Crop and Canopy Management Field Seminar 2009

Dr. Andrew G. Reynolds
Professor of Viticulture, Cool Climate Oenology & Viticulture Institute
Inniskillin Hall, room 311, Brock University
500 Glenridge Ave., St. Catharines, Ont. L2S 3A1

I-Shoot density and Crop Management by Cluster Thinning

1. Shoot Density

French-American hybrids. Reynolds et al. (1986) first introduced the concepts of "shoot density" and "balanced thinning" for French-American hybrid grape production. They recommended 13-19 shoots/m of row and **balanced thinning** (of flower clusters) to obtain consistent yields in 'Seyval blanc'. Using this concept, all vines are pruned identically to obtain a desired leaf area and canopy density, then vines are cluster-thinned according to vine vigor; i.e. small vines are severely thinned (< 1 cluster/shoot) and large vines are lightly thinned (ca. 2 clusters/shoot).

Our New York work in the early 1980's (Reynolds et al. 1986) showed that a better approach to handling varieties with fruitful base buds was to maintain a reasonable shoot density (4-6 shoots/ft. canopy; 15-20 shoots/m canopy), and "balance thin" large-clustered varieties. Hence, big and small vines carry the same shoot number, but small vines are more severely cluster thinned. In this manner, all vines theoretically carry the same leaf area, but weaker vines are encouraged to grow by limiting the crop:leaf area ratio.

V. vinifera. *V. vinifera* have been the subject of surprisingly little investigation into optimum shoot density levels. Basler (1980, 1981) in Switzerland concluded that 5-6 and 6-7 shoots/m^2 were optimal for 'Muller-Thurgau' and 'Blauburgunder', respectively. These translate to approximately 8-11 shoots/m of row. Smart (1988) in Australia indicated that 15 shoots/m of row was probably ideal for 'Gewurztraminer', based on canopy microclimate data. It should be pointed out that Smart's data were collected on very dense vines that had been shoot-adjusted at veraison, hence the effect of lateral shoot growth at different shoot densities could not express itself. Reynolds (1988) found that 25 shoots/m of row was equivalent to 30+10 balanced pruning of moderately-vigorous 'Riesling' vines in terms of vine size, yield, and fruit composition. Later research confirmed this (Reynolds et al. 1994a,b). Pinot noir appears to have more fastidious requirements, and 20 shoots/m seems too high; somewhere between 10 and 15 shoots/m is about right (Reynolds et al. 1994c, 1996). Our recommendations for *V. vinifera* are based on these data.

If we use the 15 to 25 shoots/m of row as a "point of departure", an interpolation of the literature would suggest that shoot densities below this range should lead to improved canopy microclimate, and all that it entails: high bud fruitfulness, optimum bud hardiness, high soluble solids, low TA and pH, enhanced varietal character, minimized vegetative flavors, and improved color. Shoot densities above this range lead to shaded canopies, and all that is associated with them: low bud fruitfulness, reduced winter hardiness, low soluble solids, high TA and pH, reduced varietal character, increased vegetative flavor, and poor color.

2. Crop management by cluster thinning

French-American hybrids and some *Vitis vinifera* (e.g. Syrah, Cabernet Sauvignon, etc.) frequently overcrop due to fruitful base shoots and extremely high cluster weights (> 400 g). De Chaunac, Seyval blanc, Verdelet, and Chancellor are four in particular that cannot be successfully grown by simply relying on either balanced pruning or maintenance of a specific shoot density.

Some definitions

Shoot thinning. On vines trained to cordons, short spurs are retained, and the base of each spur is a reservoir for base shoots. These are usually removed in late spring by **shoot thinning** or **cordon suckering** to reduce shoot number to a specific shoot density. This is also a crop control measure since most shoots are fruitful.

