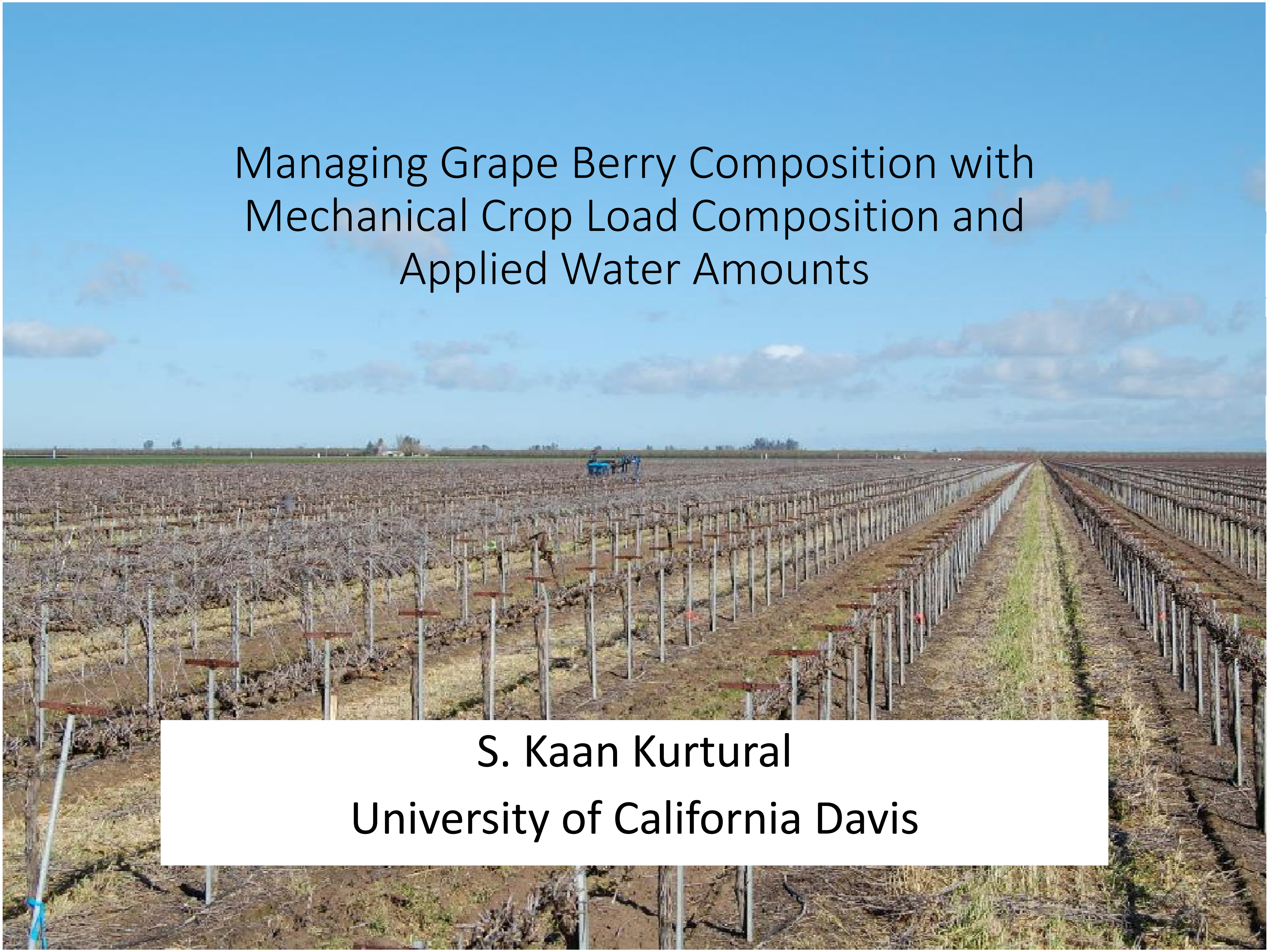


Managing Grape Berry Composition with Mechanical Crop Load Composition and Applied Water Amounts

S. Kaan Kurtural
University of California Davis

From the Canopy to Crop Load

- Shoot system of the grapevine:
  - Stems
  - Leaves
  - Clusters
- Collectively: <u>Microclimate</u>
  - Length
  - Height
  - Width
  - Leaf area
  - Shoot density
  - Leaf layer number

Climate within the Grape Canopy

- Microclimate is affected by:
  - Amount of leaf area
  - Distribution of leaf area
  - Their interaction with above ground climate

Why?

Berry composition

Vine health improvement

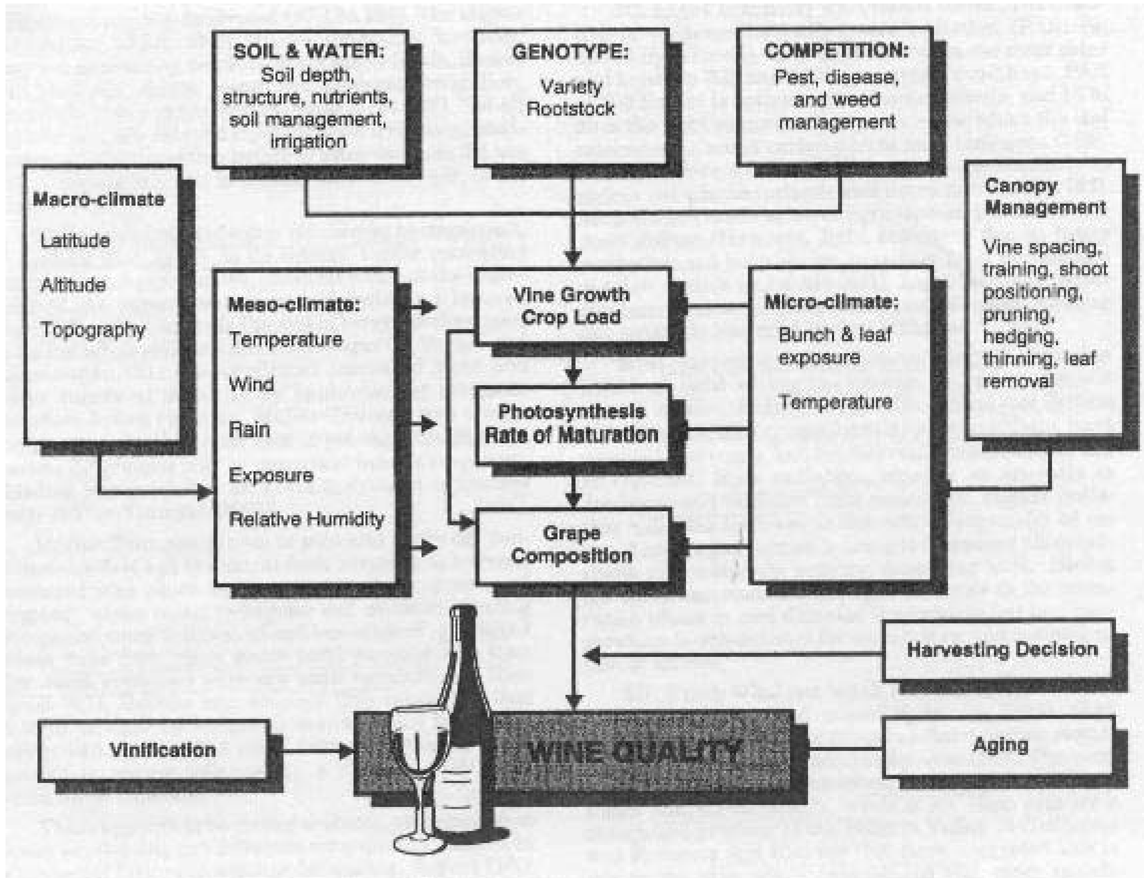


Fig. 2. Environmental and viticultural inputs into grape composition and wine quality.

Fruit Maturity: The point at which fruit composition most closely matches that required to make the style of wine desired

Desirable Aspects

- Uniformly ripe fruit
- Sound fruit
- An abundance of flavor
  - With correct composition
- Reaches peak at ideal time
  - Avoiding inclement weather
  - Winery logistics

General responses to elevated light and temperature

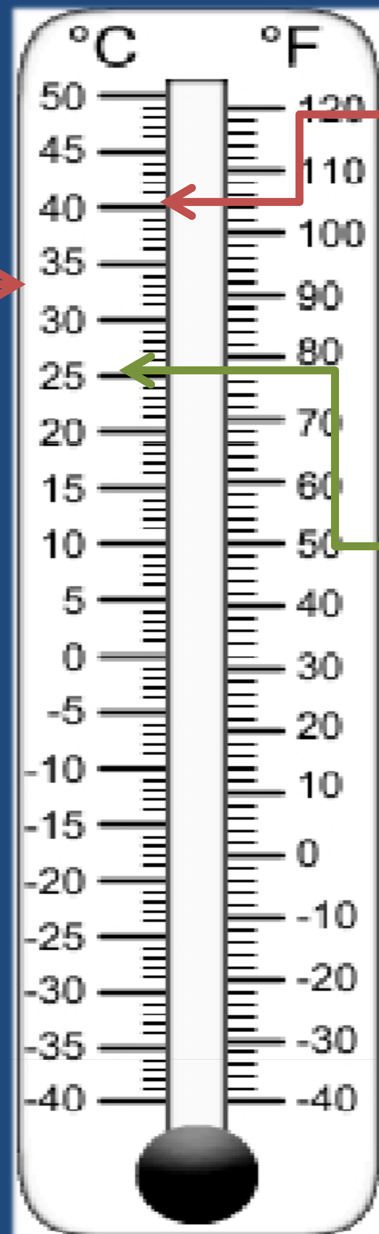
	Light	Temperature
Berry growth	+	+ / -
Berry composition:		
Sugar	+	+
Organic acids	+ / -	-
pH		+
Anthocyanins	+	+ / -
Phenolics	+	+ / -
Methoxypyrazines	-	-
Monoterpenes	+	-

Temperature Thresholds of *Vitis*

86 – 95ºF

- Many metabolic processes slowed or halted

- Anthocyanins
  1. genetic repression
  2. degradation



95 - 105ºF

- Inhibition of carbon assimilation and skin tissue formation

77ºF

Optimal day temperature

Pinot noir example

Temperature (°F)	Light	Skin color (OD units)
68	Low	63
	High	122
86	Low	58
	High	90

Kliewer (1970)

Berry Anatomy

Flesh (pulp)
- juice
- hydroxycinnamates

Seed
- tannins (bitter)
- flavan-3-ols
- hydroxybenzoic acids

Skin
- color pigments
- tannins (astringent)
- flavan-3-ols
- flavonols
- hydroxybenzoic acids

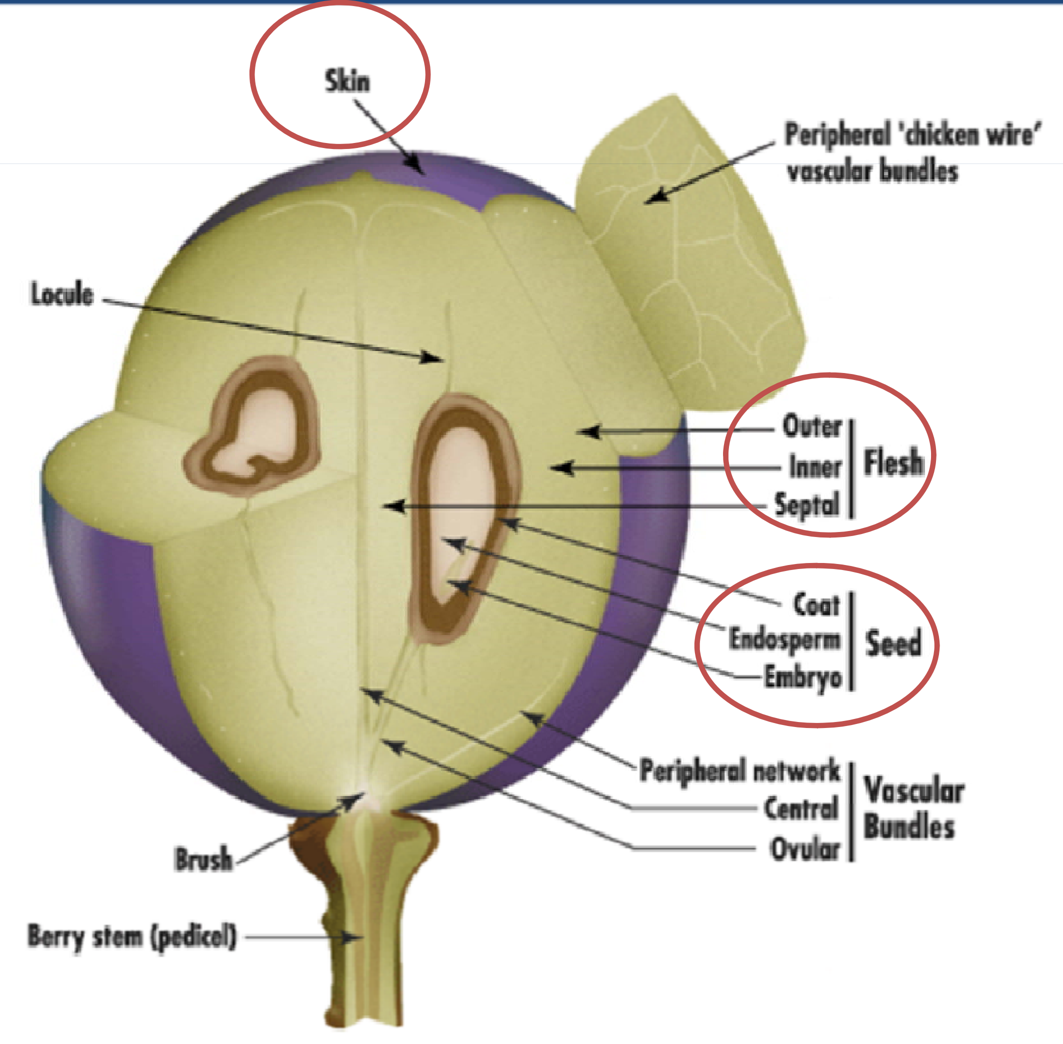


Figure 1: Structure of a ripe grape berry partially sectioned on the long and central axis to show internal parts. Illustration by Jordan Koutroumanidis, Winetitles.

