
- Spacing - 0.8 m within row and 3 m between rows
- Single drip irrigation line/overhead sprinklers for freeze protection
- Plastic put on in September/removed in April-May
- Ends and sides closed during cold weather events
- Bumblebee colonies in tunnels and honey bee hives on ends

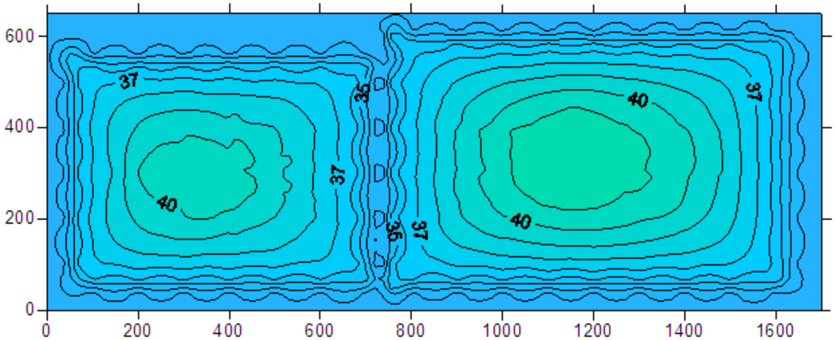
Days at or near freezing and max/min temperatures in open fields and tunnels

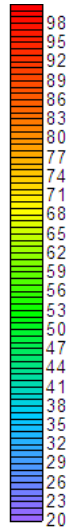
	Oct 2009-Sept. 2010			Oct 2010-Sept. 2011		
Production system	**Days ≤ 1.1 °C**	**Min temp (°C)**	**Max temp (°C)**	**Days ≤ 1.1 °C**	**Min temp (°C)**	**Max temp (°C)**
Open fields	27	-7.1	34.2	34	-6.3	40.8
Tunnels	2	-0.2	36.1	1	0.3	40.8