Cluster thinning. Even with shoot thinning, the large-clustered varieties can overcrop. **Cluster thinning** is thus necessary. In so doing, the basal clusters are retained and the distal cluster(s) are removed at the time of flowering. At this point, maximum **yield compensation** is achieved, since the clusters retained have: i] More berries set, and; ii] Larger berries, than unthinned vines, hence their clusters are larger. However, fewer photosynthetic sinks are retained, and overcropping is minimized. Even reducing crop down to one cluster per shoot is sometimes insufficient. The **balanced thinning** concept (Reynolds et al. 1986) can be used as a guide for severity of cluster thinning; using this formula, as many as two clusters/shoot could be retained for large vines, but < one cluster/shoot would be retained for weak vines (< 0.5 kg cane prunings/vine).

What can cluster thinning do?

Increase	Decrease
Vine size (weight of cane prunings)	Yield
Yield	Berry weight
Cluster weight	Titratable acidity
Berries per cluster	
Berry weight	
Brix	
Titratable acidity	
Anthocyanins and phenolics	
Monoterpenes	
Wine varietal character	

Important questions: *When can cluster thinning increase yield, and when can it decrease yield? What determines the response? Why could it increase or decrease berry weight or TA, depending upon circumstance? How can you predict what it might do, based upon the facts at hand?*

Cluster thinning at a glance.

Time of thinning. I. Flower cluster thinning. By thinning, we basically mean removal of clusters. This can be done any time during the season, but when it is done produces different effects. **Flower cluster thinning** is performed prior to or during bloom. It has the advantages of being fast, because the canopy is still being formed, and hence the clusters are very easy to see. You can also

shoot thin at the same time to remove excess fruitful and unfruitful shoots. You must keep in mind, however, that yield compensation is optimized by flower cluster thinning; by removing flower clusters, berry set is enhanced in the remaining clusters. This is simply an effect of reducing competitiveness between "sinks"--the thousands of individual flowers that make up the developing clusters. Moreover, again due to reduced sink competition, berry size and weight tend to be greater at harvest in flower cluster thinned vineyards than in non-thinned vineyards. This may be a consideration if you are trying to maximize skin:juice ratios for purposes of color, tannin, and flavor extraction. The other downside of flower cluster thinning is that the clusters can get tighter, and hence bunch rot can be a problem. Add to this the fact that you are stimulating vine vigor and may be, under some circumstances, creating more canopy shade; we've often measured higher titratable acidity in fruit from flower cluster-thinned vines than that from unthinned vines (Reynolds et al. 1986, 1994c). Nonetheless, you will generally increase yield, vine size, vine hardiness, fruit soluble solids, flavor compounds, anthocyanins (color), and sometimes wine quality.

In varieties with cluster weights less than 150 g, usually yield compensation is insufficient to overcome the decrease in cluster number, hence yields are often not increased, and in varieties such as Gewurztraminer, Pinot noir, and Riesling, yield can sometimes go down (Reynolds 1989b, Reynolds et al. 1994a, c, Reynolds and Wardle 1989).

II. Post set thinning. Let's say you've decided against flower cluster thinning and opt for **post set thinning**. Often, due to pressure of bunch rot, growers prefer not to thin until after set. This allows for looser clusters by allowing competition during time of flowering and fruit set. Berry weight increases are still achieved thereafter.

The experience I've had with this method (Reynolds et al. 1986) shows that it is more expensive, because the canopy is about 75% formed, and you need to fight with the vines to find the fruit. It's also usually more difficult to do any shoot thinning effectively. The process is hence somewhat less precise than prebloom thinning. You get less yield compensation too; berries have set so you don't increase berries/cluster. However, clusters that are retained are looser than those on flower cluster-thinned vines. Bunch rot infection is hence lower. Because you are thinning prior to veraison, you still will increase berry size and weight, since you are removing competing clusters during the cell division stage. Yield, soluble solids, vine size, and vine hardiness also increase. I have not seen data that indicate that wine quality is improved by post set thinning over flower cluster thinning, but anecdotal evidence seems to indicate that it is at least as effective. Note also however, that the longer one waits before thinning, the more berry size is reduced (Reynolds et al. 1986, Weaver and Pool 1973).