Illustration by Jordan Koutroumanidis, Winetitles

Berry growth development

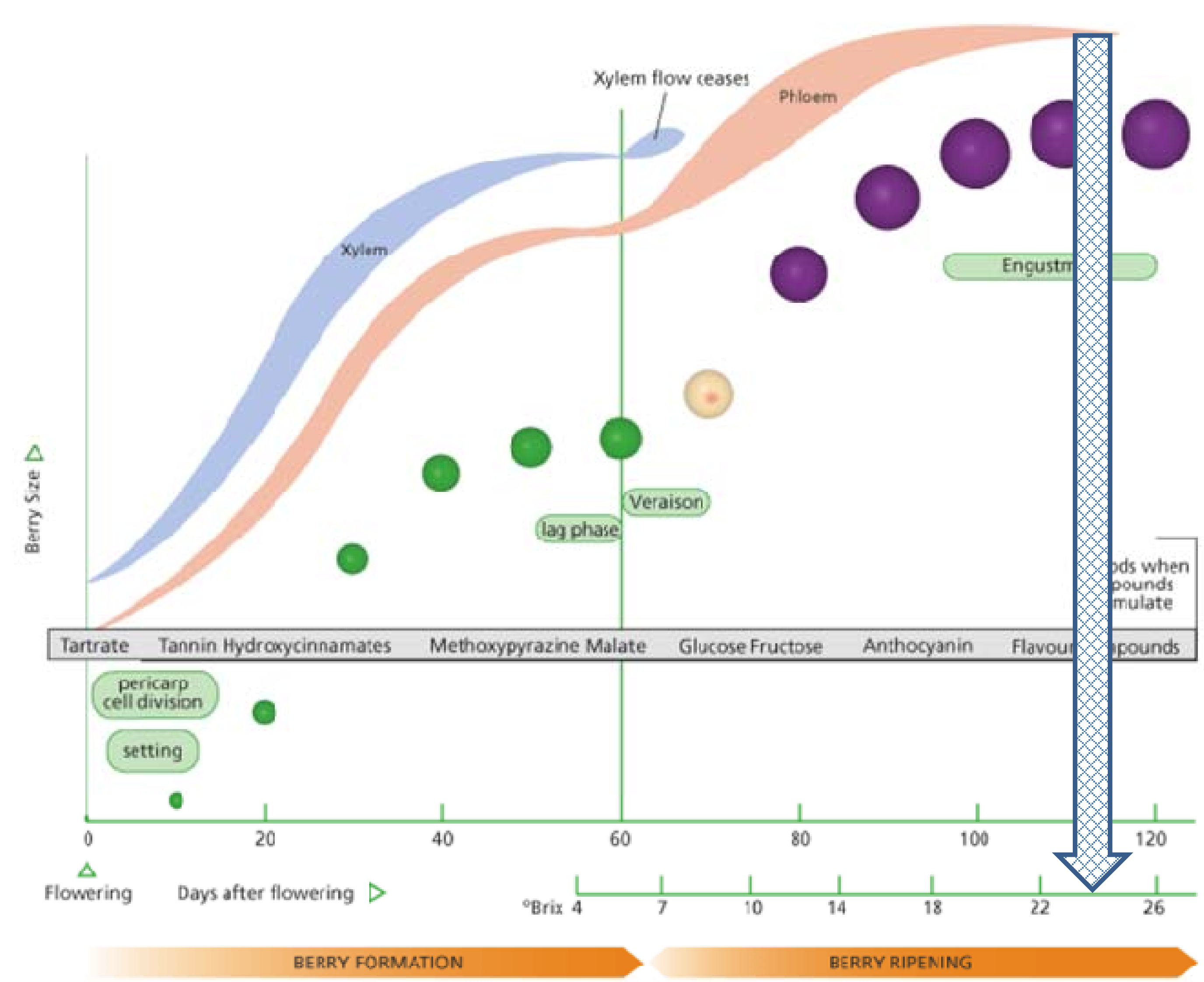
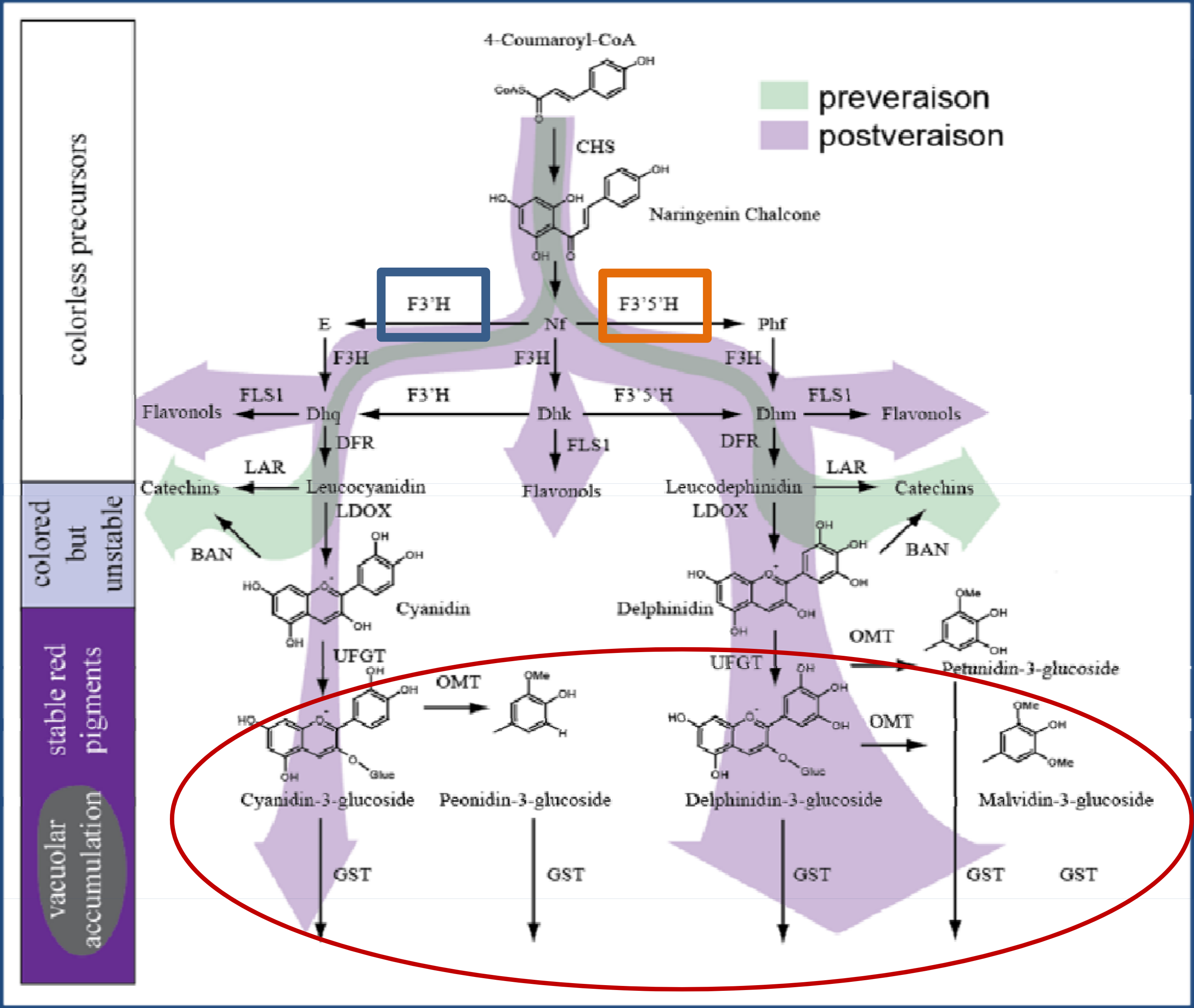


Figure 2: Diagram showing relative size and color of berries at 10-day intervals after flowering, passing through major developmental events (rounded boxes). Also shown are the periods when compounds accumulate, the levels of juice °brix, and an indication of the rate of inflow of xylem and phloem vascular saps into the berry. Illustration by Jordan Koutroumanidis, Winetitles.

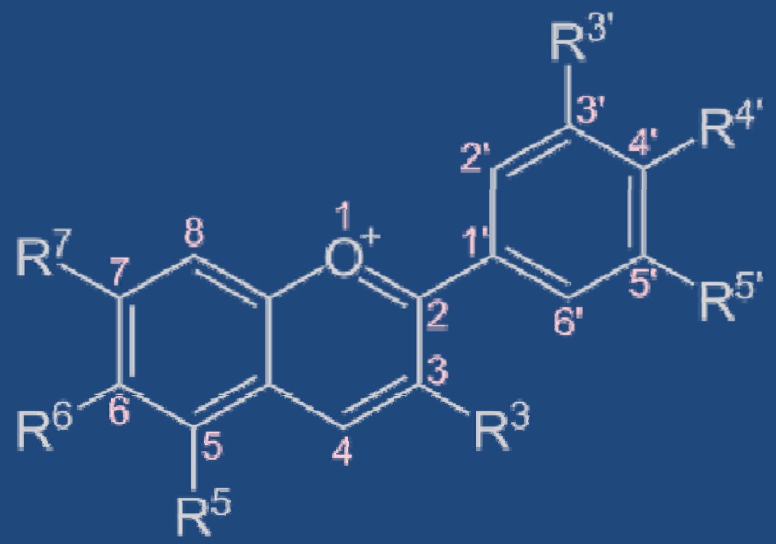
Illustration by Jordan Koutroumanidis, Winetitles

Flavonoid Pathway



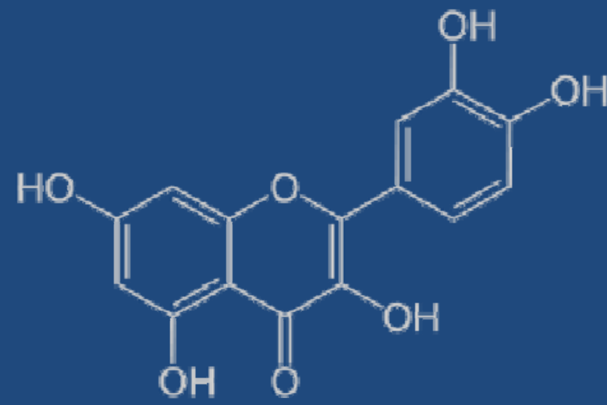
Castellarin and Matthews, 2007

Anthocyanins

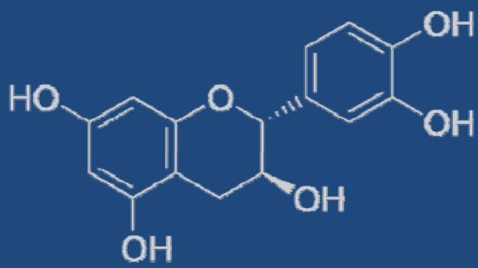


- **Berry:** attractant to animals (i.e. seed dispersal) and photo-protection
- **Wine:** visual perception, stability and age-ability of wine matrix, and antioxidative properties

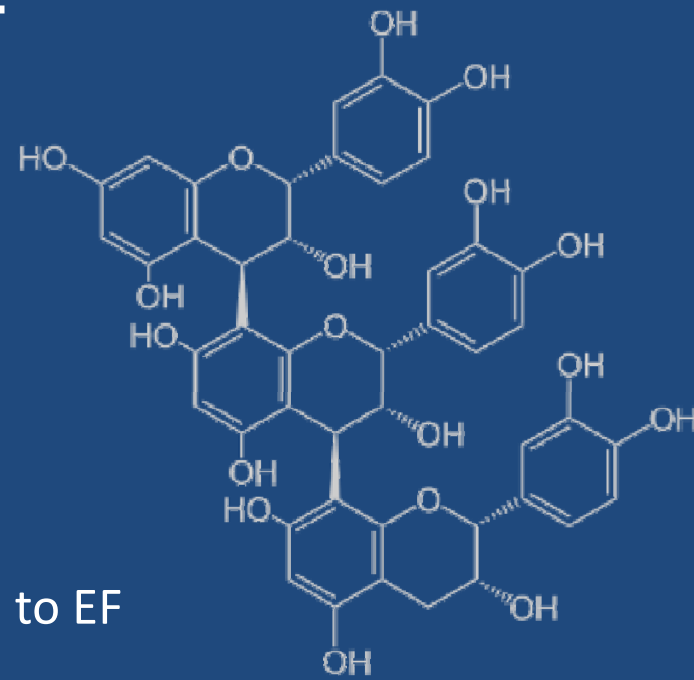
Flavonols



- **Photo-protection**
  - highly responsive to visible light and U-V
    - particularly UVB
  - less clear regarding temperature
  - studies show concentration not reliably paralleled with berry skin mass
- **Cofactor of co-pigmentation in wine matrix**



Flavanols



- Monomeric
- Polymeric (condensed tannins)

- Berry
  - most abundant flavonoid class but elusive to EF
  - deterrent towards animals

- Wine
  - bitterness and astringency (seed vs. skin)
  - critical for wine matrix stability and age-ability

Focus on aroma (volatile)

