How leaf removal and dropping fruit affects berry ripening
S. Kaan Kurtural
Sonoma Co. Grape Day 7 February 2019
From the Canopy to Crop Load

- Shoot system of the grapevine:
  - Stems
  - Leaves
  - Clusters

- Collectively: Microclimate
  - 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
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
Berry growth development

Illustration by Jordan Koutroumanidis, Winetitles
EVOLUTION OF GRAPE COMPOSITION AT OAKVILLE, CA

1. **Berry Mass (g)**
   - Dates: 7/11 7/21 7/31 8/10 8/20 8/30 9/09 9/19
   - Values: 0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4

2. **Berry Size**
   - Dates: 7/15 7/25 8/04 8/14 8/24 9/03 9/13
   - Values: 0 5 10 15 20 25

3. **°Brix**
   - Dates: 7/11 7/21 7/31 8/10 8/20 8/30 9/09 9/19
   - Values: 0 5 10 15 20

4. **TSS (°Bx)**
   - Dates: 7/01 7/11 7/21 7/31 8/10 8/20 8/30 9/09
   - Values: 0 5 10 15 20

5. **Total Anthocyanins (mg g⁻¹ BFM)**
   - Values: 0 0.5 1.0 1.5

6. **Total Proanthocyanidins (mg g⁻¹ BFM)**
   - Values: 0 2 4 6 8

7. **Total Proanthocyanidins (…AND OTHER PHENOLICS)**
   - Values: 0 2 4 6 8

8. **Astringency/Bitterness**
   - Values: 0 2 4 6 8

9. **Acidity**
   - Dates: 7/15 7/25 8/04 8/14 8/24 9/03 9/13
   - Values: 0 5 10 15 20
RELATIONSHIP BETWEEN TSS AND COLOR

SHRIVELING VS RIPENING IN C. SAUVIGNON

Martinez et al. 2018
Anthocyanin loss during “hang time” in three plots

### Central Valley

<table>
<thead>
<tr>
<th>TSS (°Brix)</th>
<th>mg Anthocyanins g⁻¹ BFM</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>1.9</td>
</tr>
<tr>
<td>20</td>
<td>0.95</td>
</tr>
<tr>
<td>25</td>
<td></td>
</tr>
</tbody>
</table>

### Napa

<table>
<thead>
<tr>
<th>TSS (°Brix)</th>
<th>mg Anthocyanins g⁻¹ BFM</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>1.6</td>
</tr>
<tr>
<td>20</td>
<td>1.33</td>
</tr>
<tr>
<td>25</td>
<td>1.47</td>
</tr>
</tbody>
</table>

### Sonoma

<table>
<thead>
<tr>
<th>TSS (°Brix)</th>
<th>mg Anthocyanins g⁻¹ BFM</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>2.38</td>
</tr>
<tr>
<td>20</td>
<td>2.15</td>
</tr>
<tr>
<td>25</td>
<td></td>
</tr>
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</table>

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<table>
<thead>
<tr>
<th></th>
<th>Plot 1</th>
<th>Plot 2</th>
<th>Plot 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw data</td>
<td>50%</td>
<td>8.1%</td>
<td>9.6%</td>
</tr>
<tr>
<td>Adjusted</td>
<td>63.1%</td>
<td>16.9%</td>
<td>24.4%</td>
</tr>
</tbody>
</table>

Martinez et al. 2018
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 warm climates
Effects of Solar Radiation on Fixing Carbon by A Grapevine

ROLE OF CANOPIES: To fix Carbon – Make Sugar!

$R^2=0.9729$  
p<0.001

More leaves  
Less leaves

LEAVES: SOURCE

PHOTOASSIMILATES  
(MAINLY SUGARS)

FRUIT: SINK

ROOTS: SOURCE AND SINK

Martinez-Luscher et al., 2015 Plant Science
EXPOSURE TO SOLAR RADIATION IS NOT NECESSARY TO REACH MAXIMUM SKIN ANTHOCYANINS

Martínez-Lüscher et al., 2019

<table>
<thead>
<tr>
<th>Treatment</th>
<th>0 DAC</th>
<th>60DAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>2% Sucrose</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>4% Sucrose</td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>8% Sucrose</td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
<tr>
<td>12% Sucrose</td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
</tr>
<tr>
<td>16% Sucrose</td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
</tr>
</tbody>
</table>
Sugar influx kick starts anthocyanin production
ROLE OF CANOPIES:
Regulation - synthesis of ABA precursors
(ripening signal)

- Deficit irrigation
- Leaf removal

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Ren et al., 2007 J. Exp. Bot.
How do photoassimilates travel within the plant?