III. Pre- & post-veraison thinning. I've seen a lot more **pre- and post veraison thinning** in the industry now that red wines have become more popular. This has minimal impact in terms of yield compensation; in fact, yields per vine are usually reduced in all but the largest-clustered varieties such as Chancellor. And, it's usually done on overcropped vines where berry size is potentially low. This, therefore, is a true bandaid solution to an overcropped vineyard. It is effective, but very expensive. You are spending money on labor as well as losing yield. If post veraison thinning is being considered, you need to be very sure that it will be effective. And remember, the longer past veraison you wait, the less effective the practice becomes. What are the benefits? The remaining crop is allowed to ripen. Wine quality should improve. Yield goes down. Vine size is unaffected. Vine hardiness is also probably unaffected, based on the data collected so far. If you need to do this every year, you would be well advised to review your fertilization and soil management practices (i.e. are your vines too low in vigor?) and your pruning practices (could you be leaving too many buds?).

Making the decision. We've spent some time discussing the roles and uses of thinning and

pruning for controlling crop. How each practice is used must be based upon accepting the concept that balance between vegetative and reproductive growth (i.e. vine size and crop size) in the grapevine is essential for high wine quality. For reductionist thinkers, balance is indicated by mean cane weights of 25 to 40 g, cane pruning weights of 0.3 lbs/ft canopy (0.4 kg/m canopy), and crop loads (crop size:vine size ratios) $\geq 5 \leq 12$. Some of our data with Chancellor and Seyval blanc trained to Geneva Double Curtain seem to increase the crop load ceiling to 17 or more. Balance may mean something like 2 tons/acre in Chateau Margaux, but in excess of 10 tons per acre in some vineyards in California, the Pacific Northwest, and other "New World" winegrowing districts. Thinning can help us achieve that balance.

So, when would I thin if I were a vineyard manager? Four main scenarios:

1. To reduce a potential overcrop situation in a specific year, due to climatological conditions the previous year. For example, high fertility in buds formed in many Ontario vineyards in 2007 (due to high light conditions during and following bloom) led to monster crops in 2008. Even though vines were treated (pruned, etc.) as usual in preparation for the 2008 season, we needed to thin some varieties substantially to prevent overcropping.

2. To maintain consistent yields and winegrape quality in varieties with very fruitful base shoots, 2^o buds, and 3^o buds. In most cases, this may involve cluster thinning, but may require shoot thinning too if shoot density becomes too high. This is especially so with cordon-trained, spur-pruned vines.

3. To avoid overcropping in large-clustered varieties. This pertains especially to large-clustered hybrids (Bradt 1962) and *Vitis vinifera* varieties such as Cabernet Sauvignon and Merlot, which benefit from annual cluster thinning due to their propensity to overcrop. We are assuming that vine size is average to low; if we adhere to the balanced thinning concept, little thinning will be required on vigorous vines. On small vines (made smaller by severe pruning in the absence of thinning), thinning must be more severe to strike a suitable balance between leaf area and crop retained.

4. To get the crop to ripen in a bad year. If the weather is lousy mid- to late summer, and you know the snow flies in October (or even if it doesn't), you may need to make the decision to thin some crop on the late varieties. Granted, there's a certain amount of crystal ball gazing for this one, but let's face it, if your 8 ton/acre crop of Riesling is little marbles on the 1st of September, I'd think about pulling off some crop.

Some case studies.

I have specifically not made any recommendations on how much to thin, because that is something that varies with variety, site, and situation. However, a few case studies, taken from both research and industry, should provide some guidelines. Thinning is effective in *Vitis labrusca* varieties (Bradt 1967), but I'll confine my discussion here to *Vitis vinifera* and French-American hybrids.