Desirable

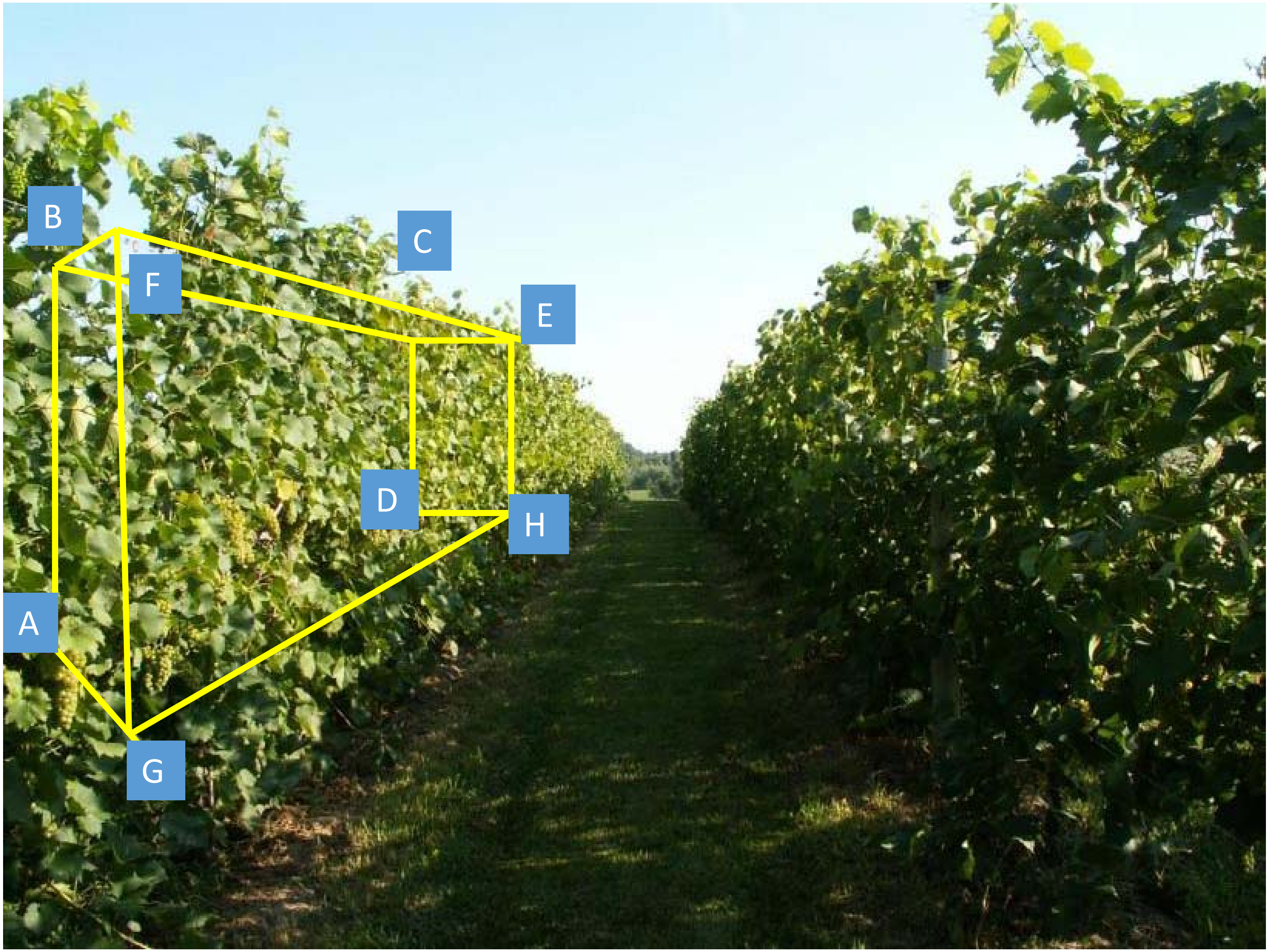
- **Β-damascenone**
- Present in both red and white
  - Fruity-flowery
  - Honey-like
  - Stewed apple aroma
- In berries, carotenoid levels increase until about veraison and then decrease
- C13 norisoprenoids are low prior to veraison and increase after veraison
- This change proposes that formation of norisoprenoids is linked to the degradation of carotenoids

Undesirable

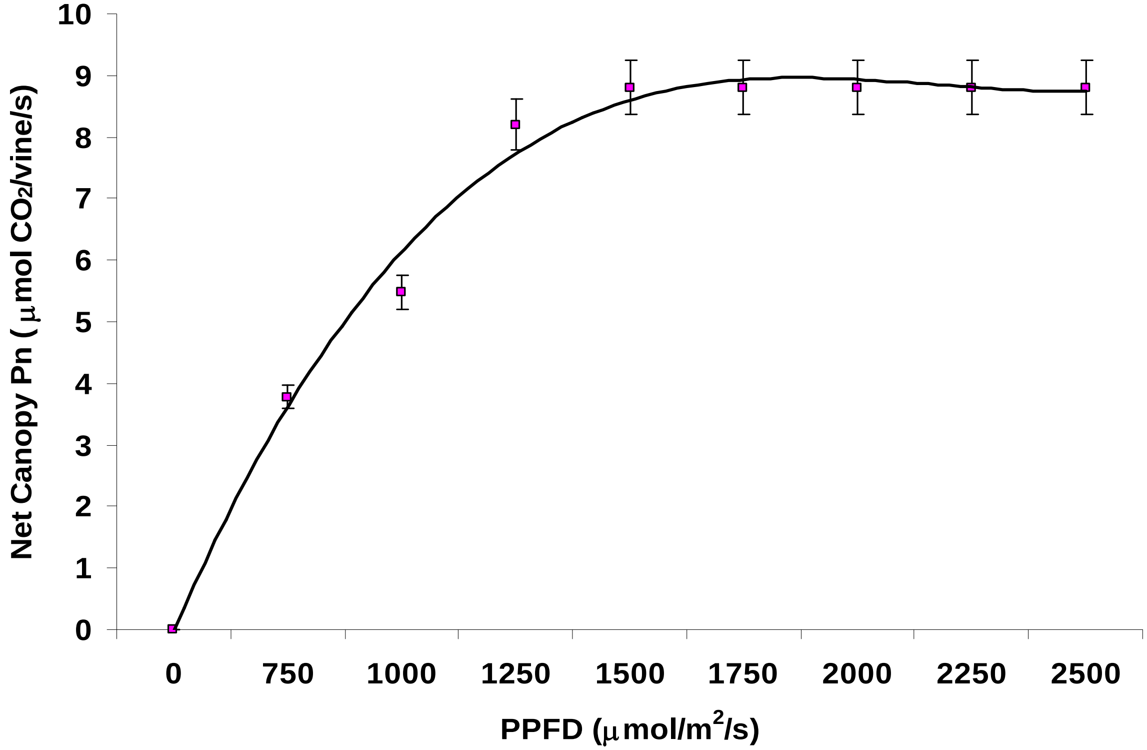
- **3-isobutyly-2-methoxypyrazine (IBMP)**
- MP content increases during berry formation, reaches a peak at veraison and then decreases during ripening
  - CS: 5.4 ng/L near veraison, 4.7 ng/L ripe
  - CF: 200 pg/g near veraison, 10 pg/g
- The decline in MPs content after veraison is thought to take place because the level of gene expression and enzyme activity decreases and the major influence of IBMP metabolism becomes the degradation process
- Typically levels of MP are higher in berries grown in cool climates than those from warm climates

Optimum light environment in the fruit zone during ripening

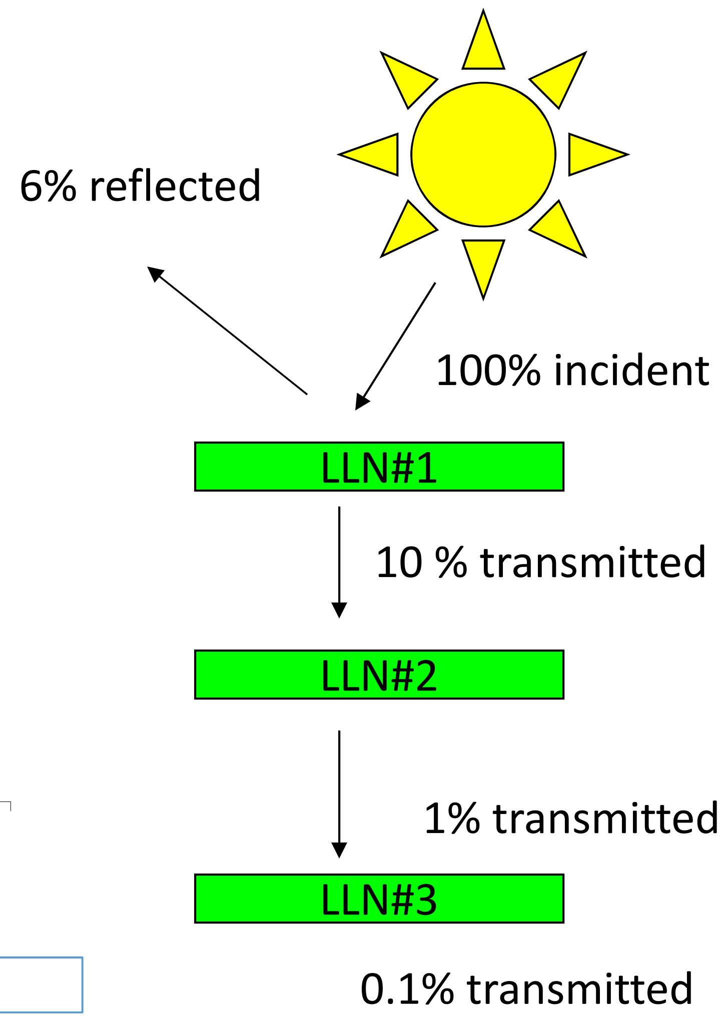
- Maximize diffuse or indirect sunlight within the canopy interior
- Minimize exposure of clusters to direct sunlight – particularly in <u>warm climates</u>


B
C
F
E
D
H
A
G

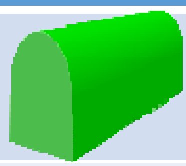
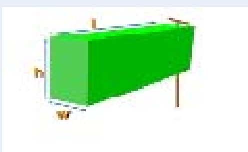
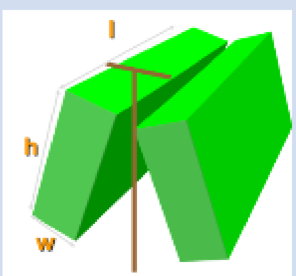
Radiation Effects on Whole Canopy



Kurtural et al. 2003; Dami et al. 2005; Kurtural et al. 2005; 2006



Common canopy types

Canopy type	Leaf area per vine	Exposed leaf area	Interior leaf area
	22 m^2	8 m^2 (35%)	14 m^2
	22 m^2	6 m^2 (25%)	16 m^2
	22 m^2	15 m^2 (70%)	7 m^2

Irrigation regimes

- Sustained Deficit Irrigation (SDI)
  - 80% ET_c from bloom to harvest

- Regulated Deficit Irrigation (RDI)
  - 80% ET_c from bloom to fruit set, 50% ET_c from fruit set to veraison, 80% ET_c from veraison to harvest

  - Moving forward…
    - Calculating ET_c

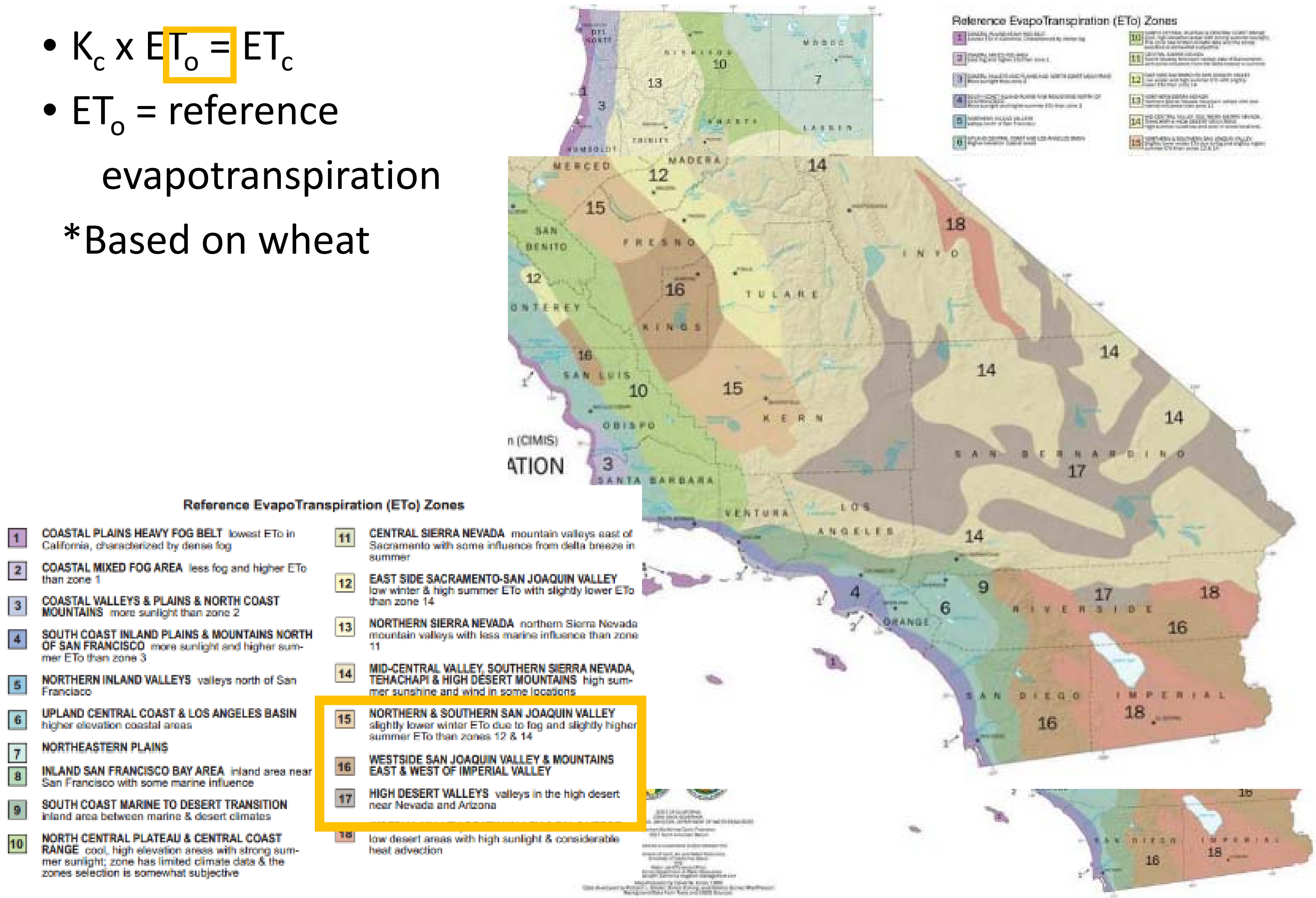
Irrigation scheduling

- $Et_c = K_c \times ET_o$
- K_c = crop coefficient
  - Calculated by weekly shade estimates
  - Remotely sensed and extrapolated from energy balance models
- ET_o = reference crop evapotranspiration
- ET_c = cultivar specific evapotranspiration
- Strongly affected by **drought**

Reference (ET)

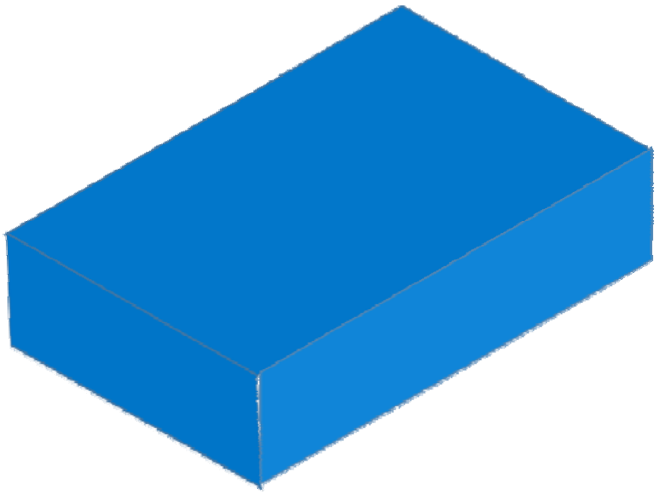
- K_c x ET_o = ET_c
- ET_o = reference evapotranspiration

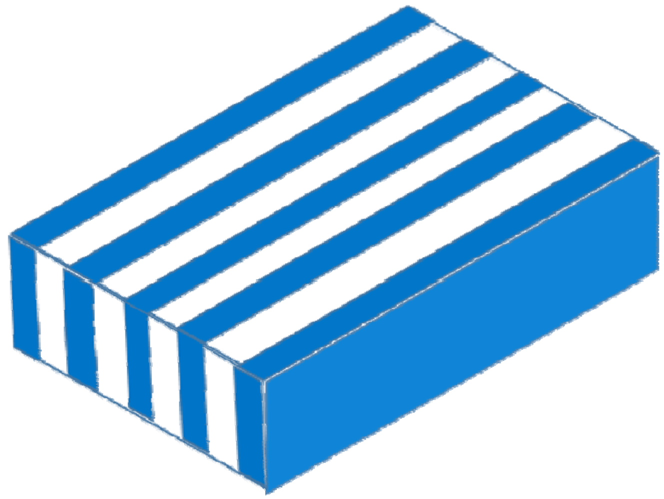
*Based on wheat



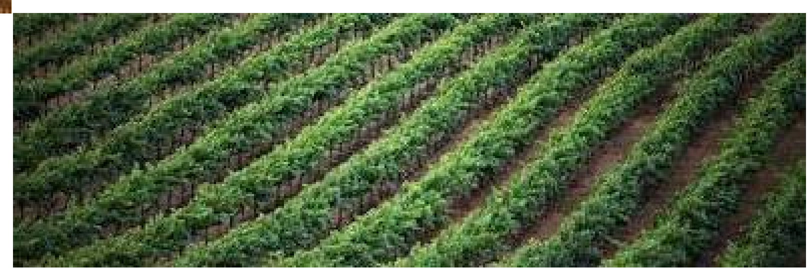
Why use a crop coefficient (K_c)?