Table IV. Total Carbohydrate Content of 4-Year-Old Trunk Girdled and Control Thompson Seedless Grapevines

<table>
<thead>
<tr>
<th>Vine Organ</th>
<th>June 3</th>
<th></th>
<th>June 18</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Girdled</td>
<td>Control</td>
<td>Girdled</td>
<td></td>
</tr>
<tr>
<td>Clusters</td>
<td>39</td>
<td>61</td>
<td>128 a</td>
<td>236 b</td>
<td></td>
</tr>
<tr>
<td>Leaves</td>
<td>78 a</td>
<td>219 b</td>
<td>84</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>Stems</td>
<td>61</td>
<td>82</td>
<td>65</td>
<td>106</td>
<td></td>
</tr>
<tr>
<td>Canes</td>
<td>22</td>
<td>43</td>
<td>26</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>Trunk</td>
<td>79</td>
<td>70</td>
<td>84</td>
<td>77</td>
<td></td>
</tr>
<tr>
<td>Roots</td>
<td>197</td>
<td>105</td>
<td>261 a</td>
<td>157 b</td>
<td></td>
</tr>
<tr>
<td>Vine total</td>
<td>476</td>
<td>580</td>
<td>648</td>
<td>742</td>
<td></td>
</tr>
</tbody>
</table>

Roper and Williams, 1989 Plant Phys.
Leaf area:Fruit Ratio or Ravaz Index: INTERCHANGEABLE

Kliwer and Dokoozlian, 2005 AJEV; Bravdo et al., 1984 and 1985 AJEV
YIELDS IN WINE GRAPE

LETS DROP LESS FRUIT...
...NOT SO SIMPLE


THERE IS AN APPARENT TRADE OFF BETWEEN YIELDS AND QUALITY

<table>
<thead>
<tr>
<th>District X</th>
<th>District Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,300,000 tons</td>
<td>140,000 tons</td>
</tr>
<tr>
<td>$380M</td>
<td>$683M</td>
</tr>
<tr>
<td>$300 a ton</td>
<td>$5000 a ton</td>
</tr>
<tr>
<td>77,000 Acres</td>
<td>45,000 Acres</td>
</tr>
<tr>
<td>16 tons/acre</td>
<td>3.1 tons/acre</td>
</tr>
<tr>
<td>5000 $/acre</td>
<td>15,300 $/acre</td>
</tr>
<tr>
<td>600 Vines/acre</td>
<td>800 Vines/acre</td>
</tr>
</tbody>
</table>

Source: Grape Crush report (Approximate data)
Wine Grape quality is an extremely complex topic:

• Subjective

• Gradually changing

• Hundreds of chemical compounds, hard to measure and hard to give a relative importance to each

• Aspects not related to grape quality determining wine price: Market niche and how much invested in winemaking

...Nobody likes sour grapes
Vintage failure is strongly associated to reaching a certain sugar level.

Source: Bordeaux Vintage quality
NOAA: Bordeaux Airport meteorological station
Reanalyzed from Jones and Davies 2010 AJEV
Although temperature is key for sugar. Harvest precocity can be also based on sudden events that force the decision of picking.
The planet is getting warmer
…and so are Viticulture regions

Napa, CA
Temperature

Growing degree days

1°C = 1.9°F
Experimental Design

Pre treatment: laterals removed and vines adjusted to 22 shoots per vine in 6m

<table>
<thead>
<tr>
<th>33% of fruit kept</th>
<th>66% of fruit kept</th>
<th>100%: ~45 clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>33%: of leaves kept</td>
<td>66% of leaves kept</td>
<td>100% of leaves kept</td>
</tr>
<tr>
<td><img src="image1" alt="33% leaves" /></td>
<td><img src="image2" alt="66% leaves" /></td>
<td><img src="image3" alt="100% leaves" /></td>
</tr>
</tbody>
</table>