French-American hybrids. *De Chaunac.* Fisher and colleagues in Ontario (Fisher et al. 1977) showed that flower cluster thinning this variety to one cluster per shoot increased vine size, yield, and fruit soluble solids. This variety is not grown much anymore, but this work is significant in that the effects were consistent over a very long period. Work in B.C. (Looney 1981, Reynolds 1989a) confirmed this, and also showed increases in anthocyanins with thinning (Reynolds 1989a). Furthermore, it was shown how ineffective balanced pruning was in the absence of cluster thinning. In fact, balanced pruning seemed totally useless; vines on which all "count" nodes were removed (leaving base buds and bare cordons only) yielded as much as conventionally-pruned vines.

Thinning was the only effective mode of crop regulation.

Seyval blanc. Work in NY (Reynolds et al. 1986) showed that this variety needed a fixed shoot density and balanced thinning to minimize bunch rot and optimize yield, vine size, winter hardiness, and winegrape quality. Nine shoot density x flower cluster thinning combinations were tested, but also looked at post set thinning as a vehicle for reducing bunch rot (it worked). The best combination of treatments appeared to be 4 to 6 shoots/ft. canopy and 17 clusters/lb. cane prunings. This assumed "average" vines (2.5 lbs. cane prunings/vine) would be thinned to 1.5 clusters/shoot, less-vigorous ones to one cluster/shoot, and very vigorous ones to 2 clusters/shoot. Vine size at thinning time can be estimated roughly by trunk diameter and shoot length. You obviously don't need to weigh all your vines to figure out a thinning strategy.

Vitis vinifera. ***Cabernet Sauvignon.*** In areas where Cabernet is difficult to ripen, I recommend cluster thinning. I will admit that this is based on gut feeling rather than solid numbers. Interestingly, in the Napa Valley, a study by Ough and Nagaoka (1984) showed that cluster thinning down to one-third the original crop had minimal impact on fruit composition and wine quality. The take home message again is justifying crop loss plus labor cost against potential increase in wine quality.

Gewurztraminer. When we began looking at terpene flavorants routinely as a quality index, we decided to include cluster thinning as a treatment in our first trial (Reynolds and Wardle 1989). As with many previous studies, fruit soluble solids increased, and so did free and bound terpene flavorants. We unfortunately couldn't link this to wine quality.

Pinot noir. A study (Reynolds et al. 1994c, 1996) between Summerland, BC and Oregon State University (OSU) looked at cluster thinning in combination with different shoot densities and Scott Henry training. Cluster thinning essentially removed half the potential crop; we did flower cluster thinning and OSU waited till after fruit set. There weren't any major surprises; cluster weight, berry weight and berries/cluster went up at our site, yield decreased slightly, and fruit composition was improved. Wine quality also was increased, but only if shoot density and fruit environment were optimal (Reynolds et al. 1996). Thinning had no impact on wine quality when shoot density was 20 shoots/m canopy. That's another thing worth noting: cluster thinning is a complement to, and not a replacement for, good viticulture.

Dr. Daniel Roberts, formerly of Sterling Vineyards in the Napa Valley of California, reported on some thinning research with Pinot noir conducted by his company in the Carneros region (Roberts 1994). I was fortunate enough to taste the wines from the treatments, and there was a marked improvement in the two thinned treatments over the control. The most severe thinning brought the crop down to 2.5 tons/acre, which was considered uneconomical.

Riesling. The cynics will say that quality doesn't matter for Riesling because it won't sell anyway. The informed among us know otherwise. We found in a small trial in the mid-1980's that wine quality in Riesling could be improved by flower cluster thinning, along with vine size, soluble solids, and yield consistency (Reynolds 1989b). It was not so much a function of yield per vine *per se* as much as it was balance and crop load; Rieslings with crop loads between 7 and 10 gave us highest aroma intensity.