* K_c based on canopy development; changes as season progresses, only irrigating effective rooting zone

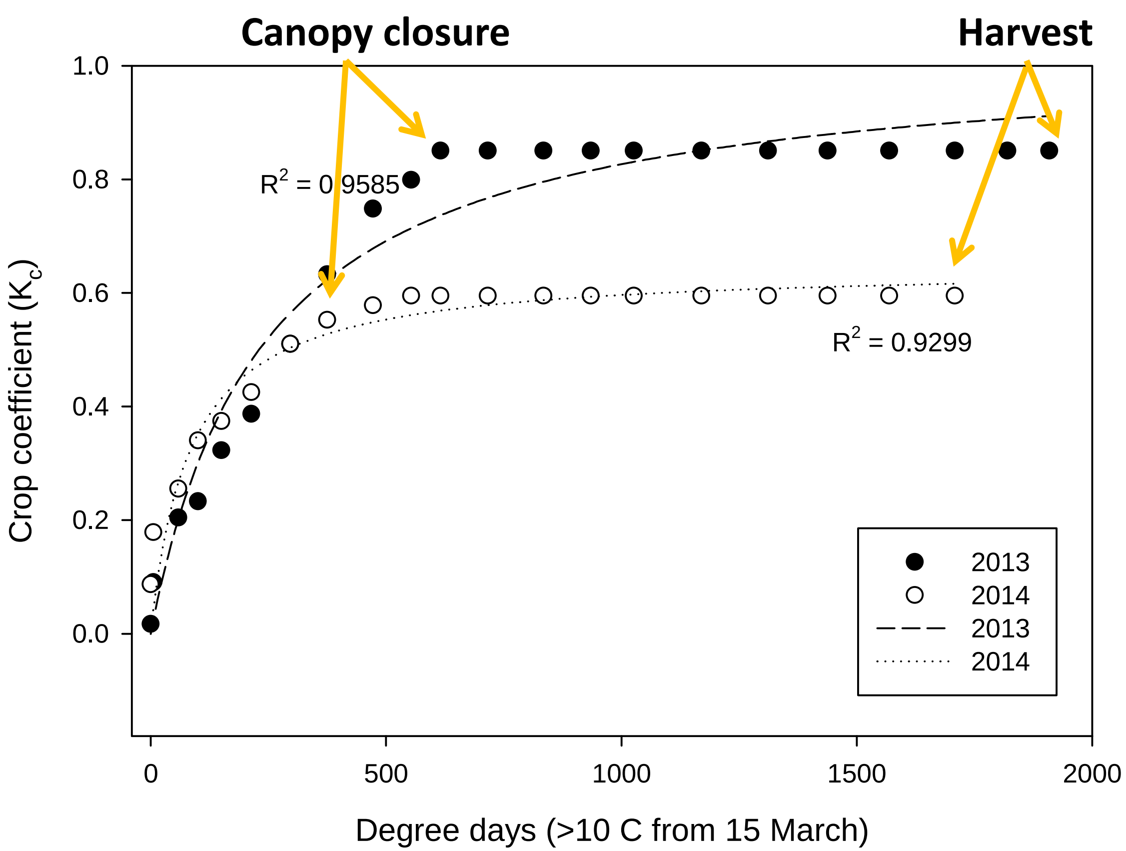




*If no grape K_c used, over-irrigating to full field capacity the entire season



Seasonal development of (K_c)

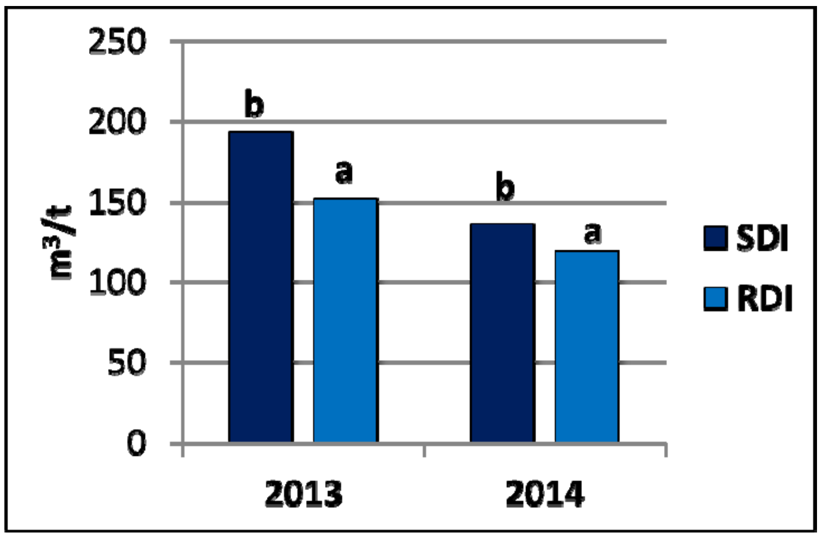


K_c x ET_o = ET_c

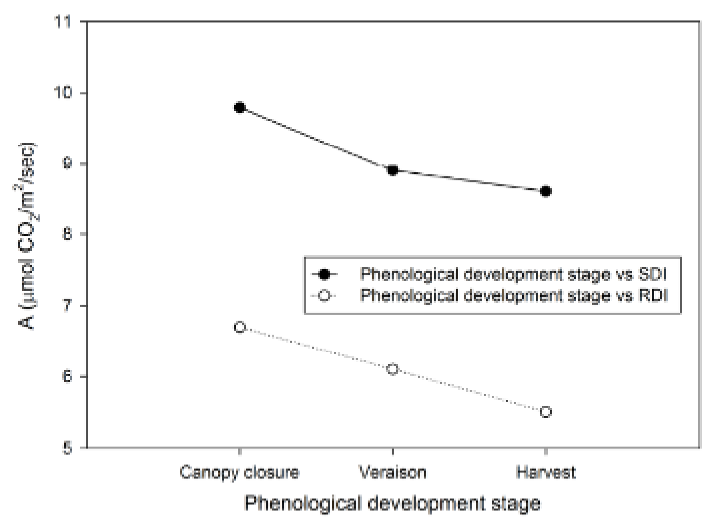
29% reduction from '13 – '14

Comparison of Sustained vs. Regulated Deficit

Water productivity



Net whole canopy photosynthesis



Steps in Canopy/Crop load Management

- Dormant Pruning*
- **Shoot thinning**
- Shoot positioning
- **Cluster thinning**
- **Leaf removal**
- Summer pruning hedging

Green season ops

Dormant pruning

- When?
  - Depends on where you are
  - Dormant season
  - Incidence of rain
- Severity
  - Defines bearing surface
  - Capacity
- Costs:
  - Spur: $0.29/vine
  - Cane w/ tying: $0.48/vine
  - Mechanical w/ hand follow up: $ 0.36/vine:
  - Box-prune single-high wire: $0.07/vine

How do you set up a mechanical pruning head?

- Spur height
  - Sets the height of the bearing surface
    - Commonly:
      - 4 inches = Precision prune
      - 6 inches = Pruning + follow up
      - 8 inches = Pre-pruning
- Bearing surface girth
  - Set the width and depth of bearing surface
    - Commonly
      - Sprawl: Completely removed
      - Width: 4 to 6 inches
- Ground speed
  - T-top or VSP canopy
    - 1.0 to 1.5 miles/h
  - Single high-wire
    - 2.0 miles/h
- Measure, and measure often!

Shoot thinning

- When?
- During dormant pruning*
- Trunk suckering
  - 1” – 3” shoot length
- Cordon
  - 8” – 12” shoot length
- In FROST PRONE AREAS WAIT TILL ALL DANGER OF FROST HAS PASSED!

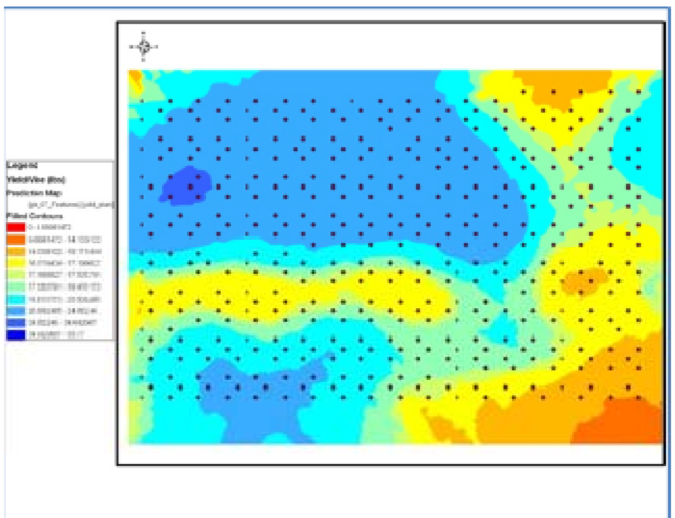
- Reduces shoot density, but impact on canopy density is often temporary if irrigation is unchecked
- Efficient method of crop thinning
- Assists in the establishment of spur positions
- Reduces pruning costs next season
- Cost per acre - $80 – $300/acre

Application – Manual/Mechanical

How do you set up a mechanical shoot thinner?

- Consider:
  - Target shoot density:
    - Count shoots
    - Non-count shoots
  - Cordon brush
  - Rotary paddles
    - 2 to 12 paddles
  - Tractor ground speed
    - 1 to 1.2 miles/h

Variable rate mechanical shoot removal

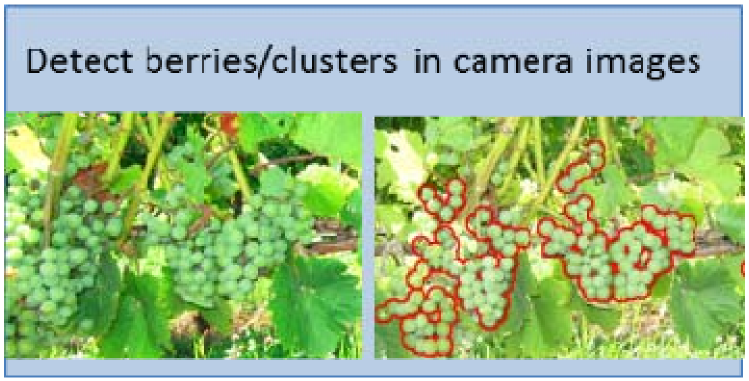


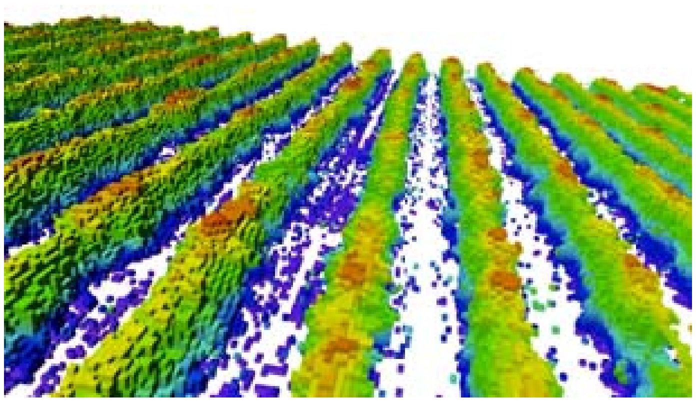
Berry/Cluster thinning

- Pre-bloom thinning
- Post fruit set-thinning
  - Rule of thumb for post fruit-set cluster thinning
  - If shoot is < 12” long remove all clusters
  - If shoot 12” – 24 “ long retain one cluster
  - If shoot > 24” long retain 2 clusters
- We are seeing most beneficial responses if applied
  - Berries b-b size
  - Post veraison applications – self gratifying