Oakville 2018 – CS on 110R – 10 years old – 2m by 2.4 m – Relaxed VSP
Peppercorn size
Laterals removed in all vines

33% of fruit
33%: 2/3 of leaves removed

100% of fruit
100% of leaves
(only laterals removed)
Treatment application

33% of fruit
33%: 2/3 of leaves removed

100% of fruit (no secondary)
100% of leaves
(only laterals removed)
Leaf area determines carbon fixation: NOT FRUIT

A_{net} (\mu \text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1})

Main effects in Two-way ANOVA (post hoc)

Effect of defoliation

Effect of crop load

Only extreme treatments plotted
Leaf area determines plant water status: NOT FRUIT

Effect of crop load

Combination treatments

Main effects in Two-way ANOVA

Effect of defoliation

Only extreme treatments plotted

**Stoma open**

- Stoma
- Nucleus
- Chloroplasts
- Vacuole
- Guard cell
- Cell wall

**Stoma closed**

- 100% Leaves – 100% Fruit
- 100% Leaves – 33% Fruit
- 33% Leaves – 100% Fruit
- 33% Leaves – 33% Fruit
Leaf area determines plant reserves: NOT FRUIT

Main effects in Two-way ANOVA
Effect of defoliation

Effect of crop load

100% Leaves – 100% Fruit
100% Leaves – 33% Fruit
33% Leaves – 100% Fruit
33% Leaves – 33% Fruit
Leaf area:fruit determines speed of ripening

Main effects in Two-way ANOVA
Effect of defoliation

Effect of crop load

Only extreme treatments plotted
Time to reach a desired Brix: Determined by Leaf area:Fruit Ratio

- $R^2 = 0.007$
- $R^2 = 0.445$
- $R^2 = 0.505$
Self adjustment of yields due to “carbon starvation”

Small canopy $\rightarrow$ lower yield
Berry size determined by leaf area: NOT FRUIT!

Only extreme treatments plotted

% of leaves had an effect on berry size
Berry size is determined by leaf area: NOT FRUIT

Mechanical pruning leads to smaller berries…sink competition?
Yield comparison between vintages?

- Is this a reliable yardstick?
- There is 1.6x amount of yield in 2018
Yield comparison between vintages? Is it a reliable ‘Yardstick’

2017

- $P_{(\text{leaf})} < 0.001$
- $P_{(\text{fruit})} < 0.001$
- $P_{(\text{leaf} \times \text{fruit})} = 0.056$

2018

- $P_{(\text{leaf})} < 0.001$
- $P_{(\text{fruit})} < 0.001$
- $P_{(\text{leaf} \times \text{fruit})} = 0.08$

Yield comparison between vintages:
- 2017:
  - 100% of leaves
  - 66% of leaves
  - 33% of leaves
- 2018:
  - 100% of leaves
  - 66% of leaves
  - 33% of leaves
Although yields were different. Leaf area to fruit ratio was maintained.

2017

Leaf area/Yield (m²/kg)

P_{(leaf)} < 0.001  P_{(fruit)} < 0.001  P_{(leaf x fruit)} = 0.047

100% of fruit
66% of fruit
33% of fruit

2018

Leaf area to fruit (m² Kg⁻¹)

P_{(leaf)} < 0.001  P_{(fruit)} < 0.001  P_{(leaf x fruit)} = 0.02

1.23~5 Ravaz
0.65~10 Ravaz

Although yields were different. Leaf area to fruit ratio was maintained.

