Canopy fruit zone management IN WINEGRAPE VINEYARDS

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Introduction

The practices collectively known as *canopy management* aim to maximize canopy leaf exposure, maintain crop yield and quality, decrease disease, and improve vineyard health. Though labor–intensive, canopy management should not be considered optional if the goal is annual production of high–quality grapes and wines. Fruit–zone leaf and lateral shoot removal (fruit–zone leaf removal) is often implemented in conjunction with, or slightly after, the initial shoot positioning. Fruit–zone leaf removal is primarily practiced in winegrape vineyards. Failure to remove some foliage from the fruit zone can result in excessive shading of grape clusters. When foliage surrounds the fruit zone, airflow, pesticide spray penetration, and evaporation rates are reduced. Such phenomena greatly increase disease incidence and severity on grape clusters, especially in humid climates. Varietal character, positive wine aroma compounds, and color development are all generally reduced in shaded fruit zones. Fruit–zone leaf removal is a tool used to manage bunch rots and wine quality potential, especially in variably cloudy, humid climates like those of the eastern United States.

Figure 1. A primary count (spur–originating) shoot bearing clusters at node positions 4 and 5 (see red arrows).

The fruit zone

Fruitful shoots bear two or three grape clusters, depending on cultivar. Grape clusters are typically produced from the third through fifth nodes of primary shoots (Figure 1). Fruitful, primary shoots originate from 1–year–old wood whereas secondary (lateral) shoots grow laterally from the nodes of primary shoots. The fruit zone of a grapevine canopy is defined as the region of the canopy where the greatest density of grape clusters exists. Within a training system, fruit zones comprise a confined region

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of the canopy in order to facilitate cultural practices, optimize spray targeting, and improve harvest efficiency (Figure 2). The fruit zone can be positioned 30–36 in. above the ground and confined in a linear space in popular training systems such as the vertical–shoot–positioned (VSP) system, or exist roughly 60–72 in. above the ground and manifested in a two–dimensional manner in divided canopy systems such as the Watson system (Figure 2). For more information on the Watson System, please see UGA Extension Bulletin 1522 (White et al., 2020).

Figure 2. A Chardonel fruit zone in a vertical–shoot–positioned (VSP) system (top) and a Norton fruit zone in a Watson system (bottom).

Motivation for fruit zone management

Fruit–zone leaf removal increases airflow and reduces drying time, thereby creating a microclimate that is less hospitable to fungal diseases (English et al., 1989; Wolf et al., 1986). *Botrytis* bunch rot and other late–season bunch rots (Figure 3) are often better controlled when leaf removal is implemented relative to fully foliated fruit zones (Table 1). Vineyard managers do not want to harvest or cull rotten fruit, winemakers do not want to make wine with rotten fruit, and wine consumers probably do not want to drink wine made from rotten fruit. Improved rot management alone should incentivize fruit–zone management to improve airflow and light exposure to clusters — especially in humid climates where fungal diseases are extremely prevalent.

Leaf removal may indirectly increase usable crop via reducing bunch rots, and may improve fruit quality. Compounds that positively influence wine sensory perception can be increased in exposed relative to shaded grapes (Hickey et al., 2018a; Razungles et al., 1998). Compounds that produce vegetal/herbaceous aromas, such as methoxypyrazines, can be reduced by cluster exposure (Ryona et al., 2008). Exposed grape clusters tend to have lower acidity than shaded clusters due to temperature–driven respiration of malic acid (Lakso et al., 1975; Figure 4). Therefore, a *wine must* (juice) comprised of exposed clusters often has a greater sugar–to–acid ratio. Relative to the inverse, a greater sugar–to–acid ratio may enable an earlier harvest, minimize wine tartness of rot–prone whites, and reduce "sharpness" or astringency in red wines.

Table 1. Fruit–zone leaf removal effect on *Botrytis* bunch rot incidence and severity in two Cabernet franc clones in North Carolina in 2017.

