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Research News from Cornell's Viticulture and Enology Program Research Focus 2019-2

Research Focus

How Radical Manipulation of Sources and Sinks Affected Riesling Yield, Bud Hardiness, and Return Crop

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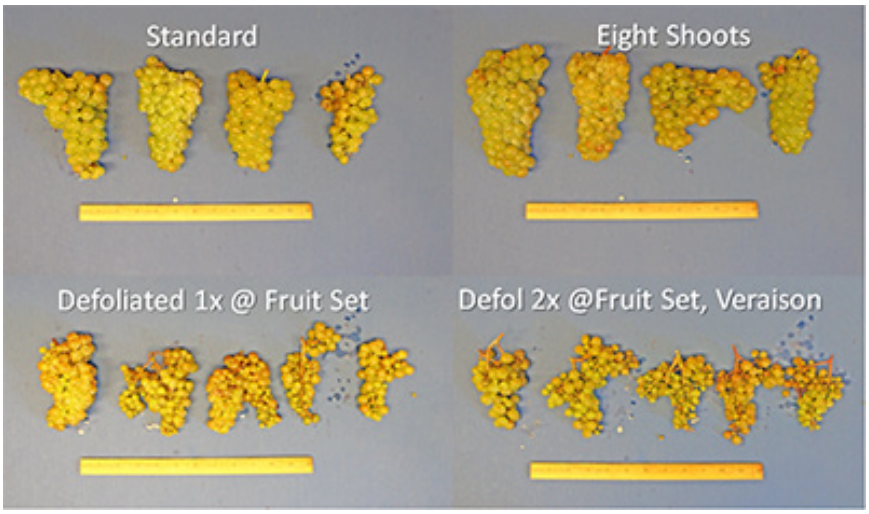


Riesling clusters harvested from standard vines (4 flat canes, 24 shoots per vine), compared to vines shoot-thinned to 8 shoots, vines defoliated once at fruit set (July 6), and vines defoliated twice (at fruit set and veraison, August 24).

In a two-year experiment, we defoliated, defruited, or severely limited shoot number in Riesling vines to radically alter leaf area to fruit ratios. We measured how these practices affected yield and yield components, fruit composition, shoot lengths and pruning weights, bud hardiness, and return crop. Defoliating vines either once (at fruit set) or twice (at fruit set and veraison) reduced berry size and yield by >50%, but fruit composition was only affected by the twice-defoliated treatment. Defruiting increased vine pruning weight by 20%. Reducing shoot number by 2/3 reduced the crop and pruning weight, but increased fruit set by 30% and increased cane length by 39%. Bud hardiness was significantly reduced only in the twice-defoliated treatment – which most of the buds died in midwinter. In 2018, clusters per vine and clusters per shoot were reduced by 40% in only the once defoliated vines.

Key Concepts

- Carbon assimilated by leaves (sources) gets allocated to shoot tips, clusters, storage in roots and canes (sinks) to support vine growth, fruit production and cold tolerance.
- We radically altered sources and sinks on mature Riesling vines in 2017 by severe pruning, defruiting, and defoliating them at fruit set or fruit set and veraison.
- Shoot-limited vines produced larger clusters and longer but fewer canes.
- Defruited vines produced 20% higher pruning weights than standard vines.
- Vines defoliated early set smaller berries, but regrew their canopy and ripened normally.
- Vines defoliated twice failed to ripen, buds were less hardy, and most didn't survive the winter.
- Bud hardiness was significantly reduced only in the twice-defoliated vines.
- Vines defoliated at fruit set had many fruitless buds and significant carryover effects.
- Defruited vines set more clusters in 2018; fruit composition in all treatments was equivalent at harvest.

Background. Crop load, or the ratio of leaf area to fruit, is a basic measure underlying viticultural theory and grower practice. Balancing vegetative growth with fruit growth to optimize yield and quality is the (often elusive) goal. In physiological terms, the goal is to balance carbon assimilation *sources* (exposed leaf area) with carbon *sinks* (shoot tips, roots, but most importantly the crop).

As vineyard managers, we want carbohydrates produced by leaves to be allocated in the right relative amounts to canopy growth, fruit development, and replenishing vine reserves to make it through the winter and support early season growth the following season. We do this by limiting the number of buds through pruning, the density of shoots through shoot thinning and shoot positioning, the vine's leaf area through summer hedging and cluster-zone leaf removal, and the crop size by cluster thinning.