100% of leaves
66% of leaves
33% of leaves
100% of leaves 66% of leaves 33% of leaves

TSS (°Brix)

Soluble solids on 9/13/2017

100% of fruit
66% of fruit
33% of fruit

Soluble solids on 9/24/2018

$P(\text{leaf}) < 0.001 \quad P(\text{fruit}) < 0.001 \quad P(\text{leaf} \times \text{fruit}) = 0.96$
CLUSTER/BERRY THINNING DOES NOT IMPROVE ANTHOCYANIN CONTENT IN CABERNET SAUVIGNON

Total Anthocyanins (mg g Berry$^{-1}$)

- 100% of fruit
- 66% of fruit
- 33% of fruit
- Untreated

$P_{\text{leaf}} = 0.009$

$P_{\text{fruit}} < 0.001$

$P_{\text{leaf x fruit}} = 0.921$

Untrt 100%F 66%F 33%F

Untrt 100%L 66%L 33%L

A AB

B B

CBC

CLUSTER/BERRY THINNING DOES NOT IMPROVE ANTHOCYANIN CONTENT IN CABERNET SAUVIGNON
CLUSTER THINNING INTRODUCES MORE RADIATION INTO FRUIT ZONE
EFFECT ON SKIN PROANTHOCYANIDIN CONTENT (2017)

Skin Proanthocyanidins (mg g⁻¹ Berry)

- 100% of fruit
- 66% of fruit
- 33% of fruit
- Untreated

$P_{(leaf)} = 0.014$

$P_{(fruit)} = 0.196$

$P_{(leaf \times fruit)} = 0.671$
LEAF REMOVAL DECREASES, FRUIT REMOVAL INCREASES TANNIN CONTENT

Seed + Skin Proanthocyanidins (mg per Berry)

- 100% of fruit
- 66% of fruit
- 33% of fruit
- Untreated

- Untreated
- 100% of leaves
- 66% of leaves
- 33% of leaves

P(leaf) < 0.001
P(fruit) = 0.0347
P(leaf x fruit) = 0.901

LEAF REMOVAL DECREASES, FRUIT REMOVAL INCREASES TANNIN CONTENT
Canopy size and shape

Plant reduced carbon pool

Berry size

Berry enlargement/Sugar allocation

Water deficit

Crop load control

Ripening (SS accumulation)

ABA precursors

Other ripe grape traits
Polyphenols, flavor…
Main take home messages

Berry size (and thus yield) are more sensitive to canopy size more than crop load or irrigation

Small canopies are more likely reducing plant reserves (root starch) than over cropping

Challenge for increasing yields is controlling big canopies in EARLY SEASON
Main take home messages

Berry size (and thus yield) are more sensitive to canopy size more than crop load or irrigation

Small canopies are more likely reducing plant reserves (root starch) than over cropping

Challenge for increasing yields is controlling big canopies
Climate may be on our side…for now

Perspectives…
Heat...the more the better?

Polyphenols in danger

Sugar
Alcohol

Acidity
What if it gets warmer?

- Addition of water and tartaric
- Shade nets (kaolin applications did not work for us)
- Breeding efforts for low sugar (INRA and University Montpellier): 135-150 g/L at ripe stage (max berry vol.)
- IPCC projections:
  - 77% increase of surface burned annually by the end of the century

Can you breed a variety to produce cold weather wine in hot climate?

Source: cal-adapt.org
Typical grapevine trellis -> Fruit zone

Exposure – Good to induce ripening (remove herbal characters)

Over exposure – Grapes can take a lot but at some point damage appears
Shift towards positioned and sprawling systems

The UCDavis30 Trellis
Kinetic development of total anthocyanin concentration

Date
24 July 3 August 17 August 1 September 12 September

Total anthocyanin mg/g berry FM
0.0 0.5 1.0 1.5 2.0 2.5 3.0

25% ETc
50% ETc
100% ETc

24 July 3 August 17 August 1 September 12 September

Total anthocyanin mg/g berry FM
0.0 0.5 1.0 1.5 2.0 2.5 3.0

Control
Pre-bloom
Post fruit-set

Date 0.0001
Irrigation 0.001
LR NS
LR x IR NS
Kinetic development of total flavonol content