Treatment[a]	*Botrytis* incidence (%)[b]	*Botrytis* severity (%)[b]
	Clone 214	
NO	54.0	4.6
PB6	30.0	1.6
PFS6	10.0	0.1
	Clone 327	
NO	44.0	0.9
PB6	32.0	0.6
PFS6	32.0	0.3

[a]Treatment = no leaf removal (NO); removal of six leaves before bloom (PB6); removal of six leaves after fruit set (PFS6). Data adapted from Hickey et al. 2018b.

[b] Incidence = visual inspection of the infection of one berry or more per cluster; severity = visual inspection of percent damage per cluster.

Due to the variance in fungal disease tolerance and differences in canopy vigor, optimal leaf removal in the southeast can depend on the training system and grape cultivar, and likely even between clones (Table 1). European grapes (*Vitis vinifera*) trained on VSP trellis systems can benefit from fruit–zone leaf removal when grown in humid regions, while native or hybrid cultivars, like Norton or Villard blanc, grown on high–wire systems generally require less fruit–zone management for successful production.

Figure 3. Chardonnay clusters with *primarily Botrytis* bunch rot (left) and *primarily* sour rot (right) harvested from shaded fruit zones.

Figure 4. The same two Chardonnay clusters photographed from the shaded side (left) and sun–exposed side (right). The shaded grapes in the left photo are likely to be more acidic than the sun–exposed grapes in the right photo.

How to remove leaves from the fruit zone

Leaves surrounding clusters are commonly removed by hand in eastern U.S. vineyards with modest acreage (5–10 acres). *Petioles* (leaf stems) are removed from the primary shoot, thereby removing leaf blades as well. Tender and slim lateral shoots produced from nodes surrounding the fruit zone can also be removed by hand if foliage is removed between the "bloom" and "BB–size berries" growth stages. However, hand shears will be required to remove the thicker, lignified lateral shoots that are present near the "bunch closure" growth stage. Mechanical leaf removal machines are becoming popular in the eastern United States (Figure 5). While the cost of such equipment can exceed $15,000, their purchase can offset labor costs spent on manual canopy management. Recent economic insight into manual versus mechanical leaf removal showed that mechanical leaf removal can eventually result in cost savings when compared to manual leaf removal (Table 2). Costs savings with mechanical leaf removal are predicted to be realized earlier with increased vineyard acreage. For example, it is predicted that cost savings with mechanized leaf removal would be attained in year 3 in a 15–acre vineyard while it would take several years to realize cost savings in a 5–acre vineyard (Table 2).

Perhaps as important as cost savings, the strategic use of a mechanized leaf remover allows *timely* leaf removal, especially across large vineyard acreages (> 20 acres), and can aid in pesticide spray penetration during critical periods for cluster disease management (bloom through bunch closure). An experienced labor crew of two people could remove leaves and apply spray zone–targeted pesticides over approximately 6 acres of vineyard per day with the simultaneous use of two tractors (one leaf removal, one pesticide application). Thus, in situations of labor scarcity, mechanical leaf removal machines can offer an efficient solution to effectively implement fruit–zone management over large acreages at a targeted growth stage.

Investment in mechanical leaf removers shows industry acknowledgement that fruit–zone management is an important tool to manage grape disease and quality (Tables 3 and 4; see references for additional publications). However, some vineyards may not be suitable for mechanical leaf remover use. Mechanical leaf removal is most effective in training systems with defined fruit zones (e.g., VSP systems). Slope of the vineyard, ground cover, and tractor operator skills are limiting factors for the use of a mechanical leaf removal machine. For example, mechanical leaf removal will increase in difficulty in vineyards with frequent topography changes and on highly sloped sites (e.g., > 15–20 degrees). Note also that some mechanical leaf removal machines use rollers to pull and cut foliage while others use pulses of compressed air to remove or shred foliage. Cluster damage may be experienced with both machine types; operator experience with the machine is likely to limit the incidence and magnitude of cluster damage. The pulses of compressed air may aid in the removal of floral tissue debris which could limit fungal disease prevalence, but these air pulses also may reduce fruit set during bloom if the result is reduced pollen availability. Cutting machines may best be used after berries have enlarged (around the "pea–size berries" stage) and clusters hang down in the canopy with the aid of gravity. For a video review of mechanical leaf removal fundamentals, see *Mechanized Grapevine Fruit Zone Leaf Removal* (Hickey & Centinari, 2021).