Experimental treatments. What happens when we take these practices to extremes by severely limiting leaf area (sources) or removing all the fruit (sinks)? In 2017, we established five different treatments to find out. All vines started out as cane-pruned VSP vines, pruned to 4 ten-bud canes, tied flat to two offset midwire fruiting wires. After bud burst the following practices were applied:

- **Standard.** We thinned the shoots to a standard 24 shoots per vine, or approximately 6 per foot of canopy. Shoots were vertically positioned with catch wires, but wrapped around the high wire and not hedged or shoot-tipped. *(Balanced cropping)*
- **Eight Shoot.** We thinned these vines to 8 shoots instead of 24 shoots. *(Source and sink-limited, undercropped due to severe pruning).*
- **Defruited.** We thinned shoots to 24 shoots/vine and removed clusters at fruit set *(Sink-limited, no crop)*
- **Defoliated 1x.** We removed all leaves at fruit set, but retained the leaf at the shoot-tip. *(Source-limited, overcropped)*
- **Defoliated 2x.** We defoliated at fruit set and again at veraison. *(Source-limited, overcropped)*

There were 24 replicate vines for the standard, 8-shoot, and defruited treatments, and 12 for each of the defoliation treatments.

Figure 1. Schematic of five treatments applied in 2017.

We measured yield and yield components (cluster and berry weight, berry number), pruning weights and individual cane lengths and weights, and bud freezing temperatures (LTEs) at 2 wk intervals during the dormant season. To look at carryover effects from 2017 treatments, in 2018 we again pruned all vines to 4 canes, and adjusted shoot number to the 'standard' 24 shoots per vine. No further differential treatments were applied. We counted shoot and cluster numbers in early June 2018. At the end of the season we measured yield, cluster number and berry weight. We determined pruning weights during the winter of 2018-2019.

Defoliation treatments. Early defoliation at fruit set (July 7) on 24 vines was accomplished by removing all leaves except the terminal leaf and shoot tip. Shoot growth continued, and by August 24, defoliated vines had produced another 10-20 leaves per shoot – essentially producing a second canopy. We selected 12 vines, and again defoliated them by cutting the shoots off at nodes 12-14. We retained the pruned wood to let it dry and weigh it as part of the total pruning weight.

Expected responses. We expected the treatments to affect yield, maturity, and vine growth. But we were even more interested in how extreme source/sink manipulations would affect bud hardiness, winter survival, and the return crop in 2018. Grower experience suggests that both

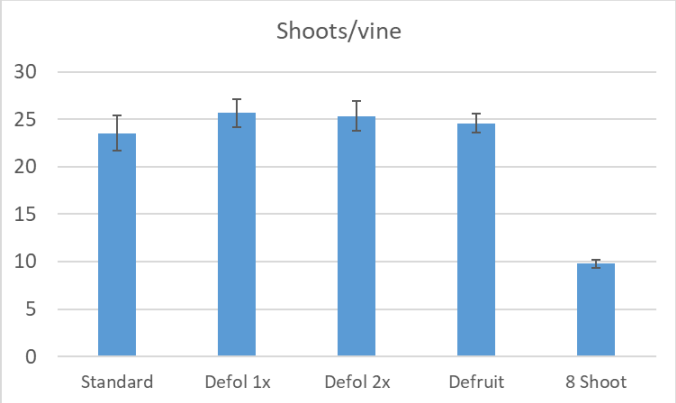
Figure 2. Vine after first defoliation on July 7 (left) with terminal leaf retained on each shoot. By veraison (August 24) regrowth had 'replaced' the canopy (center). For the second defoliation on August 24, shoots were trimmed at the 12th-14th node (right). Pruned wood was retained and weighed.

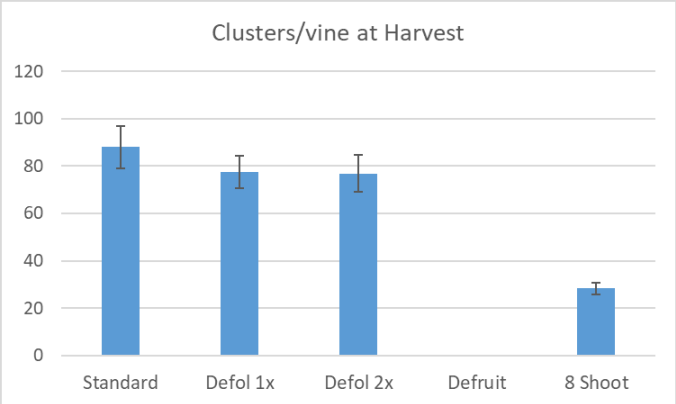
overcropping (high fruit to leaf area ratio) and undercropping (low fruit to leaf area ratio) would result in reduced bud hardiness, higher bud mortality, and reduced return crop, while undercropping by defruiting or severe pruning (8 buds) would result in excess shoot vigor and large 'bull canes' that would be less winter-hardy.

Results. The figures that follow will walk you through how the treatments affected the 2017 crop, vine growth, bud hardiness, and the carryover effects we observed in the 2018 cropping season.