Date 0.0001
Irrigation NS
LR 0.003
LR x IR NS

Total flavonols mg/berry

100% ETc
50% ETc
25% ETc

Control
Pre-bloom
Post fruit-set

UC DAVIS
Applied water amounts

Water deficits

**INDIRECT EFFECT**
- ↓ Berry mass
- ↑ Ratio of skin to pulp

**DIRECT EFFECT**
- Stimulation of anthocyanin biosynthesis ↔ Gene activation
  - 3OH forms of anthocyanins are favored

**CONCENTRATION**
- ↑ Concentration of ANTHOCYANINS
- ↑ Concentration en FLAVONOLS

**FLAVONOL biosynthesis**
- ↑ FLAVONOL biosynthesis

**MINOR EFFECT**
- Minor effect on Proanthocyanidins

**SEVERITY**

**TIME AND DURATION**
Leaf Removal (Early or Late)

↑ Solar radiation exposure of berry

Excessive temperature (> 37°C berry temperature)

Light and temperature

Adaptive mechanism

Impact of light

Biosynthesis of anthocyanins

↑ Berry skin mass

↑ LAR and BAN

ANTHOCYANINS

↑ Anthocyanin degradation

COLOR STABILITY in RED WINE

FLA VONOLS

↑ PROANTHOCYANIDINS

ASTRINGENCY

Canopy manipulation
Thanks for your attention!

- Johann Martinez PhD
- Luca Brillante, PhD
- Christopher Chen
- Runze “Cliff” Yu
- Cassandra Plank, PhD
- Marshall Pierce
- Constance Cunty
- Andrew Bebee
- August D’Amato
- Wei-Chao Cheng
- Katie Rouse
- Longjiao Zhang
- Vincenzo Messana

Research funded by

For more information: skkurtural@ucdavis.edu

Department of Viticulture and Enology
Experiment 1: Colored Shade Net Trial

- Control: Uncovered
- 20% shading factor – White
- 40% Shading factor - Black
- 40% Shading factor – Blue
- 40% Shading factor - Aluminet

n=4 (3 vines per rep)
Cabernet Sauvignon on VSP
Oakville (Napa)
NE to SW row orientation
Fruit-Zone Light Conditions

- Spectral radiation wavelengths in the fruiting zone
  - Quantified using a spectrometer with a cosine-corrected head for net treatments, controls, and in an open field at solar noon (~15:00 h PDT).

- Total Irradiance (Fig. a)
  - The sum of direct and diffuse irradiance ($\mu$mol m$^{-2}$ s$^{-1}$)
  - Shows that shade nets worked particularly well in reducing irradiance from within the visible range (410-700 nm).
    - Reduction of up to 60% of irradiance
    - Infrared wavelengths (>700 nm) were reduced greatly as well.

- Diffuse Irradiance (Fig. b)
  - Although diffuse radiation makes up <20% of the total radiation received in the fruit-zone, it contributes.
  - Diffuse irradiance was mostly modulated by the canopy itself, with nets having little influence outside of the visible range.

- Direct Irradiance (Fig. c)
  - Making up the majority of radiation the fruit zone receives, direct irradiance was drastically reduced by the application of a shade net.
  - Few differences were observed between controls and an open field, save for the decrease in green, yellow, and orange wavelengths. Possibly due to leaf interference.
Results

- Blue nets with 40% shading factor exhibited preferential exclusion.
- Other nets were fairly consistent in shading across the spectrum.
- Black nets had the greatest exclusion of solar radiation in the fruit zone.

**Period of direct solar radiation exposure**

During the period of direct solar radiation exposure, there were differences in the degradation rate of flavonols in Black-40 compared to the control. Black-40 had less accumulation of flavonols than the control, but the degradation rate was also slower. This was due to the hydroxylation profile of anthocyanins and flavonols of berries under Black-40 shade nets having higher, relative 3’,4’,5’OH substituents. This increased stability of tri-hydroxylated flavonoids, preventing rapid degradation; modulated by partial shading.

Hydroxylation profile of anthocyanins and flavonols of berries under Black-40 shade nets had higher, relative 3’,4’,5’OH substituents. Comes down to stability of tri-hydroxylated flavonoids, preventing rapid degradation; modulated by partial shading.