Manual cluster thinning

Variable mechanical cluster thinning





Effect of cluster numbers on canopy variables and fruit composition

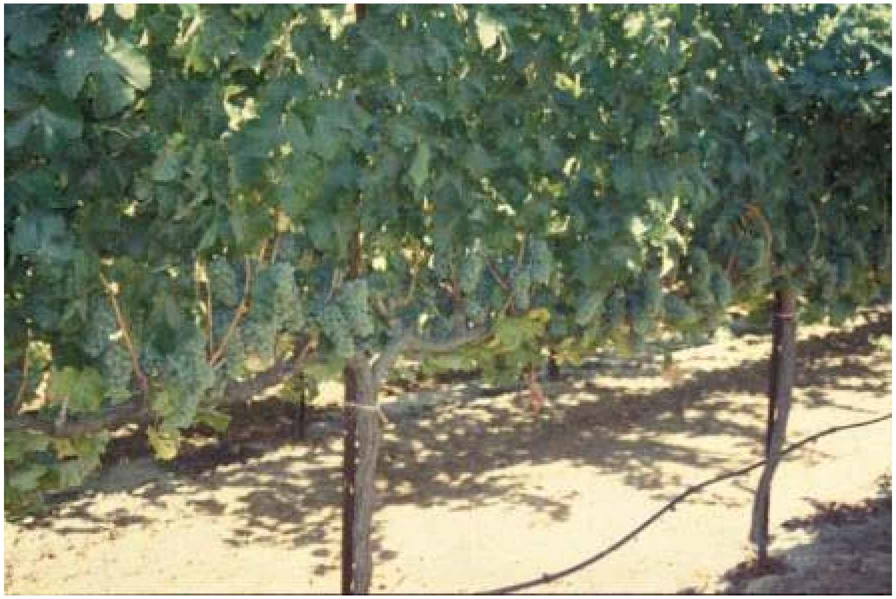
Clusters	γ (cm^2/cm)	LLN	Δ shoots (cm)	TSS(%)	pH	TA(g/L)
1 per	32.1	3.7	8.1	23.2 a	3.43 a	8.0
2 per	23.8	2.7	7.8	21.9 b	3.34 b	7.7
> 2 per	27.0	3.0	8.3	21.2 a	3.29 b	7.6
P	*0.1601*	*0.2691*	*0.7721*	*0.0001*	*0.0014*	*0.1332*
Trend	NS	*NS*	*NS*	*Linear* ***	*Linear* **	*NS*

Kurtural et al. 2006

Leaf Removal

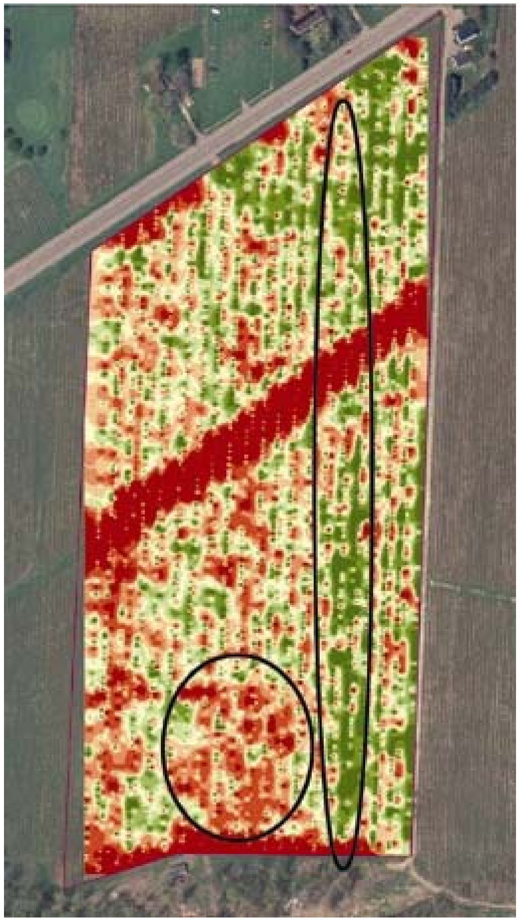
- Consists of the removal of basal leaves and lateral shoots opposite clusters on the primary shoot.
- Effects on microclimate
  - Increases sunlight AND temperature in the fruit zone
  - Decreases humidity in the fruit zone
- Sunburn
  - Risk minimized if fruit is exposed immediately after berry set
  - Risk maximized if fruit developed in canopy shade is exposed prior to berry softening
- Severity
  - Both sides of the canopy
  - Shade side of the canopy
    - East side if rows N-S *
    - North side if rows E-W
  - Cost
    - $80 to $250/acre depending on
    - Trellis type
    - Hand vs. Machine
    - Timing
    - Canopy density

Leaf Removal Manual Application



Leaf removal

Variable rate leaf removal application



Leaf Removal Influence on Fruit Composition

Pre-bloom

- Applied 1 week prior to bloom
  - ~20% of exposed leaf area removed
  - Increased
    - Anthocyanin concentration
    - Flavonol concentration
    - Not much affect on astringency
  - Best bang for your buck

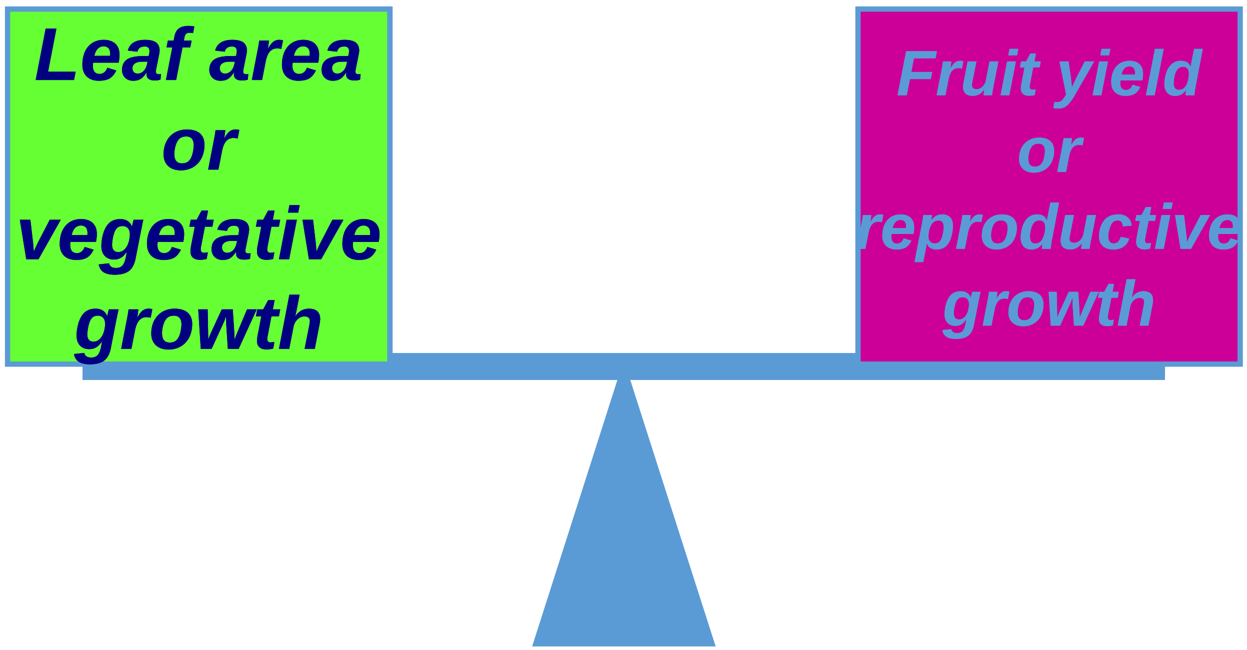
Post fruit-set

- Applied 2 weeks post-set
  - ~20 % of exposed leaf area removed
  - Increased
    - Flavan-3-ol monomers
    - Consistently increases astringency
  - Canopy repopulates
    - Repeated application may be necessary

That's Great, so what?

- You have to relate this to
  - Production Efficiency
- How do you measure efficiency?

- Production Efficiency



Production Efficiency

$\frac{\text{Vine yield}}{\text{Pruning weight}}$	Situation
< 5	**Undercropped**
5 – 10	**Optimum**
> 10	**Overcropped**

Grapevine Balance through Canopy/Crop load Management

- Balancing vegetative growth with reproductive growth
- Single most important practice

- Vine balance thresholds
- Crop load : 5 to 10 lbs/lbs
- Pruning weight/ ft of row:
  - Up to 0.7 lbs/ft

- Unbalanced vines
  - Large canopies
  - High water demand
  - Fruit of inferior quality
  - High green flavors
  - Low fruit flavors
- High priority for industry

Putting Mechanical Canopy/Crop Load Management to Practice

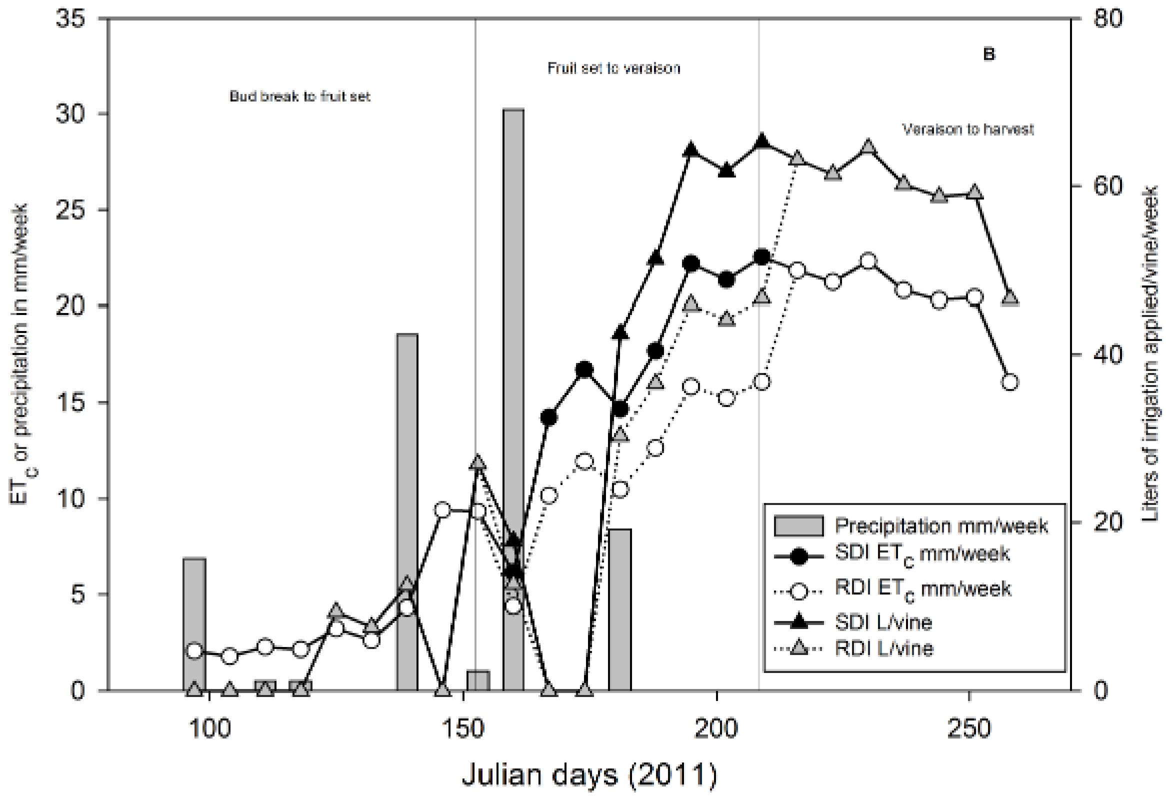
Red wine grape cultivars

Red Wine Grape Irrigation Strategy

- **Cool climate**
- Bud break to bloom
  - Irrigation trigger at -10 bars mid-day leaf water potential (Ψl)
- Bloom to set
  - Replace 70% of ET_c, Ψl = -12 bars
- Fruit set to veraison:
  - Replace 50% of ET_c Ψl = -14 bars
- Veraison to harvest
  - Replace 80% of ET_c, Ψl = -12 bars

- **Warm climate**
- Bud break to bloom
  - Irrigation trigger Ψl = -8 bars
- Bloom to set
  - Replace 80% of ETc, Ψl = -12 bars
- Fruit set to veraison
  - Replace 80% of ETc, Ψl = -12 bars
- Veraison to harvest
  - Replace 80% of ETc, Ψl = -12 bars

Crop coefficient and irrigation schedule



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Canopy Architecture

Cool climate

- Pruning method:
  - Manual or mechanical (4” hedge)
- For drooping variety
  - Shoot density: 5 count shoots/ft
  - Combine w/RDI method
- For upright variety
  - Shoot density 7 counts/ft
  - Combine w/RDI method
- 2 to 3 leaf layers
- Leaf removal: Pre-bloom

Warm climate

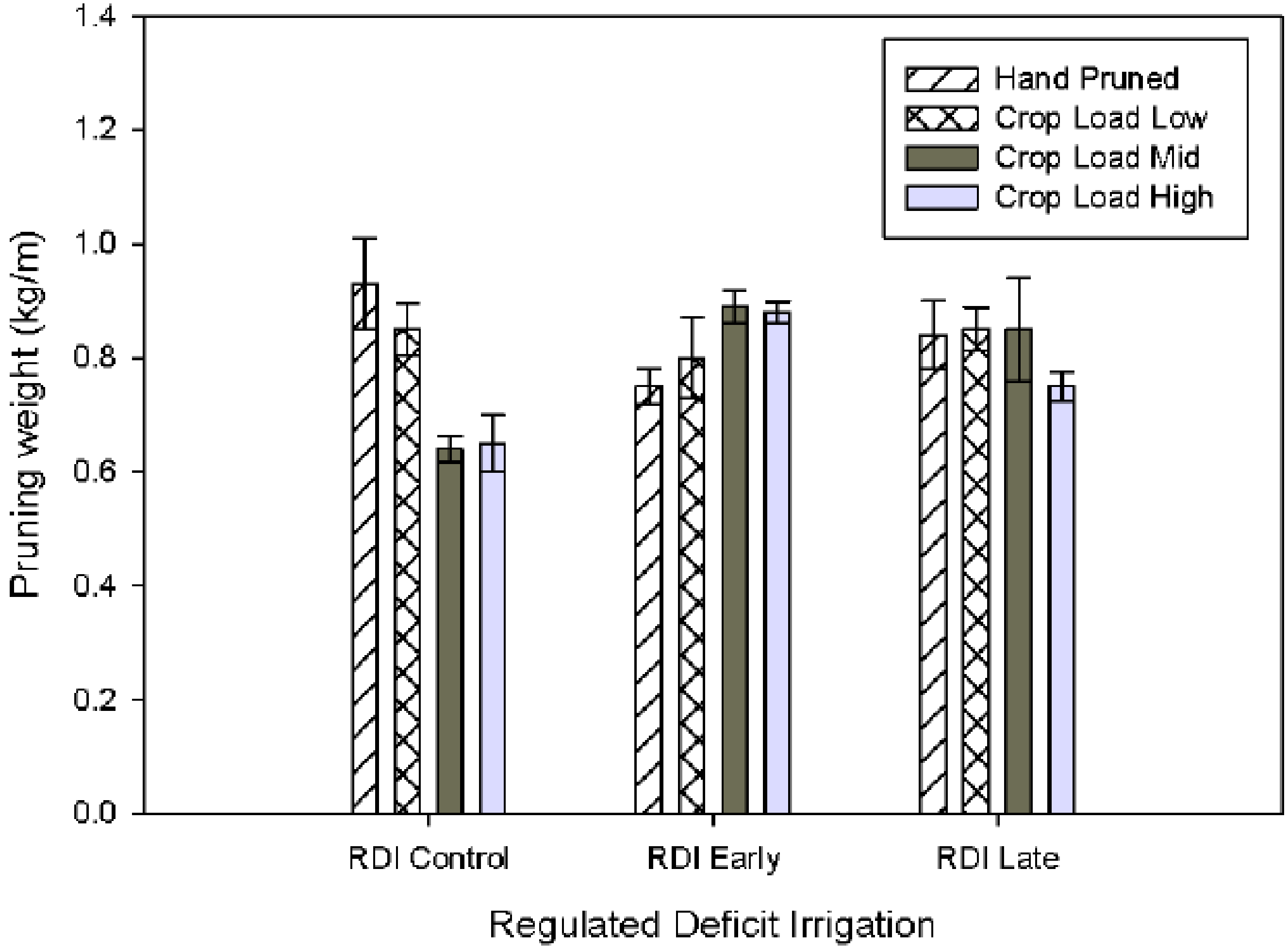
- Pruning method
  - Mechanical (4” hedge)
- For drooping variety
  - No shoot thinning
  - Combine with SDI method
- For upright variety
  - 11 count shoots/ft
  - Combine w/ RDI method
- 3 to 4 leaf layers
- Leaf removal: Pre-bloom