From Santos and Salame-Donoso, 2012

Tunnel temperatures during 2-day freeze event in Feb 2011

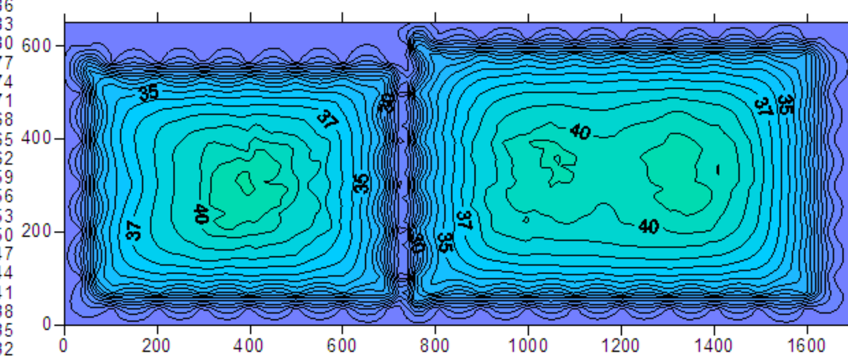
01/12/2011- 11 PM

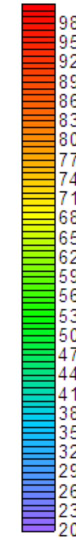




External Temperature: 0.3 C

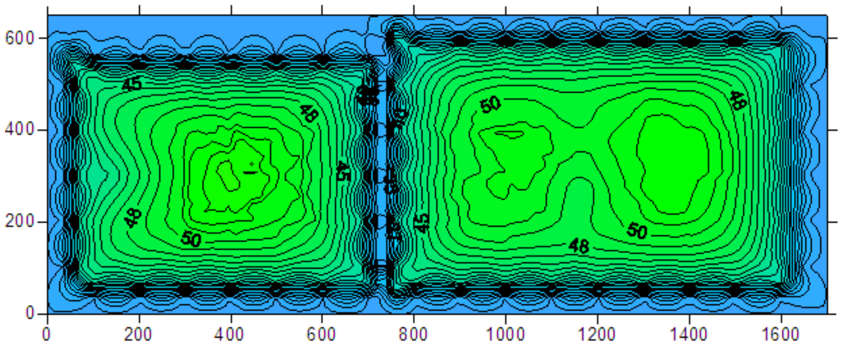
01/13/2011- 7 AM

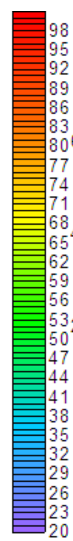




External Temperature: -4.1 C

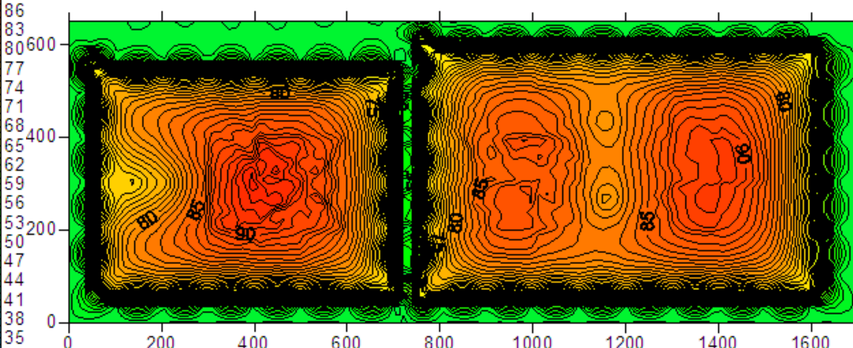
01/13/2011-10 AM

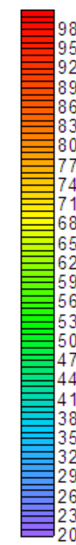




External Temperature: -0.6 C

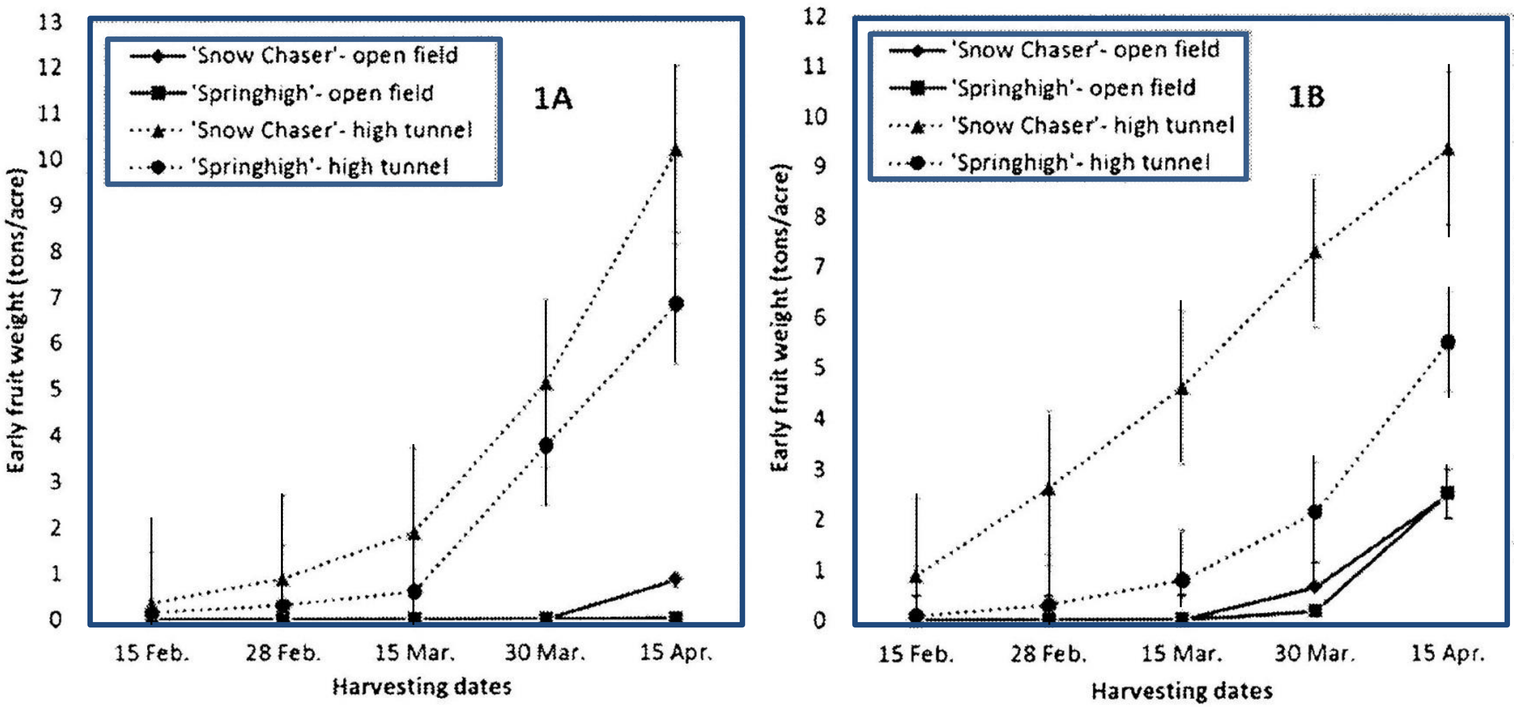
01/13/2011- 3 PM





External Temperature: 9.7 C

Credit Lincoln Zotarelli