Table 2. Manual and mechanical fruit–zone leaf removal: Approximate costs.

	Manual leaf removal	Mechanical leaf removal	Potential Savings
Variable cost per acre[a]	**$485**	**$38.30**	**$446.70**
Variable cost per ton[b]	**$173.20**	**$13.70**	**$159.50**
One–time costs	***$0***	***$20,000***	
5–acre vineyard[c]			
Year 1	$2,425	$20,191.50	**$-17,766.50**
Year 2	$2,497.75	$197.25	**$-15,466**
Year 3	$2,572.70	$203.16	**$-13,096.40**
15–acre vineyard[c]			
Year 1	$7,275	$20,574.5	**$-13,299.50**
Year 2	$7,493.25	$591.70	**$-6,397.50**
Year 3	$7,718	$609.50	**$711**
30–acre vineyard[c]			
Year 1	$14,550	$21,149	**$-6,599**
Year 2	$14,986.50	$1,183.47	**$7,204.03**
Year 3	$15,436	$1,219	**$14,217**

[a]Costs are based on the 2018 costs of a 30–acre commercial vineyard in Western North Carolina. Manual labor at $12.50/hour + benefits. Mechanical costs include tractor labor ($17/hour + benefits), fuel, and maintenance. It does not include depreciation of the mechanical leaf remover, but only reflects variable costs per acre.

[b]Total cost per ton of wine grapes, calculated on an average of 2.8 t/acre production over a 30–acre vineyard with different cultivars.

[c]Hypothetical costs for a vineyard of different sizes. We assume that costs will increase at a 3% rate every year, based on inflation rate and salary adjustments.

Table 3. Manual and mechanical fruit–zone leaf removal effect on *Botrytis* bunch rot incidence and severity in Chardonnay in North Carolina in 2018.

Chardonnay[a]	*Botrytis* incidence (%)[b]	*Botrytis* severity (%)[b]
NO	**32.0**	**4.0**
PFS4	**15.2**	**0.6**
PFS6	**17.6**	**0.9**
MECH	**16.0**	**0.5**

[a]Treatment = no leaf removal (NO); removal of four leaves after fruit set (PFS4); removal of six leaves after fruit set (PFS6); mechanical leaf removal (MECH). Data adapted from Hickey et al., 2019.

[b]Incidence = visual inspection of the infection of one berry or more per cluster; severity = visual inspection of percent damage per cluster.

Figure 5. Tractor–mounted, mechanical leaf removal machines are becoming popular in eastern U.S. vineyards with moderate acreage (e.g., 10–20 acres; top photos). Such trends are indicative of the value industry places on fruit zone management as a tool to manage grape rot and wine quality potential. Mechanical leaf removal (bottom, left) relative to manual removal of six basal shoot leaves and laterals (bottom, right).
Note: neither UGA nor the authors endorse the equipment in the photos.

When to remove leaves from the fruit zone

Standard protocol is to remove leaves in the post–fruit set period — a rather general timeframe. Perhaps this general recommendation is acknowledgement that leaf removal is a labor– and time–intensive practice that takes several weeks (and across several vine growth stages) to be implemented by hand over large vineyard acreages. Leaf removal to zero fruit–zone leaf layers immediately after fruit–set (e.g., BB–size berries; Figure 6) has been shown to maintain crop yield, reduce bunch rot (Hickey & Wolf, 2018; Hickey et al., 2018b; Hed & Centinari, 2018; Hed et al., 2015) and improve or maintain grape berry phenolics and anthocyanins (Hickey et al., 2018a; Hickey & Wolf, 2018). Implementing leaf removal immediately after fruit–set will improve fungicide spray coverage on clusters throughout most of the critical period for early–season cluster disease control (bloom through bunch closure). Recent research has evaluated the effect of prebloom leaf removal on crop quantity and quality. It is judicious to wait until roughly 10 or more leaves have unfolded before removing leaves before bloom (Figure 6); earlier implementation can damage the extremely tender shoots.