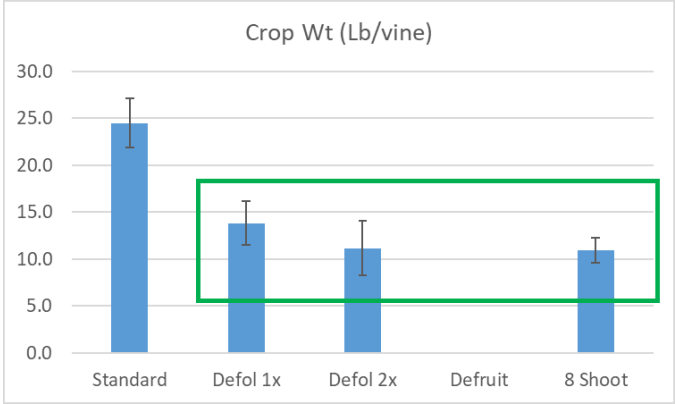
Note: For most figures, error bars encompass +- 2 SEM, roughly equivalent to 95% confidence interval. Non-overlapping error bars indicate statistically different means at the α<0.05 level. Where letters are shown, means with different letters are statistically different at the α<0.05 level.

1. Shoot and cluster number. All treatments except the 8-shoot treatment had 23-25 shoots per vine (left); 8-shoot vines had approximately one-third (32%) as many clusters per vine, while the defoliated treatments had ~90% as many clusters as the standard treatment.

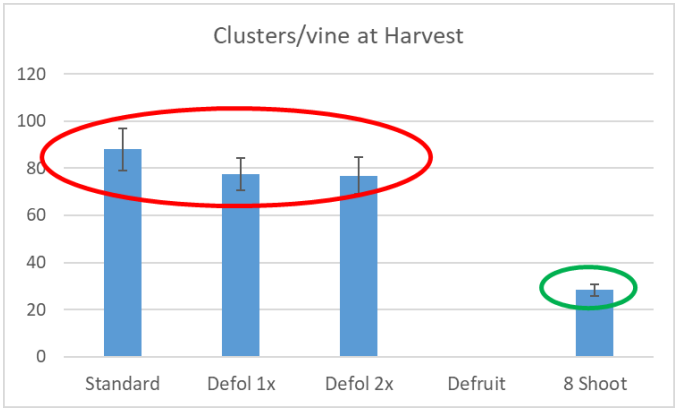




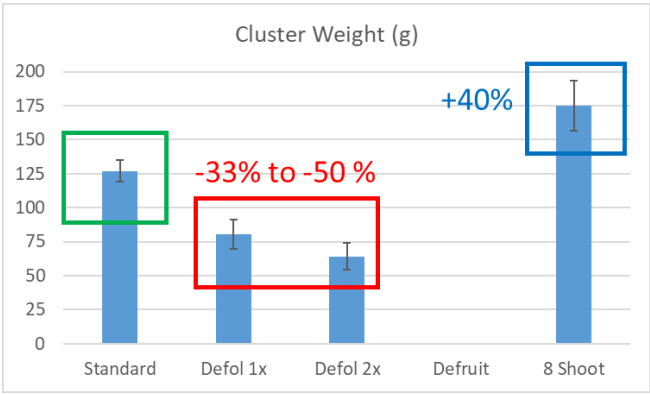
2. Yield and Yield components. Standard vines produced 24 lb (10.9 Kg) of fruit per vine – equivalent to 9.7 T/acre (20.2 Tonnes/Ha) in 2017. Yield was reduced by about one half in defoliated 1x and 2x, and 8-shoot vines, with crop weight ranging from 11-13 lb/vine (5-5.9 Kg/vine) or roughly ~4-5.2 T/acre (9.9-12.8 Tonnes/Ha). However, the yield reduction was associated with different yield components.



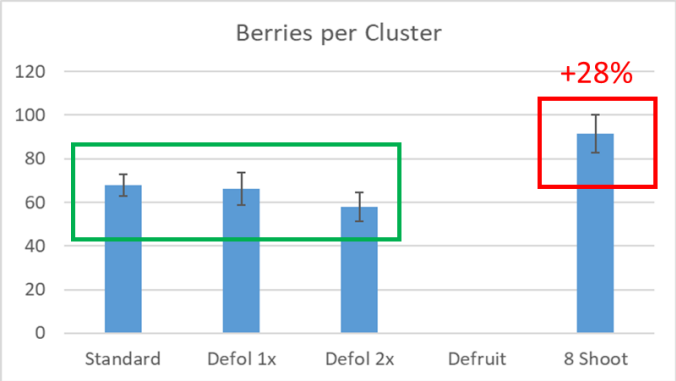
- *Cluster number.* As expected, the standard, Defol-1x and defol 2x treatments had similar number of clusters (78-83/vine) at harvest, while the 8-shoot treatment had ~25/vine – a 70% reduction from the standard treatment.