Effects of production system on cumulative early SHB yield in 2010 (A) and 2011 (B).

From Santos and Salame-Donoso, 2012





Evergreen blueberry tunnel production in Florida

Benefits

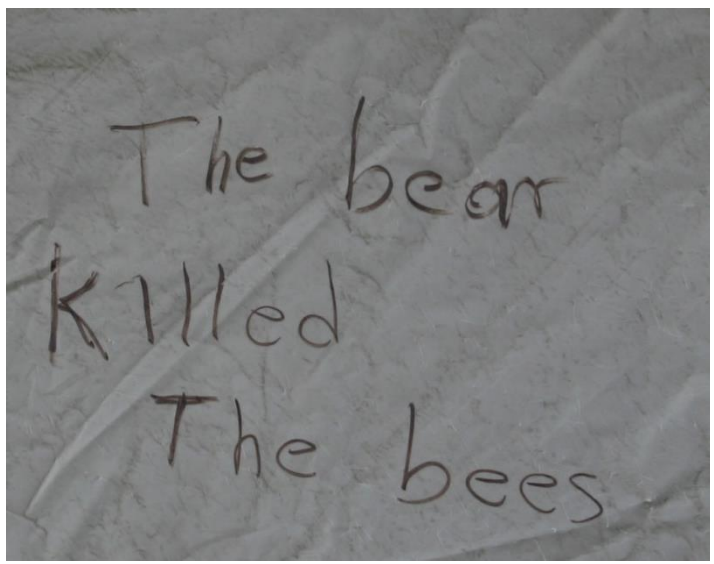
- Earlier fruiting (starting in early Jan for some cultivars/selections)
- Increased early yields
- Decreased water needed for freeze protection

Disadvantages

- Additional cost of tunnel – economic analysis needed
- Inexperience with individual cultivars
- Protracted flowering and fruit harvest – extends beyond prime market window
- Poor synchronization of bloom
- Excess heat build-up if tunnels not ventilated daily – decrease fruit set
- Pollination