There is perceived value of mechanical over hand leaf removal regarding the precision of leaf removal timing. In its efficiency, mechanical leaf removal offers the ability to implement leaf removal within a specific growth stage, as opposed to across several growth stages. Grape sunburn was infrequently observed when leaf removal was implemented early in grape development (e.g., fruit–set through BB–sized berries) in Virginia, North Carolina, and Georgia. If fruit–zone leaf removal is delayed until around pea– or marble–sized berries/or bunch closure, there may be a greater chance for sunburn to occur on the outside–facing grapes of a fully exposed cluster. Sunburn has been observed more frequently on white–berried as opposed to red–berried cultivars. However, leaf removal several weeks after fruit set may still aid in rot control and fruit quality. Thus, it is not a lost cause to implement remedial fruit–zone management if the busy start to the season has prevented fruit–zone leaf removal from occurring between the fruit–set and BB–sized berries stages.

Figure 6. Grapevine growth stage when leaves would be removed before bloom (left) and after fruit–set (right). Prebloom leaf removal occurs when single flowers are well separated. Post–fruit set leaf removal occurs when berries are BB–sized.

How many leaves to remove from the fruit zone

The number of fruit zone leaves removed will depend on the amount of labor and time budgeted for fruit–zone management. This is dictated by: (1) the perceived positive effects of leaf removal; (2) the acreage over which leaf removal will be implemented; and (3) the cultivars that are grown. In many regions, leaf removal efforts are primarily focused on the *morning–side canopy* (e.g., the east canopy side in north/south–oriented rows). Such practice is an attempt to avoid excessive radiant heating of grapes in the afternoon, which has been shown to reduce anthocyanins in the western United States (Bergqvist et al., 2001; Spayd et al., 2002; Tarara et al., 2008). Climate greatly determines grape temperature patterns and the hours above critical berry temperature thresholds for grape anthocyanin accumulation, which is approximately 30 to 35 °C (Spayd et al., 2002; Tarara et al., 2008). In some U.S. regions, radiation is persistent throughout the day while afternoon cloud coverage can reduce radiant heating of grapes in humid regions like Virginia (Hickey & Wolf, 2018) and likely other parts of the eastern United States. In regions where cloud coverage is typical, removing leaves from both sides of the canopy may increase airflow and spray penetration without reducing anthocyanin accumulation or causing sunscald (particularly when leaves are removed around bloom or BB–size berries so berries develop and acclimate to ambient radiation conditions; Table 4). In the eastern United States, extensive fruit–zone leaf removal on both sides of the canopy can improve primary chemistry and increase or maintain phenolics and anthocyanins (Table 4), thus improving wine quality potential of *V. vinifera*, in comparison to no leaf removal (Frioni et al., 2017; Hickey et al., 2018a; Hickey & Wolf, 2018). Removal of leaves exclusively on the vine canopy's morning side may not necessarily be the best management practice in humid regions where fungal disease control is of great importance and radiant heating is diminished compared to the western United States.

Table 4. Fruit–zone leaf removal effect on Cabernet franc Brix–to–titratable acidity (TA) ratio and canopy–side specific total grape phenolics and anthocyanins in North Carolina and Georgia in 2017.

	East canopy side			West canopy side	
Treatment[a]	Brix–to–TA ratio	Phenolics (au/g berry)	Anthocyanins (mg/g berry)	Phenolics (au/g berry)	Anthocyanins (mg/g berry)
North Carolina					
NO	6.1	87	0.56	82	0.59
PB6	6.6	97	0.61	103	0.66
PFS6	6.1	98	0.59	98	0.65
Georgia					
NO	3.7	102	0.64	101	0.67
PB6	4.2	135	0.81	131	0.75
PFS6	4.3	132	0.74	114	0.73

[a]Treatment = no leaf removal (NO); removal of six leaves before bloom (PB6); removal of six leaves after fruit set (PFS6)