Canopy gaps at veraison

Yield averages 2009-2011 (Syrah/1103 P)

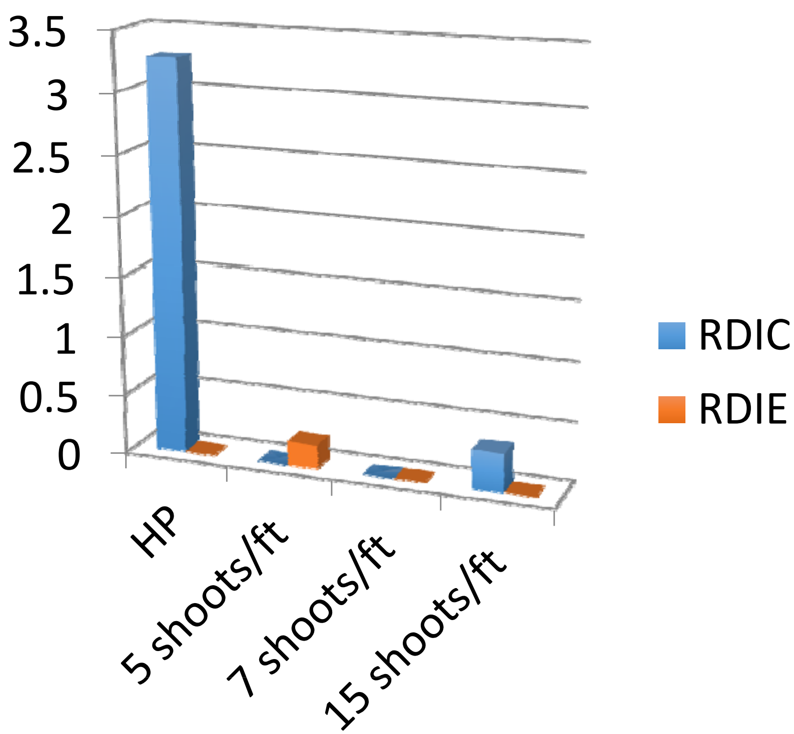
Canopy Management	**Berry wt(g)**	**Cluster wt (g)**	**Yield (T/A)**
HP	1.33 a	189 a	7.0 b
5 shoots/ft	1.30 ab	151ab	8.3 c
7 shoots/ft	1.26 b	148 c	12.1 ab
15 shoots/ft	1.20 c	137 d	15.0 a
P	0.0191	0.0008	0.0006
RDI			
SDI	1.35 a	172 a	14.0 a
RDIE	1.13 b	126 b	12.1 b
RDIL	1.33 b	172 a	13.9 a
P	0.0001	0.0001	0.0001
CM x RDI	0.0802	0.0499	0.6897

Pruning weights

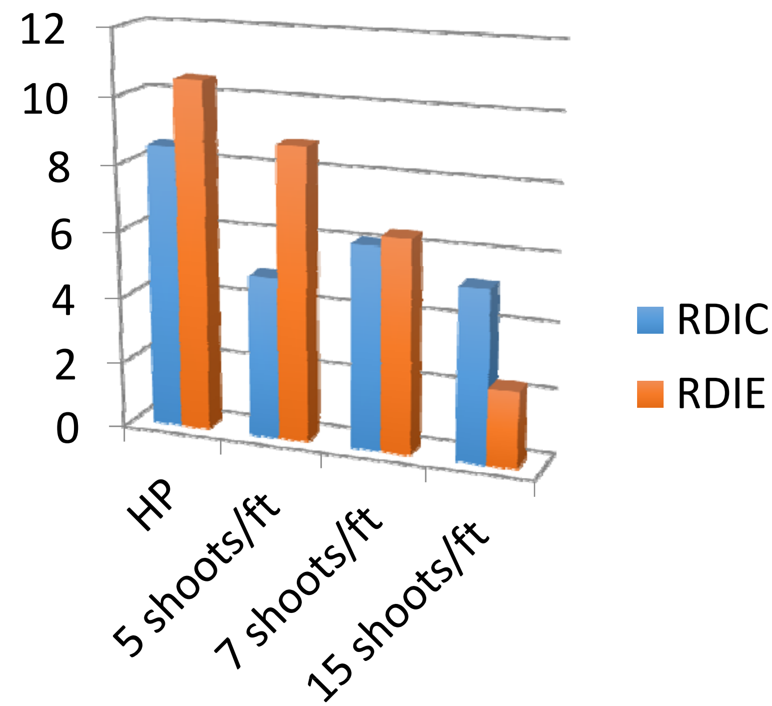


Red Wine Flavor Indicators

IBMP (green flavor)



B-damascenone (jammy, fruity flavor)

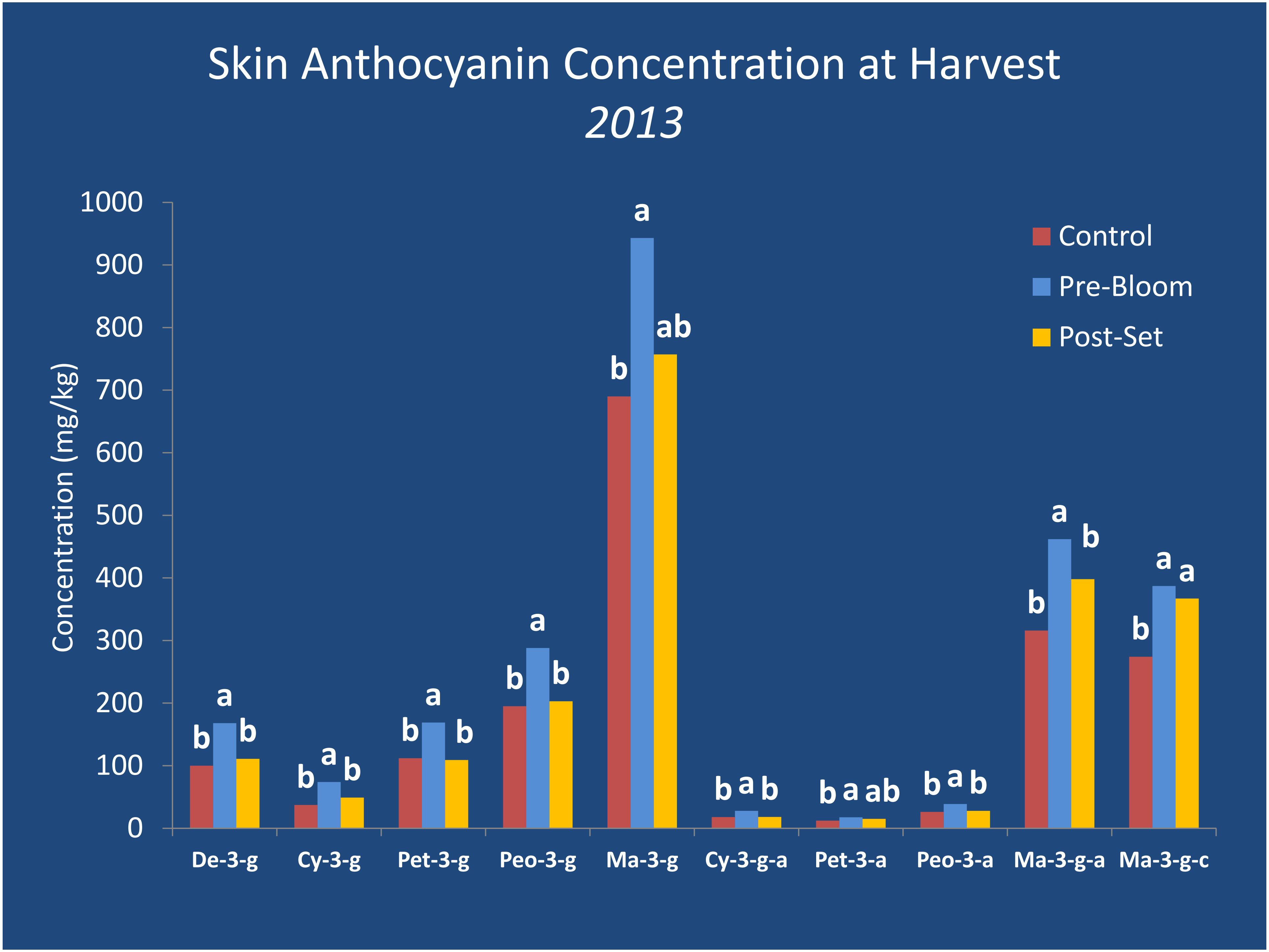


Mechanical leaf removal effects on flavonoid composition (Merlot/Freedom) in mg/kg

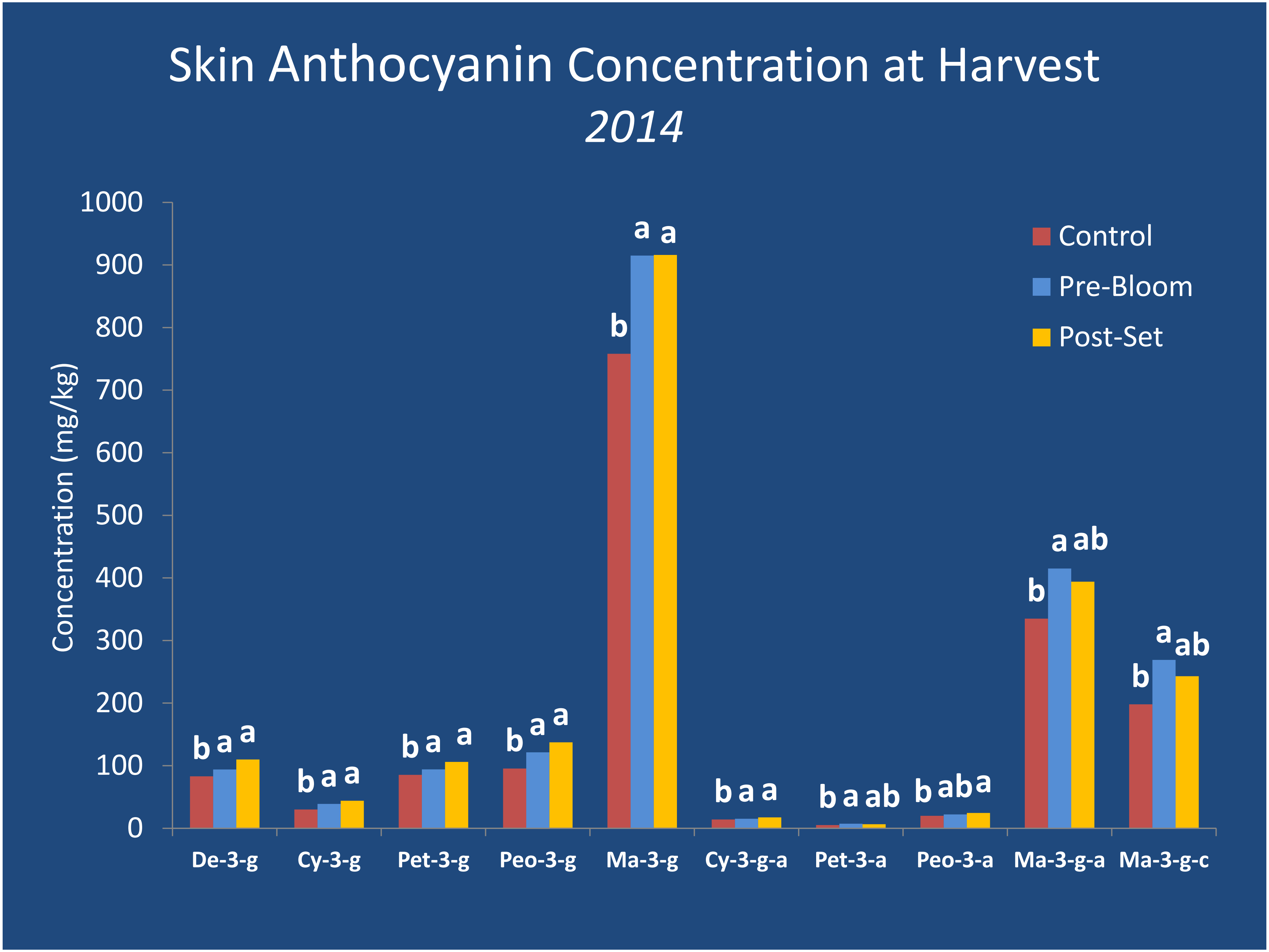
	quercetin	myricetin	Total skin anthocyanin	mDP
		Year 1		
No leaf removal	180 b	16.4 b	2066.4 b	14.1ab
Pre-bloom	335 a	23.7 a	2763.9 a	13.9 b
Post-fruit set	262 a	22.9 a	2381.5ab	15.9a
Pr>F	0.0003	0.0133	0.0055	0.0172
		Year 2		
No leaf removal	325 b	17.9 b	1554.1 b	20.2 a
Pre-bloom	390 ab	22.0 a	2135.3 a	17.9 b
Post-fruit set	432.1 a	22.3 a	2044.9 a	18.6 a
Pr>F	0.0132	0.0395	0.0014	0.0454