QUAD


The bear
Killed
The bees


The bear
Killed
The bees

Tunnel production of strawberry

- Early production (season extension)
- Higher yields
- Crop diversification



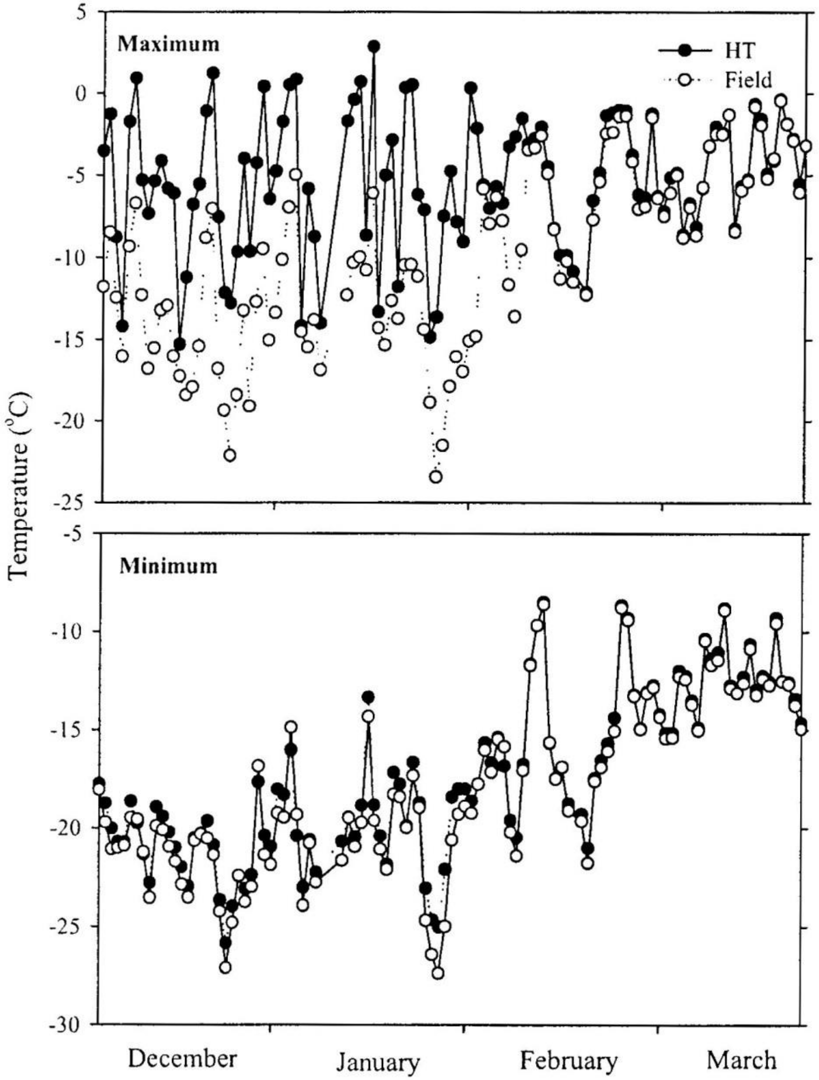




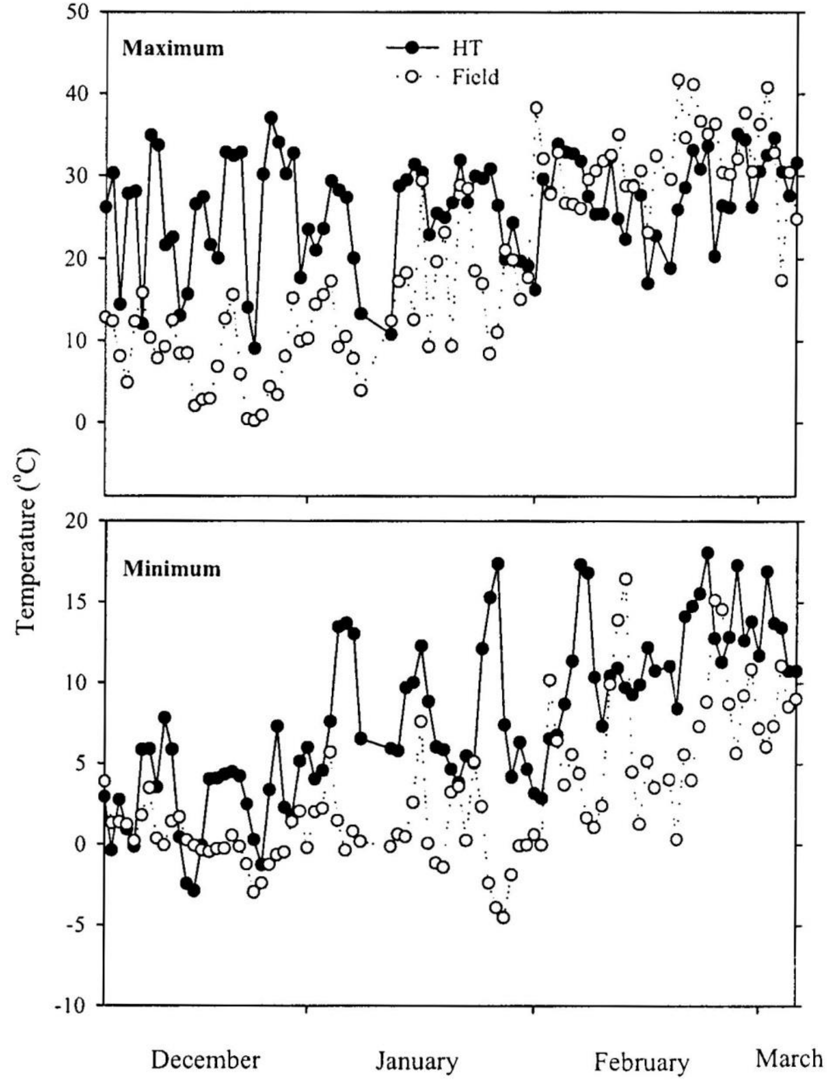
Tunnel vs field production - Kansas

- Average min temperature -6°C, average max temperature 36°C
- ‘Chandler’ and ‘Sweet Charlie’ in raised 2-row beds with black plastic
- Spacing 45 x 45 cm between plants in beds; 1.5 m between beds
- Drip irrigation/fertigation
- Row covers used inside tunnels and in field when temperatures < -7°C
- Tunnel sides opened when tunnel temperatures reached 30°C
- Bees?