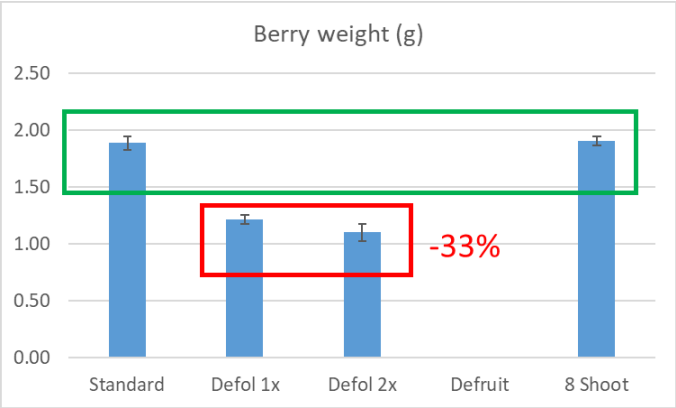
- *Cluster weight.* Defoliation at fruit set reduced cluster weight by 33%, and the second-defoliation at veraison further reduced cluster weight by 50% from the standard. Eight-shoot clusters were 40% larger than standard clusters.



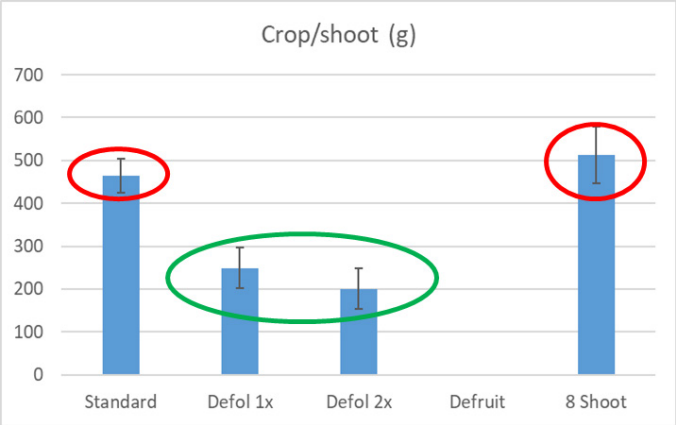
- *Berry number:* The standard and two defoliated treatments had similar numbers of berries per cluster. Eight-shoot clusters had 28% more berries than the standard.



- *Berry weight:* Berry weight was dramatically lower (-33%) on both the defoliated treatments – reflecting lack of carbon supply during the 'cell-division' phase of berry growth.

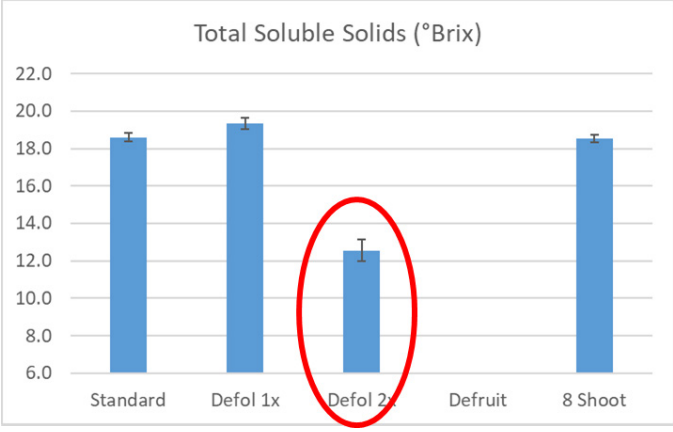


- *Crop per shoot:* On a per-shoot basis, yield per shoot in the eight-shoot vines was equivalent to the standard vines. Defoliation treatments reduced the crop/shoot by about half.