Effect of applied water amounts on anthocyanin composition in presence of leaf removal

Applied water amount	Less stable (%)	More stable (%)
	Year 1	
Sustained deficit irrigation	22.9 a	77.1 b
Regulated deficit irrigation	20.5 b	79.5 a
Pr>F	0.0011	0.0483
	Year 2	
Sustained deficit irrigation	15.9 a	84.1 b
Regulated deficit irrigation	12.1 b	87.9 a
Pr>F	0.0012	0.0011



Skin Anthocyanin Concentration at Harvest
2013
Concentration (mg/kg)
0
100
200
300
400
500
600
700
800
900
1000
Control
Pre-Bloom
Post-Set
b a b
b a b
b a b
b a b
b a ab
b a b
b a ab
b a b
b a b
b a a
De-3-g
Cy-3-g
Pet-3-g
Peo-3-g
Ma-3-g
Cy-3-g-a
Pet-3-a
Peo-3-a
Ma-3-g-a
Ma-3-g-c



Skin Anthocyanin Concentration at Harvest
2014
Concentration (mg/kg)
1000
900
800
700
600
500
400
300
200
100
0
Control
Pre-Bloom
Post-Set
b a a
b a a
b a a
b a a
b a a
b a a
b a ab
b ab a
b a ab
b a ab
De-3-g
Cy-3-g
Pet-3-g
Peo-3-g
Ma-3-g
Cy-3-g-a
Pet-3-a
Peo-3-a
Ma-3-g-a
Ma-3-g-c

Putting Management to Practice

White wine grape production for cool and warm climate regions

Constraints to consistent production

- Profit margins are low
  - Yield is paramount in the warm climate
  - 12 tons/A
    - (based on 7' x 11' spacing)
- Growers can only afford to prune
  - Mechanical hedging:
    - Retains too many nodes
    - **Out of balance vines**
    - <u>Too much fruit</u> for the amount of leaf area
    - <u>Too much leaf area</u> for the amount of fruit
- CROP LOAD MANAGEMENT instead of Canopy Management

White Wine Grape Irrigation Strategy

- **Cool climate**
- Bud break to bloom
  - Irrigation trigger at -10 bars mid-day leaf water potential (Ψl)
- Bloom to set
  - Replace 70% of ET_c, Ψl = -10 bars
- Fruit set to veraison:
  - Replace 80% of ET_c Ψl = -12 bars
- Veraison to harvest
  - Replace 80% of ET_c, Ψl = -12 bars

- **Warm climate**
- Bud break to bloom
  - Irrigation trigger Ψl = -8 bars
- Bloom to set
  - Replace 80% of ETc, Ψl = -10 bars
- Fruit set to veraison
  - Replace 80% of ETc, Ψl = -12 bars
- Veraison to harvest
  - Replace 80% of ETc, Ψl = -10 bars

Canopy Architecture

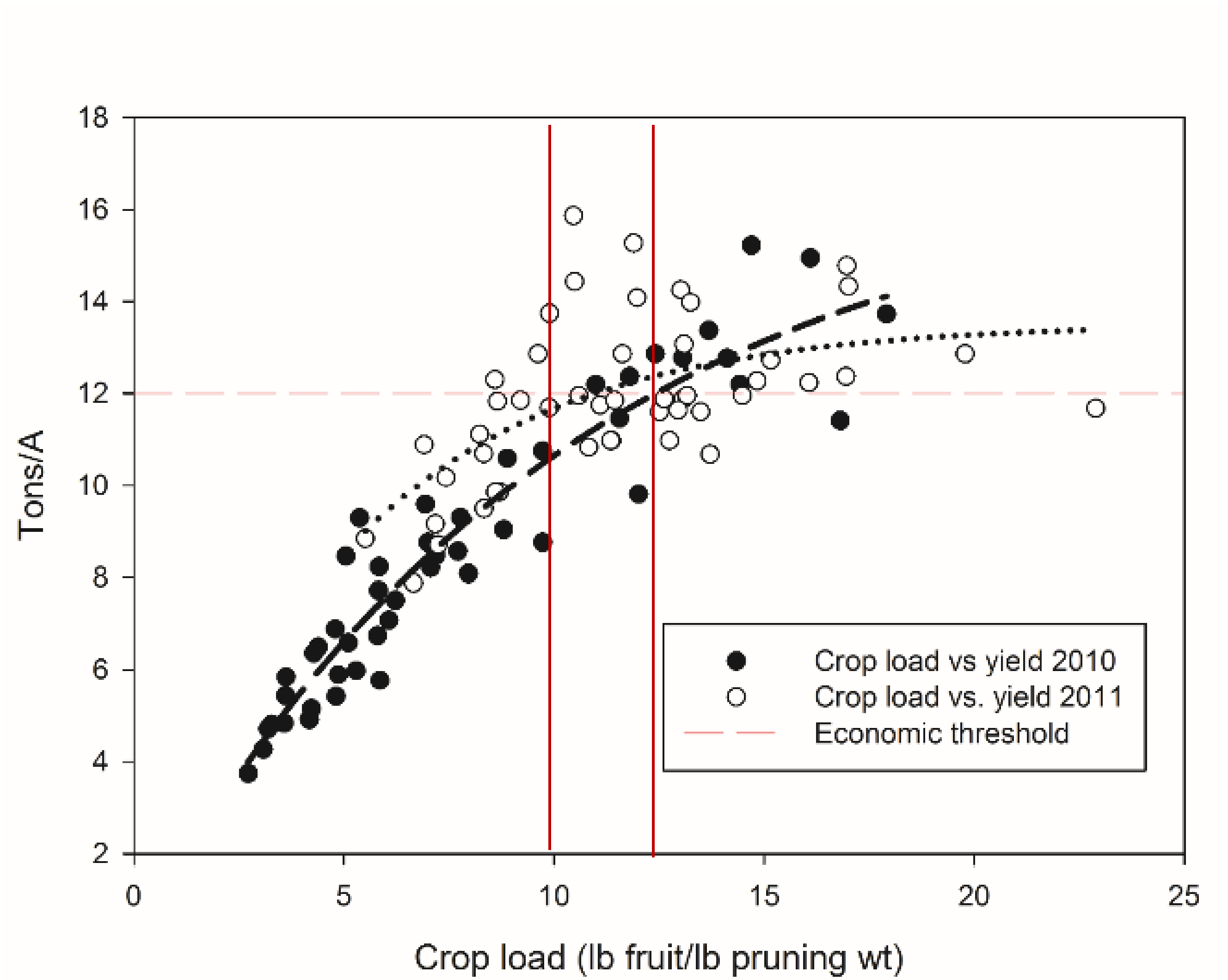
Cool climate

- Pruning method:
  - Manual or mechanical (4” hedge)
- For upright variety
  - Shoot density 5 count shoots/ft
- 2 to 4 leaf layers
- Leaf removal: None *
- * SB and RS excepted

Warm climate

- Pruning method:
  - Mechanical (4” hedge)
- For upright variety
  - Shoot density: 11 count shoots/ft
- 4- 4.5 leaf layers
- Leaf removal: None

Crop Load Management



Crop load management

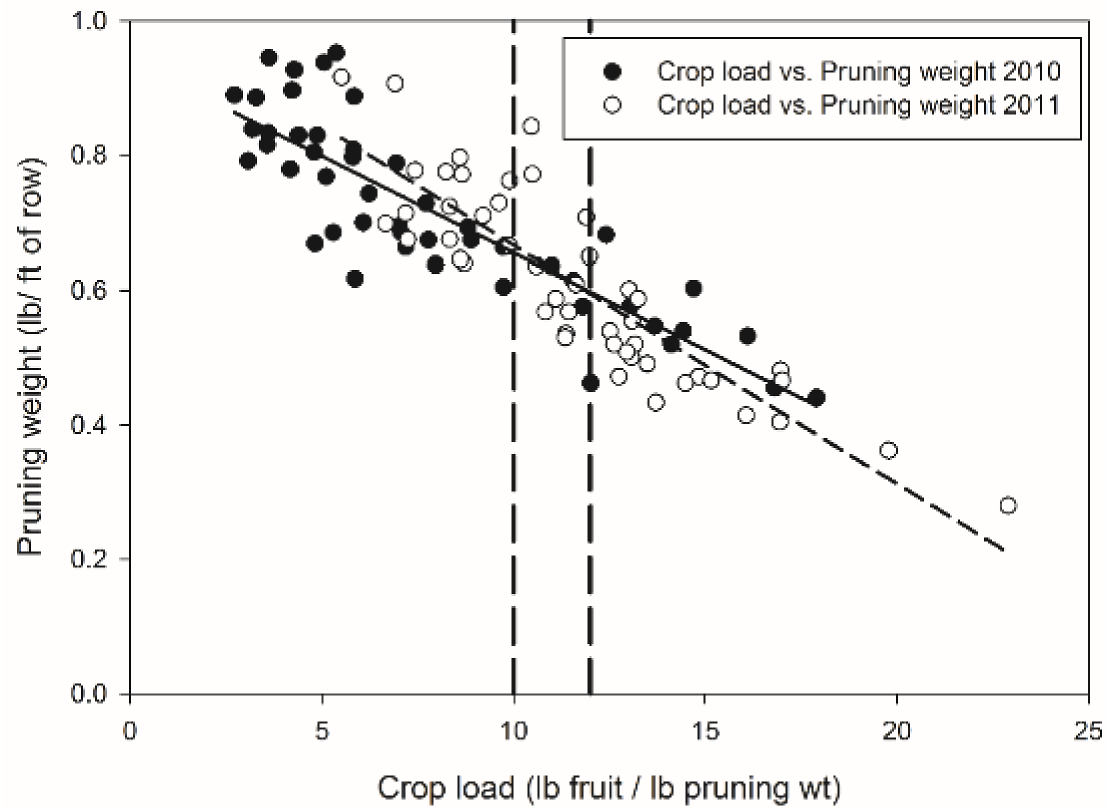


Table 6 Average labor operation cost for canopy management treatments and net benefit for canopy management of Pinot gris grapevines in 2010 and 2011.

Treatment[a]	Canopy management cost/ha ($)[b]	Gross income/ha ($)[c]	Net income/ha ($)[d]
HP + low ST	1,058.60	8,253.00	(-4,384.00)
HP + medium ST	1,058.60	9,361.26	(-3,275.74)
HP + high ST (control)	997.10	10,870.38	(-1,766.62)
MH + low ST	217.10	11,389.14	(-1,247.86)
MH + medium ST	217.10	12,733.20	96.20
MH + high ST	155.60	13,652.82	1,015.82
HP + low ST + LR	1,120.10	8,350.60	(-4,286.40)
HP + medium ST + LR	1,120.10	9,739.24	(-2,897.76)
HP + high ST + LR	1,058.60	10,338.07	(-2,298.93)
MH + low ST + LR	278.60	10,422.95	(-2,214.05)
MH + medium ST + LR	278.60	12,143.99	(-4,93.01)
MH + high ST + LR	217.10	13,450.11	813.11

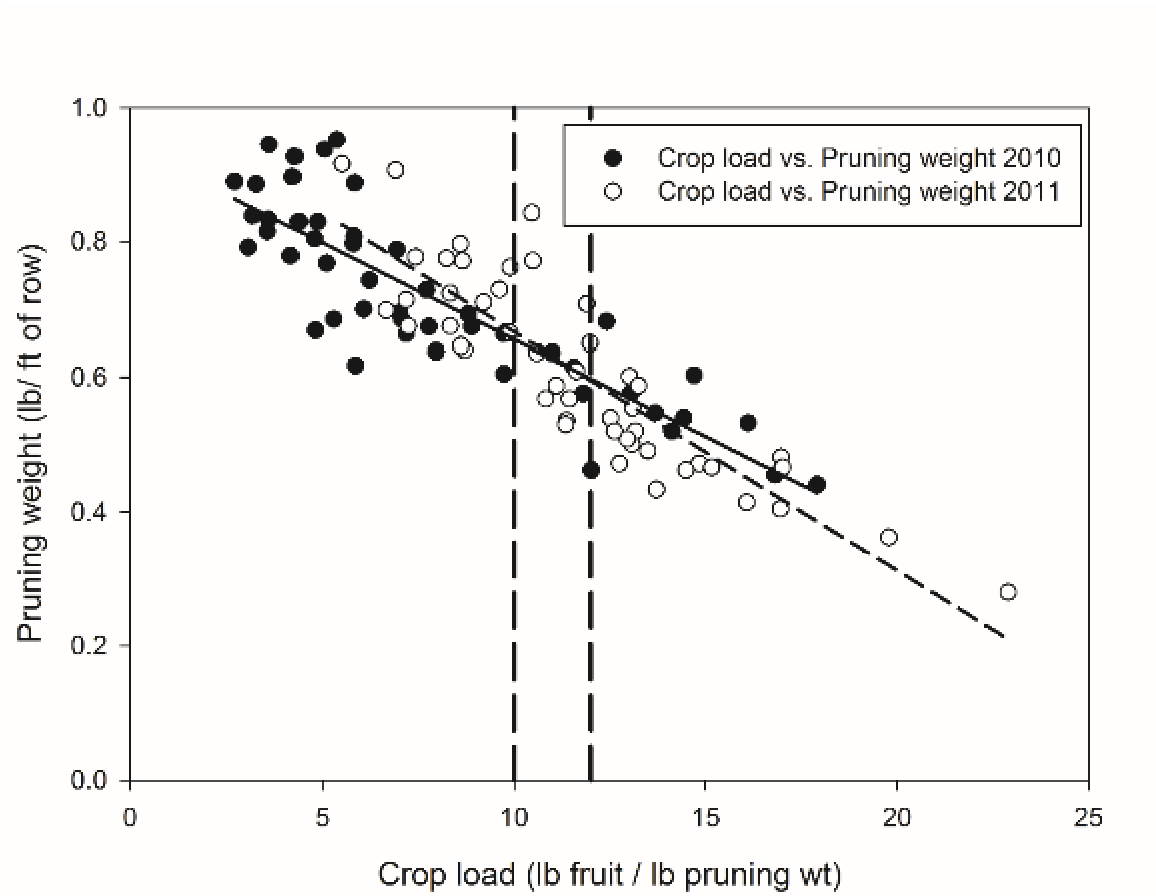
[a]HP: hand pruning; MH: mechanical hedging; ST: shoot thinning; and LR: and leaf removal.