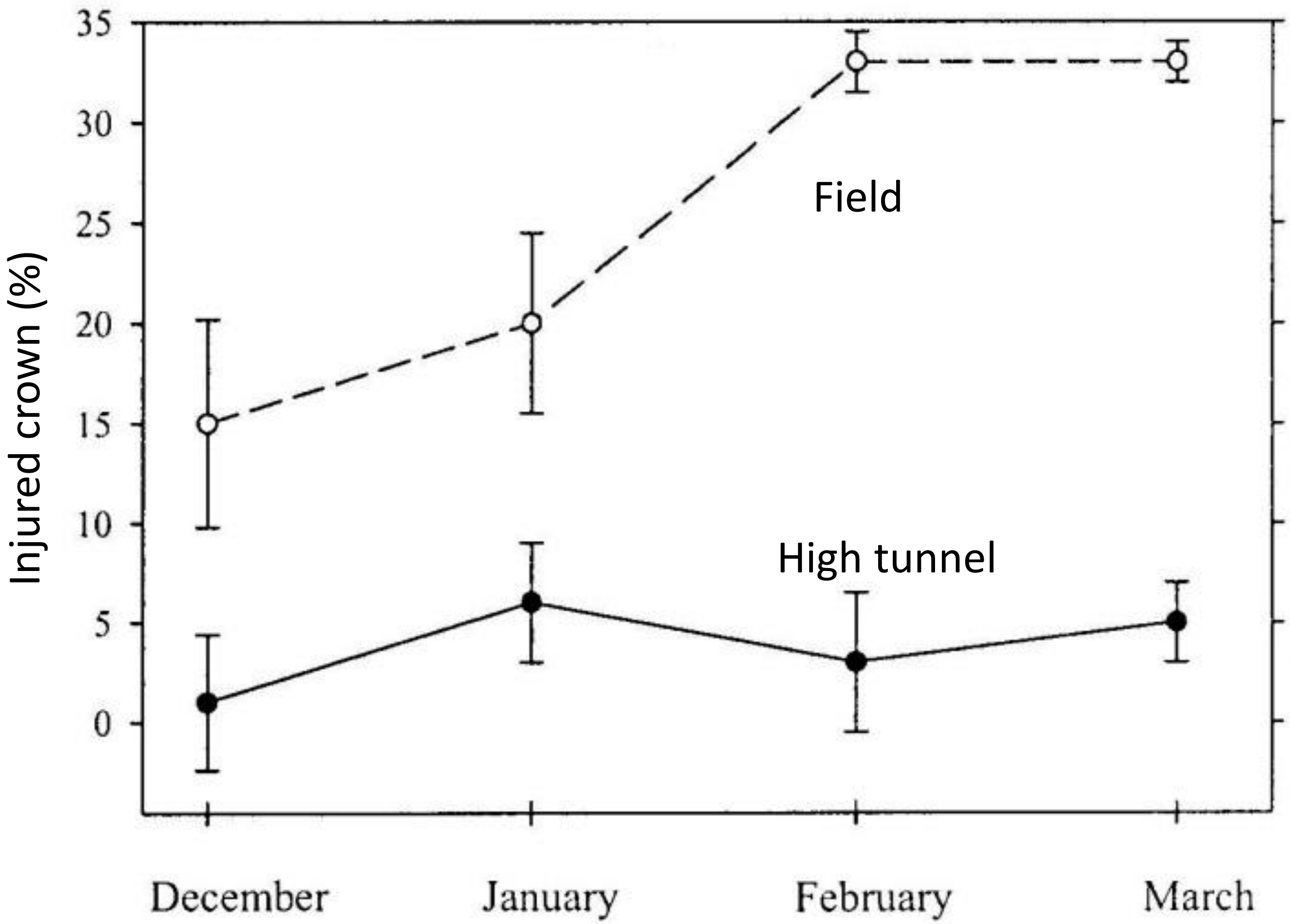
Air temperature

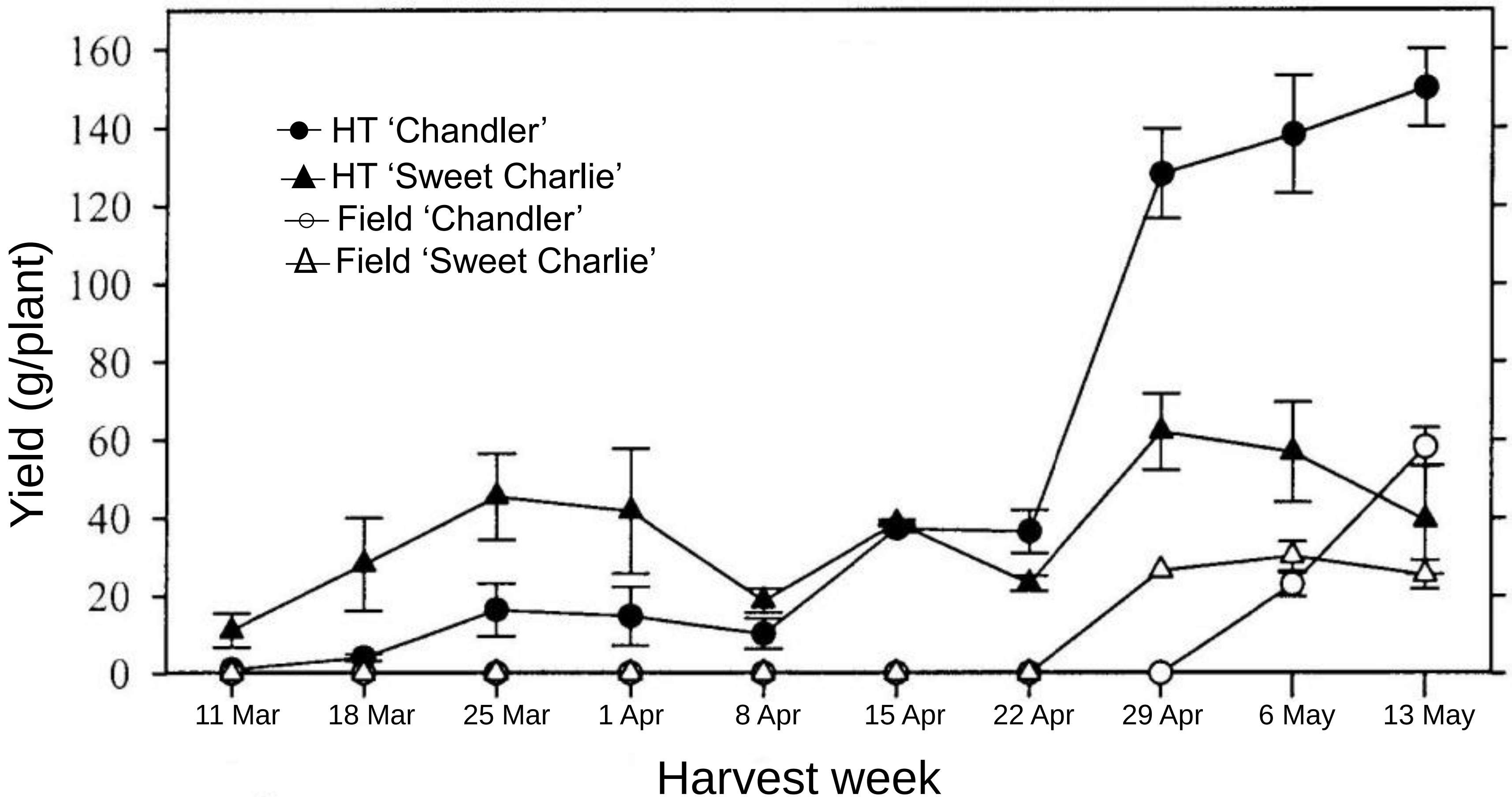


Crown temperature



From Kadir et al., 2006


35
30
25
20
15
10
5
0
Injured crown (%)
Field
High tunnel
December
January
February
March



HT ‘Chandler’
HT ‘Sweet Charlie’
Field ‘Chandler’
Field ‘Sweet Charlie’
Yield (g/plant)
160
140
120
100
80
60
40
20
0
11 Mar
18 Mar
25 Mar
1 Apr
8 Apr
15 Apr
22 Apr
29 Apr
6 May
13 May
Harvest week

Tunnel production of strawberries

- Protected crowns from winter injury
- Earlier, higher yields (increased fruit no. and size)
- Decreased runner production
- Increased no. unmarketable fruit (excess heat?)

Tunnel production in Spain (Ariza et al., 2012):

- Increased early production of ‘Camarosa’, ‘Medina’, and ‘Ventana’
- Increased incidence of misshapen fruit → correlated with tunnel temperatures < 7°C (EPP)

Tunnel production in Florida (Salame-Donoso et al., 2010):

- Increased early and total marketable yield of ‘Strawberry Festival’, ‘Winter Dawn’, and ‘Florida Flyana’ compared with open field
- Decreased water use for freeze protection
- Protected fruit from rain
- Decreased fruit soluble solids (due to excess heat?)

Tunnel production of strawberries

Benefits

- Earlier/later production (season extension)
- Higher yields
- Decreased use of freeze protection

Disadvantages

- Increased production cost
- Potential pollination problems
- Decreased fruit quality (temperature extreme effects)

Need relevant economic analyses for location and market

What we've covered:

1. Basics
2. General growth & development
3. Environmental effects
4. Manipulations to blueberry growth & development

Strawberry tunnel production

Blackberries – Guillermo Calderon & Bernadine Strik

Raspberries – Jorge Rodriquez

Questions?
Discussion?