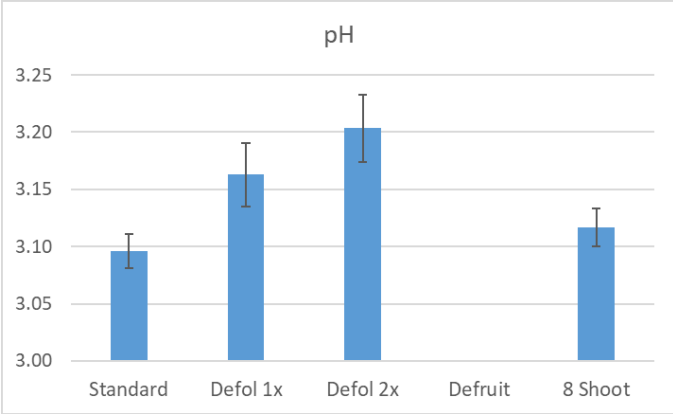


3. Fruit composition.

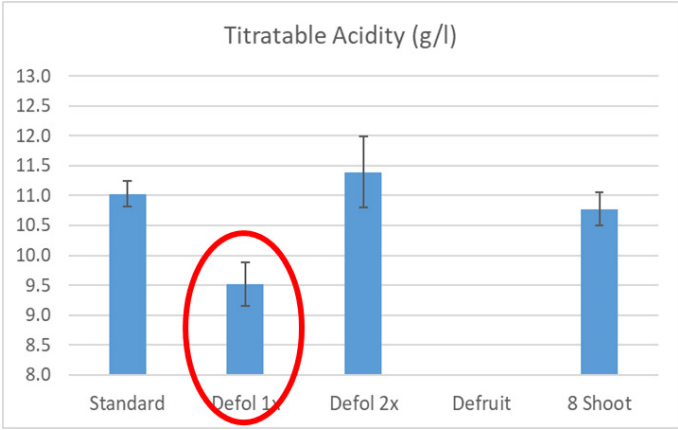
- *Soluble Solids.* At harvest, all treatments except the defoliated 2x treatment reached 18-19° Brix. With no leaf area to support ripening, the defoliated 2x treatment only reached 12° Brix.



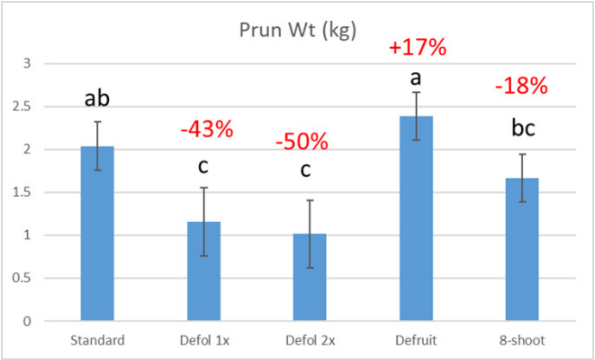
- *Juice pH.* Juice pH was significantly higher than the standard in both the defoliated treatments, likely in response to the increased cluster exposure resulting from defoliation in the cluster zone.

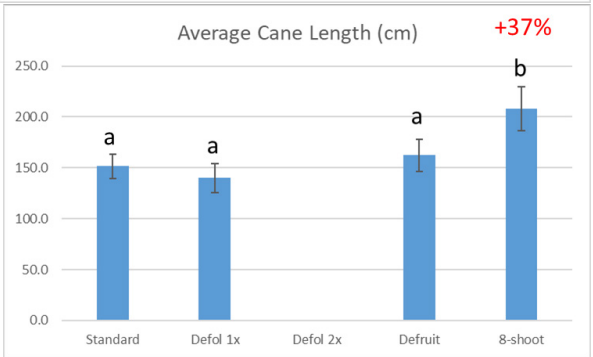


- *Titratable acidity.* The standard, defoliated 2x and 8 shoot treatments had similar levels of titratable acidity (TA) (~10.5-11.5 g/l), but the Defol-1x treatment had significantly lower TA – probably due in part to increased cluster exposure resulting from defoliation at fruit set.

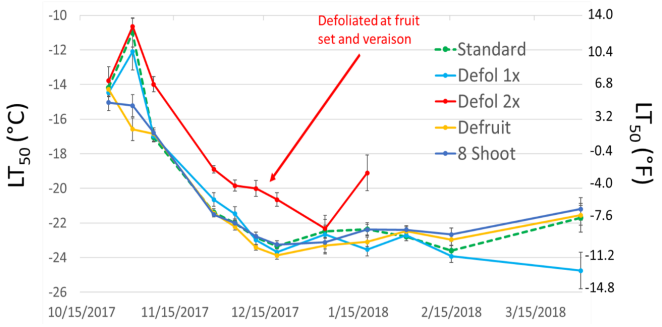


- **4. Pruning weights and cane lengths.** Defoliation treatments reduced pruning weight by 43-50%, defruiting increased it by 17% and reduced it by 18% in the 8-shoot treatment. Average cane length increased by 37% in the 8-cane treatment – but defoliation at fruit set did not reduce cane length compared to standard vines, despite the 43% drop in pruning weight.



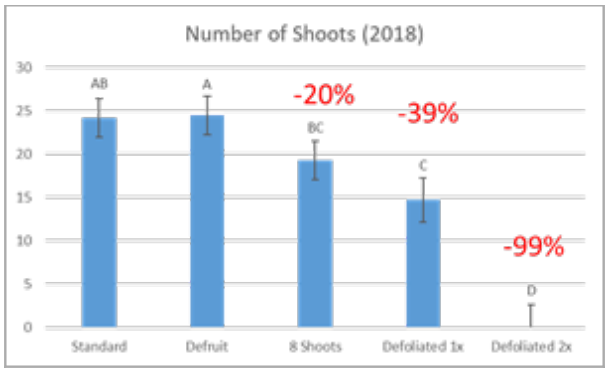


5. Bud freezing temperatures. We used controlled freezing experiments to determine bud freezing temperatures from October 15 to March 23. The only treatment that significantly reduced bud hardiness was defoliating the vines twice (at fruit set and veraison). After initial acclimation, there were no differences in LT_{50} (median bud freezing temperatures) among the defoliated 1x, defruited, and 8-shoot vines , compared to the standard treatment.