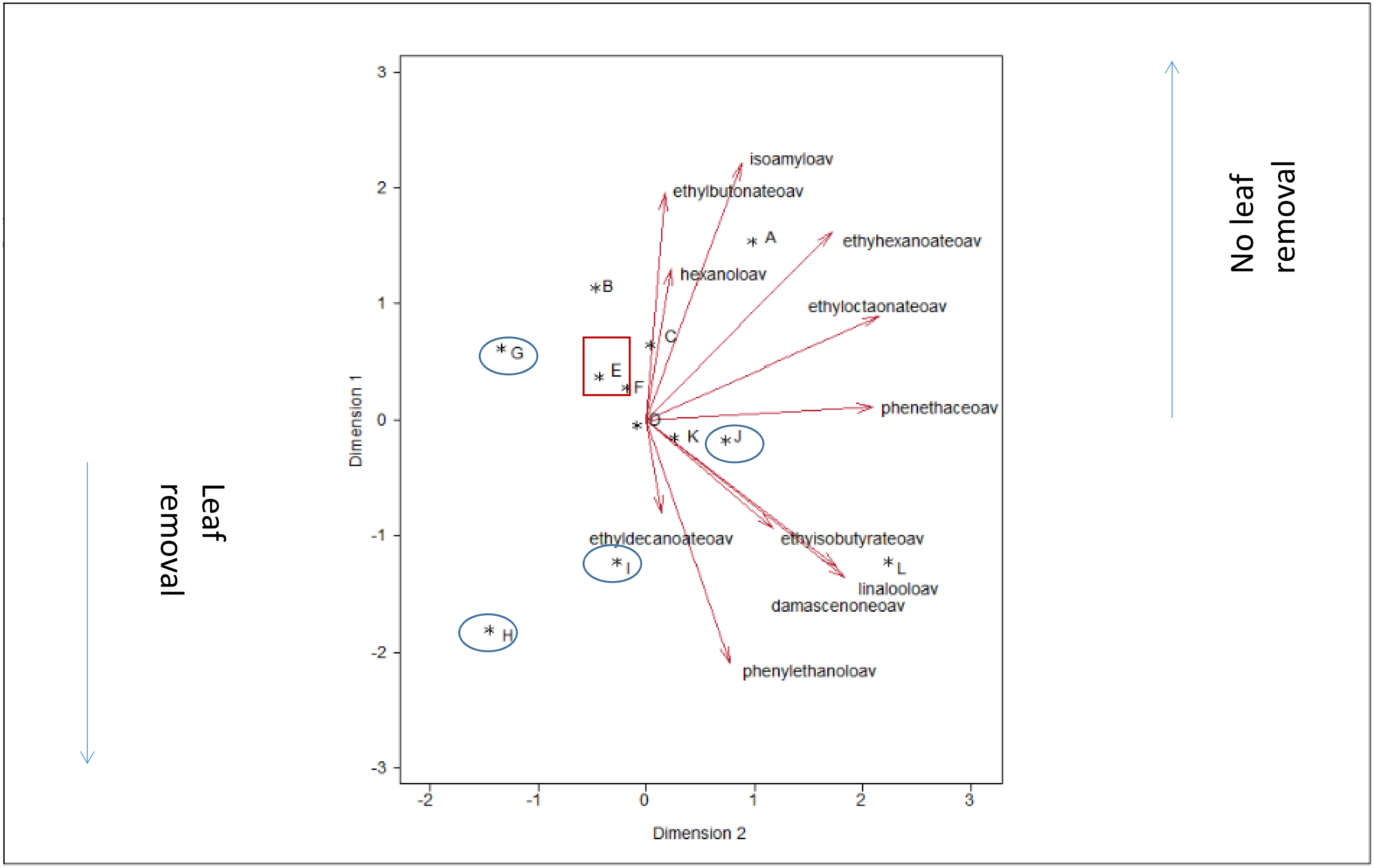
[b]Labor cost calculations per ha for canopy management (Kurtural et al. 2012, Peacock et al. 2005), based on average labor prices 2011–2012.

[c]Gross income/ha: mean yield per ha x average price per ton.

[d]Net income/ha: gross income per ha – canopy management cost per ha.

Crop load management





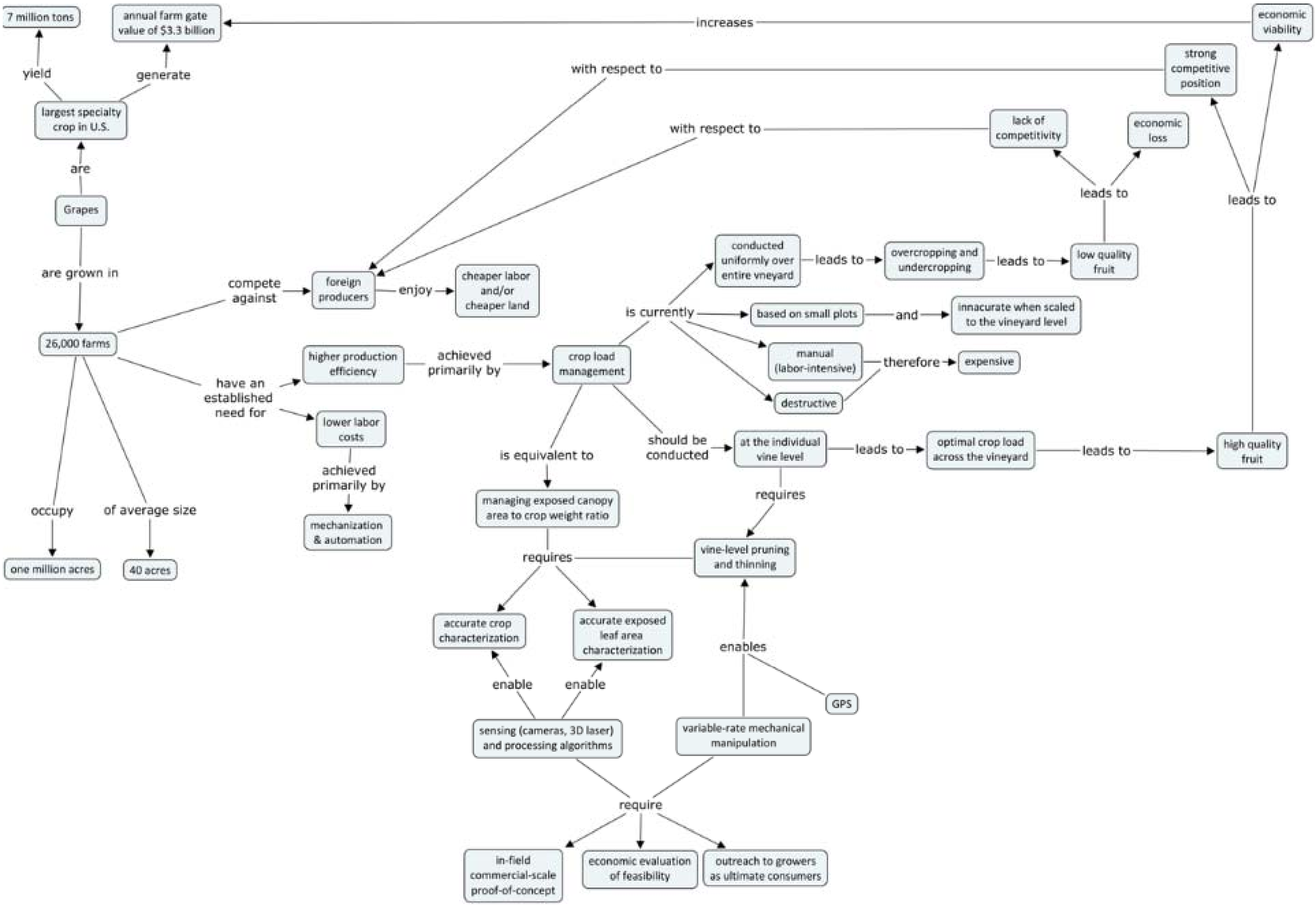
Dimension 1
Dimension 2
isoamyloav
ethylbutonateoav
ethyhexanoateoav
hexanoloav
ethyloctaonateoav
phenethaceoav
ethyldecanoateoav
ethyisobutyrateoav
linalooloav
damascenoneoav
phenylethanoloav
A
B
C
D
E
F
G
H
I
J
K
L
No leaf removal
Leaf removal

Take home messages

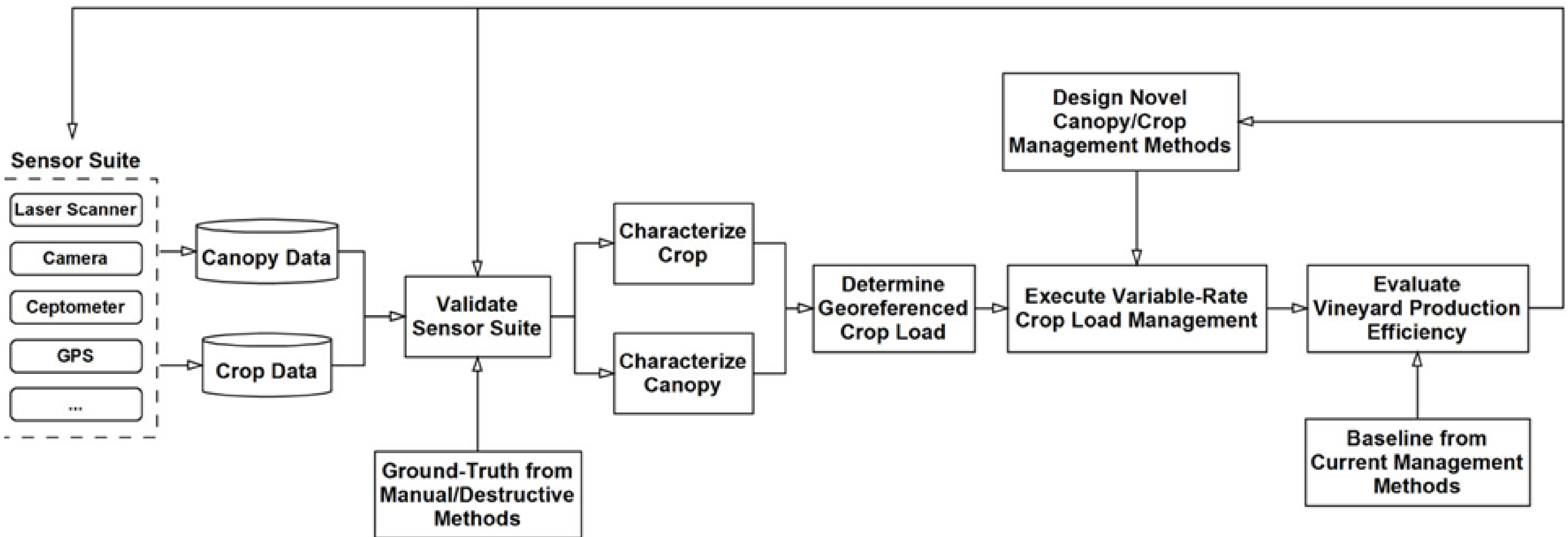
- No silver bullet
- Each vineyard is unique
- Not all treatments will work at every vineyard
- For Red wine grapes: Incorporation of early season RDI stress is **Key** to **build** phenolic composition, and **retain** it
- To burn up green flavors: Early season exposure is the only thing that works.
- To increase fruity, jammy flavors: Late season exposure will enhance them, but might decrease yield due to shrivel, raisining.
- For White wine grapes: Crop load management, rather than canopy management.

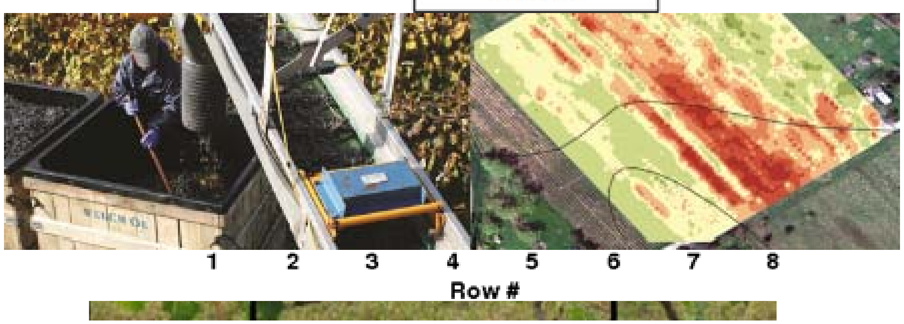
What is next?

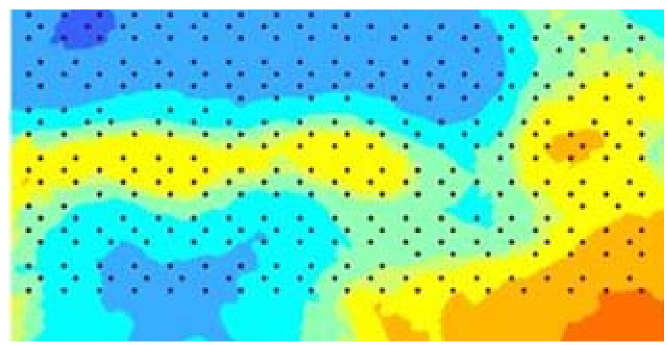
What is next?


7 million tons
annual farm gate value of $3.3 billion
increases
economic viability
yield
generate
with respect to
strong competitive position
largest specialty crop in U.S.
with respect to
lack of competitivity
economic loss
are
leads to
leads to
Grapes
conducted uniformly over entire vneyard
leads to
overcropping and undercropping
leads to
low quality fruit
are grown in
compete against
foreign producers
enjoy
cheaper labor and/or cheaper land
is currently
based on small plots
and
innacurate when scaled to the vineyard level
26,000 farms
higher production efficiency
achieved primarily by
crop load management
manual (labor-intensive)
therefore
expensive
have an established need for
destructive
lower labor costs
should be conducted
at the individual vine level
leads to
optimal crop load across the vineyard
leads to
high quality fruit
is equivalent to
achieved primarily by
requires
occupy
of average size
managing exposed canopy area to crop weight ratio
mechanization & automation
requires
vine-level pruning and thinning
one million acres
40 acres
accurate crop characterization
accurate exposed leaf area characterization
enables
enable
enable
GPS
sensing (cameras, 3D laser) and processing algorithms
variable-rate mechanical manipulation
require
in-field commercial-scale proof-of-concept
economic evaluation of feasibility
outreach to growers as ultimate consumers

Vineyard Efficiency through Spatiotemporal Crop load Management







Questions?

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