Black-40 decreased pH and increased TA at harvest.
## Conclusions

<table>
<thead>
<tr>
<th>Partial solar radiation exclusion</th>
<th>Uncovered</th>
<th>Black 40%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield (kg/vine)</td>
<td>No influence</td>
<td>No influence</td>
</tr>
<tr>
<td>Berry mass (g)</td>
<td>No influence</td>
<td>No influence</td>
</tr>
<tr>
<td>Berry temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSS (Brix)</td>
<td>No influence</td>
<td>No influence</td>
</tr>
<tr>
<td>TA (g/L)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Σ Anthocyanins</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anthocyanin 3’4’5’ hydroxylase forms</td>
<td>↓</td>
<td>↑</td>
</tr>
<tr>
<td>Σ flavonols</td>
<td>No influence</td>
<td>No influence</td>
</tr>
<tr>
<td>Flavonol 3’4’5’ hydroxylase forms</td>
<td>↓</td>
<td>↑</td>
</tr>
</tbody>
</table>

**Primary and secondary metabolism response to partial solar radiation exclusion**
Cluster Temperatures

Diurnal Cluster temperature evolution were measured using a portable infrared thermometer on both sides of the canopy on two dates (a) July-29-East; (b) July-29-West; (c) Sep-11-East; (d) Sep-11-West

- Shade nets appear to mitigate cluster temperature accumulation when solar radiation is directly on the cluster.
- Particularly on the western side of the canopy (Fig. b and Fig. d)
- Shading reduced berry temperatures by 3-4°C
Key finding: Ripe Fruit in SW side reaches 53°C...with shade nets 48°C
Visible Damage

Using a rating system we visually assessed damage to whole clusters attributed to excess exposure:
- 0 = No damage
- 1 = Minor damage
- 2 = Moderate damage
- 3 = Extreme damage

The data were recorded as percentage of damaged clusters at harvest.

- Shade nets greatly reduced incidence of visible damage in clusters
- Applied water amounts had no effect on visible damage in clusters
- We attribute the response of berries to partial shading to reductions in high energy wavelengths that confer heat to the berries; greatly reducing damages.

Using a rating system we visually assessed damage to whole clusters attributed to excess exposure:

- 0 = No damage
- 1 = Minor damage
- 2 = Moderate damage
- 3 = Extreme damage

The damage ratings and percent of clusters are shown in the table below.

<table>
<thead>
<tr>
<th>Damage Rating</th>
<th>0</th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent of Clusters</td>
<td>0</td>
<td>20</td>
<td>40</td>
<td>60</td>
</tr>
</tbody>
</table>

- **40% Shade**
  - O: 40% Shade
  - Damage Rating: 1
  - Percent of Clusters: 40%

- **Control**
  - O: Control
  - Damage Rating: 3
  - Percent of Clusters: 100%

- **1.3 ETc**
  - O: 1.3 ETc
  - Damage Rating: 2
  - Percent of Clusters: 65%

- **0.65 ETc**
  - O: 0.65 ETc
  - Damage Rating: 1
  - Percent of Clusters: 35%
## Conclusions

<table>
<thead>
<tr>
<th>Partial solar radiation exclusion</th>
<th>Uncovered</th>
<th>Black 40%</th>
<th>1.3 ETc</th>
<th>0.65 ETc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damaged clusters (%)</td>
<td></td>
<td></td>
<td>No influence</td>
<td>No influence</td>
</tr>
<tr>
<td>Berry mass (g)</td>
<td>No influence</td>
<td>No influence</td>
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Conclusions

• Climate is changing
  • Napa has increased annual, accumulated GDDs over past five decades
  • More frequent and intense heat spikes.

• Light (solar radiation) is not limiting in California
  • Damage occurs at low PAR exposure >20% of light intercepted in the fruit zone (Brillante et al. 2017; Cook et al. 2015; Dokoozlian & Kliewer, 1994; Martinez et al. 2017; Yu et al. 2016)

• Greater applied water amounts do not relieve stress from solar radiation

• Shade nets can be used to decrease incidence of solar radiation in fruit zones
  • Decreases in visible damage associated with shade net application

• Shade nets modulate the anthocyanin and flavonol profiles favoring lower rates of flavonoid degradation and higher, relative 3’4’5’-hydroxylated substituents.

• Shade nets can be considered a short-term response to increasing temperatures