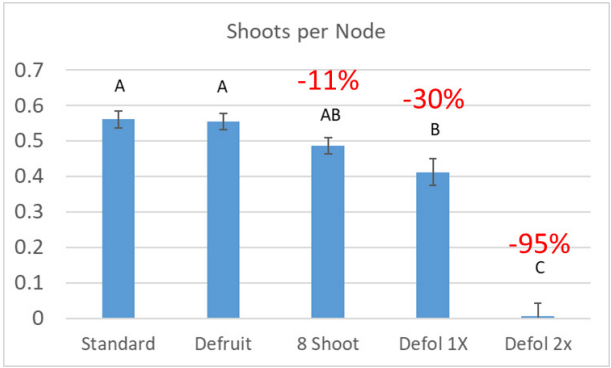


6. Return crop in 2018. After imposing the radical 'source and sink' manipulations in 2017, we went back to standard practices (pruning to 4 flat canes on two midwire fruiting wires) on a subset of the original vines in 2018 to determine carry-over effects.

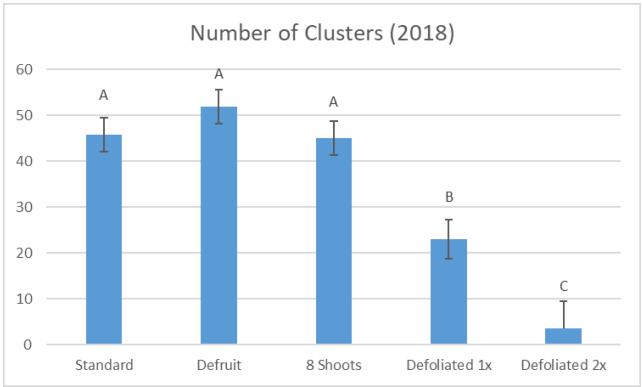
- *Shoots per vine.* Without additional shoot thinning, we ended up with ~24 shoots/vine on the standard and defruited vines. Shoot number was reduced by 20% on the 8-shoot vines, and 39% on the defoliated 1x vines. Most of the twice-defoliated vines were either dead or had 1-2 live shoots.



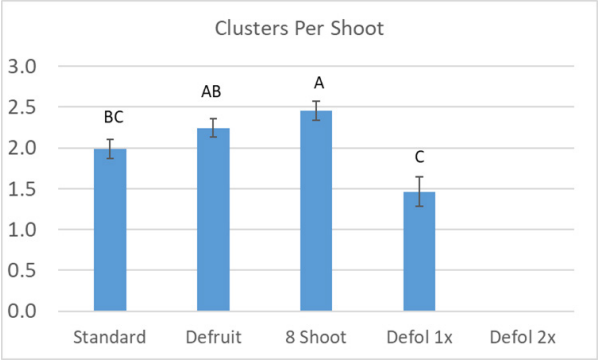
- *Shoots per retained node.* Following the heavy crop, only about 55% of retained buds produced new shoots (eg. 45% were 'blank nodes') even on the standard vines. On a per-retained node basis, the 8-shoot vines had 45% of buds producing a shoot, while the Defol-1x vines had 40% shoots per node.



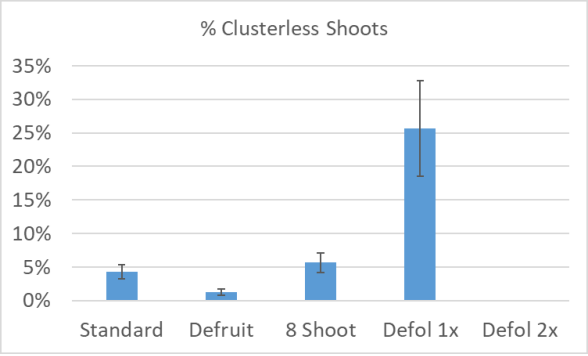
- *Clusters per vine.* Standard and 8-shoot vines produced similar numbers of clusters per vine (~45), while the defruited vines produced slightly more (~51). Because of greater variability, this was not a statistically significant difference. Cluster number on Defol-1x vines was reduced by 60%.



- *Clusters Per Shoot.* The number of clusters per shoot is one measure of bud fruitfulness. Defruited and 8-shoot vines had more clusters per shoot than the Standard treatment, and fruitfulness of the Defol-1x vines was significantly lower. Twice-defoliated vines had no clusters.