Leaf removal to zero fruit–zone leaf layers around clusters would require removal of approximately four to five basal leaves per shoot. Such effort is unnecessary and would not be commercially feasible. Further, intensive leaf removal before bloom can drastically reduce crop yield, while removal of a similar amount of leaves after fruit set will maintain crop yields (Figure 7). Thus, both timing and magnitude of leaf removal are important considerations for crop management (Figure 7). Leaf thinning to an average of one to two leaf layers has been widely recommended for eastern U.S. growing regions (Reynolds & Wolf, 2008). An average of one to two leaf layers surrounding grape clusters can be achieved by removing approximately two leaves per shoot near clusters. *Botrytis* bunch rot and sour rot severity have been shown to decrease with decreasing fruit–zone leaf layer number (Vogel et al. 2020). The practical goal is to find a level of leaf removal that: (1) is not limited by labor nor the number of acres that require leaf removal; (2) improves spray penetration and rot control; and (3) maintains or improves color and flavor compound development. “A little bit goes a long way” is true with leaf removal, meaning that modest fruit–zone leaf removal is a good practice to aid in late–season spray penetration and sensory compound development, even if implemented several weeks after fruit set.

Figure 7. Prebloom removal of four (left), eight (center) leaves and laterals, and post–fruit set removal of six leaves (right). Estimated crop yield weight per acre from those treatments are 2.12, 1.17, and 3.52 tons, respectively.

Prioritizing leaf removal

Priorities for leaf removal are dictated by several factors (Table 5). Cultivars vary in their susceptibility to bunch rots and should therefore dictate where to prioritize fruit–zone management. Chardonnay, Sauvignon blanc, Riesling, and Pinot noir are more susceptible to certain rots, and may consequently have greater need for leaf removal, relative to Petit Manseng, Petit Verdot, and Cabernet Sauvignon. Generally, hybrid cultivars have greater disease tolerance than *vinifera* cultivars; relatively modest amounts of fruit–zone leaf removal can therefore improve rot management and fruit composition in hybrids. In general, leaf removal to manage rots may be more important in white–berried relative to red–berried cultivars while leaf removal to manage primary and secondary metabolites may be equally beneficial in both white– and red–berried cultivars. Budget and labor may ultimately limit the implementation of fruit–zone leaf removal. Thus, if labor is limited, leaf removal priority could be based on cultivar rot susceptibility, which may be (in order of most susceptible to least susceptible): Sauvignon blanc/Riesling/Vignoles/Pinot noir > Chardonnay/Merlot > Cabernet Sauvignon/Petit Verdot > Chambourcin/Chardonel. Table 5 can be used as a general guide for determining leaf removal priority based on cultivar traits, growing and training scenarios, and region. For example, the bottom row suggests leaf removal is a high priority for a white–berried *vinifera* cultivar that has compact clusters, low rot tolerance, and is grown in a humid climate. There may be other considerations besides cultivar for prioritizing leaf removal, including training system, fruit–zone architecture, climate, and targeted price premium (Table 5).

Table 5. A generalized and relative prioritization for fruit–zone leaf removal based on several factors.

Priority	Species	Berry color	Cluster morphology	Rot tolerance	Training system	Fruit–zone architecture	Climate
Low	American		Loose	High	High Wire	Multi–dimensional; spacious	Mediterranean, arid
Moderate	Hybrid	Red	Normal	Medium			Humid
High	Vinifera	White	Compact	Low	VSP	Linear; confined	Humid

Summary

Fruit–zone management may have the most direct impact on fruit quality when considering all canopy management practices. The interaction of cultivar and climate will determine the need for fruit–zone leaf removal. Rot–prone cultivars grown in humid environments will necessitate open fruit zones to optimize fungal disease management. Fruit zones with few leaf layers may aid wine quality potential in humid environments characterized by variable cloudiness throughout the ripening period. Extensive prebloom leaf removal can decrease crop yield. Post–fruit set leaf removal maintains crop yield but leaves a shorter time frame to complete canopy management in a large vineyard. Investment in a mechanized leaf removal machine could remedy the time and labor constraint that fruit–zone leaf removal imposes. Careful consideration of site–specific environment and growing conditions will help prioritize leaf removal to target fruit composition as related to winemaking goals. In the eastern United States, fruit–zone leaf removal benefits may outweigh the cost of time and labor, especially when leaf removal is prioritized by cultivar needs (e.g., disease susceptibility). Leaf removal methods should be chosen accordingly based on vineyard conditions, cultivars, and resources available.

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