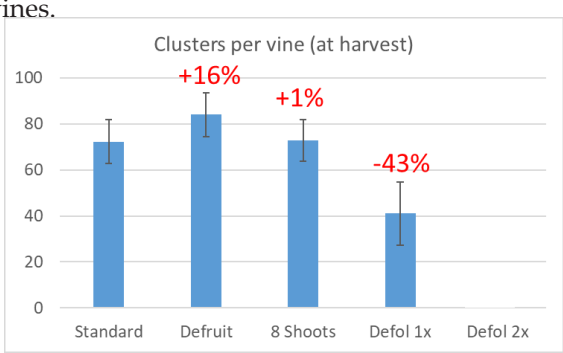


- *Clusterless shoots.* The principal reason for lower fruitfulness in the Defol-1x vine was that they had significantly more clusterless shoots than the other treatments.(25% on average vs 2-5% on standard, defruited, and 8-shoot vines

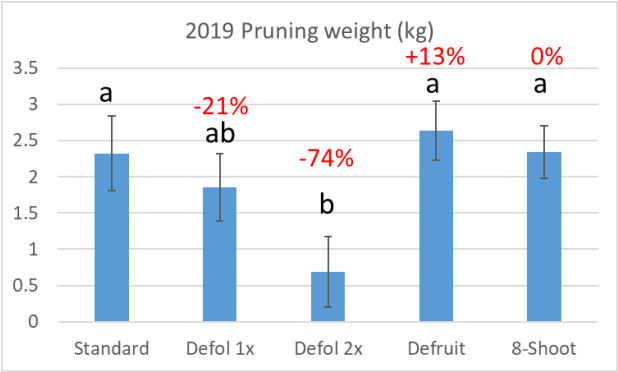


7. Harvest in 2018.

- *Fruit composition.* Brix, TA, and pH (not shown) were identical across all treatments in 2018, regardless of the treatment vines had received in 2017.
- *Clusters at Harvest.* Due to severe sour rot, yield data in 2018 was not reliable enough to share, but the range was 6.6 to 15 lb/vine (3-7 kg/vine) – much lower than in 2017. Cluster counts at harvest, however showed 16% more clusters/vine in the previously defruited vines; similar numbers in the previously 8-shoot vines, and 43% fewer clusters in the previously defoliated 1x vines.



- *Pruning weights in 2019.* Pruning weights after the 2018 crop year were not statistically different, except for the defoliated 2x vines (some of which were dead). However, even after one 'normal' cropping year, average pruning weights were still 21% lower in the Defol-1x treatment than the standard, and vines defruited in 2017 had 13% higher pruning weight following the 2018 growing season.



Practical Significance. The treatments we applied to the experimental vineyard are more extreme versions of common practices growers use to manage vines (pruning intensity, shoot thinning, shoot tipping, cluster-zone leaf removal, cluster thinning) – or simulation of weather or disease that prematurely reduces functional leaf area (early frost, foliar diseases such as downy mildew).

By severely limiting leaf area (sources) or crop and shoot number (sinks), the goal was to learn how vines would respond to these induced stresses which resulted in either functional overcropping (defoliation treatments) or undercropping (8-shoot and defruited treatments). In particular, we wanted to find out how these extremes would affect winter bud hardiness and return crop.

Overall impacts of treatments are summarized in Table 1 (2017 crop) and Table 2 (carryover effects in 2018), presented as percentage change from the standard treatment.

Pruning severity. We took mature vines with relatively high amounts of stored reserves and left roughly one-third of the recommended number of shoots in the 8-shoot treatment. Both leaf area and cluster number were reduced – but early season growth from reserves was channeled into fewer shoots. As a result, the clusters set 30% more berries and grew canes that were 40% longer than standard vines. Pruning weight was reduced by 20%. Carryover effects: Bud hardiness was not reduced, but 11% fewer shoots per retained node emerged in 2018. Production and pruning weights recovered in 2018.

Eliminating the crop. Removing the crop in 2017 (defruited treatment) resulted in a 20% increase in pruning weight at the end of the season. Canes were not longer, but had larger diameters than the standard treatment (think 'bull canes'). Midwinter bud hardiness was not affected by the treatment. In 2018, the vines had more 16% more clusters

per vine (and more per shoot) than the 'standard treatment', and 13% higher pruning weight. Carryover effects of crop elimination resulted in a slightly more fruitful buds, and larger vines in 2018.

Defoliation at fruit set. After removing all leaves except the shoot tips in early July at fruit set, the vines produced a second full canopy by veraison in late August. Source-limitation during early berry development resulted in very small berries – most likely limiting cell division (the primary source of berry growth before the mid-season 'lag phase'). After veraison, however, the berries accumulated sugars, and reduced acid in step with the standard treatment, and ended up with similar fruit composition at harvest.

Bud hardiness was not reduced compared to the standard vines. But leaf removal did limit carbon assimilation, to the point that pruning weights were reduced by 40%, even though cane length was not reduced. *Carryover effects:* In 2018, the shoot number per retained node was reduced by 30%, the cluster number by 50% and the number of clusters per shoot was reduced by one third. Notably, 25% of the shoots had no clusters – compared to 5% in the standard treatment. Starving clusters of photosynthate at fruit set greatly reduced cluster formation in basal-node buds.

Defoliation at fruit set and veraison. After fruit set, the twice-defoliated vines only had significant leaf area from mid-July through late August. Cluster and berry weight was reduced by 50%, and fruit ripened to only 12 °Brix, with significantly higher TA and juice pH than the standard vines. Pruning weight was reduced by 50%. Bud hardiness was significantly reduced, and most buds were dead by late January. Carryover effects were severe: Most vines only had one or two shoots, and over half of them died.

Conclusion. The source of all vine growth is photosynthesis from leaves exposed to sunlight. Carbon assimilated through the leaves is distributed to various tissue 'sinks' at different times in the vine's annual growth cycle to support canopy growth, fruit growth and ripening, and to accumulate reserves to survive dormancy and support early-season vine growth the following year.

Table 1. Percentage change in 2017 yield, yield components and pruning weights of 'sink-limited' and 'source-limited' treatments, compared to the standard treatment

	Sink-Limited		Source-Limited	
Attribute	**Defruited**	**8 Shoot**	**Defol 1x**	**Defol 2x**
Yield 2017	NA	↓ 50%	↓ 50%	↓ 50%
Cluster number	NA	↓ 63%	↔	↔
Cluster weight	NA	↑40%	↓ 33%	↓ 50%
Berry number	NA	↑28%	↔	↔
Berry weight	NA	↔	33%	↓ 33%
Pruning weight	↑20%	↓ 18%	↓ 41%	↓ 51%
Cane length	↔	↑39%	↔	NA

Table 2. Carryover effects on shoot and cluster number, cluster per shoot, and clusters per vine at harvest in 2018, compared to standard treatment .

	Sink-Limited		Source-Limited	
Attribute	**Defruited**	**8 Shoot**	**Defol 1x**	**Defol 2x**
Shoots/Vine	↔	↓ 20%	↓ 40%	↓ 99%
Shoots/Node	↔	↓ 11%	↓ 30%	↓ 95%
Clusters/Vine	↑10%	↔	↓ 50%	↓ 100%
Clusters/Shoot	↑10%	↑20%	↓ 30%	NA
% Clusterless Shoots	2%	5%	25%	NA
Clusters per vine at harvest	↑13%	↔	↓ 43%	NA

Vines that were source-limited through defoliation early in the season (Defol-1x) re-established an active canopy by veraison – and still managed to ripen a (reduced) crop. Vine size was reduced, as was the return crop. But bud hardiness was not compromised, and vines survived the winter – although with much reduced capacity to produce a large crop.

Vines source-limited at fruit set and veraison (Defol-2x), however, did not ripen their crop, showed reduced bud hardiness, and bud death by mid-winter. This underscores the need for active and healthy leaves during the ripening and acclimation period – and suggests that loss of canopy through frost or disease (powdery and downy) will have a relatively greater impact than loss of canopy early in the growing season.

Severe pruning (8-cane vines) reduced both leaf area (source) and fruit (sinks). Doing so greatly increased fruit set and the rate of growth of a reduced number of canes. Recall that these vines started out with a similar level of vine reserves as the standard vines. Overall vine growth was reduced, but buds were more fruitful in the following season, and yield recovered during the following year.

This experiment took place during a growing season with ample moisture, and on a fertile site with large vines. We departed from grower practice by 'wrapping and tucking' shoots, rather than summer hedging. As a result, some shoots developed several laterals with up to 10-12 nodes – and the 'standard' vines were on the larger end (2+kg/vine or 4-5 lb. pruning weight).

The overall goal was simply to find out how the vines would respond to extreme overcropping and undercropping. Unsurprisingly, overcropped vines suffered, and undercropped vines grew more canopy. But the reassuring takeaway was that it took a very extreme intervention (defoliating vines twice) to affect midwinter bud freezing temperatures.

Acknowledgement.

Alex Koeberle helped to set up the treatments, and the Field Research Unit at Cornell Agritech provided routine management tasks. This work was supported by the Cornell AgriTech Director's venture fund project entitled "Modeling and predicting bud hardiness in response to winter temperatures and source/sink limitations." The Taylor, LaCroute, and Saltonstall endowments provided support through the Director's venture fund.

Clockwise from top left: Tim Martinson is senior extension associate and Janet Van Zoeren is extension support specialist with the statewide viticulture extension program., Ray Chen and Raquel Kallas are Master of Professional Studies graduates of Cornell University and former research aides with the program.

Cornell CALS College of Agriculture and Life Sciences