We carried this study further to look at multiple shoot density and cluster thinning levels. Our recommendations at the beginning of the trial were 25 shoots/m row (Reynolds 1988). In the new trial, we found that 26 shoots/m canopy was optimal in terms of combining profitable yields with highest wine quality, and cluster thinning could be used to manipulate fruit composition and wine quality somewhat (Reynolds et al. 1994a,b). At 16 shoots/m, the shoots were more vigorous, leaves were larger, and more fruit was in the shade. Yields were lower too, but vines were over-vegetative;

and, cluster thinning made no difference in terms of wine quality. Way up at 36 shoots/m, cluster thinning also made no difference; removing crop could not overcome the problems created by a dense canopy. These wine quality differences were supported by differences in the concentrations of aroma compounds in the wines. This again illustrates the point that cluster thinning cannot be used as a replacement for good viticulture.

Some final thoughts. If you've stuck with me this far I think you can come to several conclusions:

1. There is no single time of the year or severity of thinning that can be recommended; thinning, like all horticulture, is site and variety-specific;

2. Thinning can be used as a regular part of a viticulture program, or as a special tool in unusual seasons;

3. Thinning will have desirable consequences regardless of when it is done, but it will have different effects depending on the time of year when it is implemented. Also, thinning has little effect on fruit composition if performed following veraison;

4. Thinning is effective in improving yield, fruit composition, vine size, hardiness, and wine quality, but has minimal impact under conditions of poor vineyard management.

Shoot Density and Cluster Thinning--Literature Cited

Basler, P. 1980. Zur optimalen Belastung der Reben beim Riesling X Sylvaner am Zurichsee. Schweiz. Z. Obst-und Weinbau 116(3):56-64.

Basler, P. 1981. Zur optimalen Belastung der Reben beim Blauburgunder in der Ostschweiz. Schweiz. Z. Obst-und Weinbau 117(13):354-364.

Bradt, O.A. 1962. Effect of pruning severity and bunch thinning on yield and vigor of Seibel 10878 and Seibel 9110 grapes. Rpt. Hort. Expt. Sta. & Prod. Lab., Vineland, Ont. for 1962, pp. 19-22.

Bradt, O.A. 1967. Effect of pruning severity and bunch thinning on yield and vigor of Buffalo and Catawba grapes. Rpt. Hort. Expt. Sta. & Prod. Lab., Vineland, Ont. for 1967, pp. 22-27.

Fisher, K.H., O.A. Bradt, J. Wiebe, and V.A. Dirks. 1977. Cluster thinning 'De Chaunac' French hybrid grapes improves vine vigor and fruit quality in Ontario. J. Am. Soc. Hort. Sci. 102:162-165.

Looney, N.J. 1981. Some growth regulator and cluster thinning effects on berry set and size, berry quality, and annual productivity of De Chaunac grapes. Vitis 20:22-35.

Ough, C.S., and R. Nagaoka. 1984. Effect of cluster thinning and vineyard yields on grape and wine composition and wine quality of Cabernet Sauvignon. Am. J. Enol. Vitic. 35:30-34.

Reynolds, A.G. 1988. Response of Riesling vines to training system & pruning strategy. Vitis 27:229-242.

Reynolds, A.G. 1989a. Impact of pruning strategy, cluster thinning, and shoot removal on growth, yield, and fruit composition of low-vigor De Chaunac vines. Can. J. Plant Sci. 69:269-275.

Reynolds, A.G. 1989b. 'Riesling' grapes respond to cluster thinning and shoot density manipulation. J. Am. Soc. Hort. Sci. 114:364-368.

Reynolds, A.G., C.G. Edwards, D.A. Wardle, D.M. Webster, and M. Dever. 1994a. Shoot density affects 'Riesling' grapevines. I. Vine performance. J. Am. Soc. Hort. Sci. 119:874-880.

Reynolds, A.G., C.G. Edwards, D.A. Wardle, D.M. Webster, and M. Dever. 1994b. Shoot density affects 'Riesling' grapevines. II. Wine composition and sensory response. J. Am. Soc. Hort. Sci. 119:881-892.

Reynolds, A.G., R.M. Pool, and L.R. Mattick. 1986. Effect of shoot density and crop control on growth, yield, fruit composition, and wine quality of 'Seyval blanc'. J. Am. Soc. Hort. Sci. 111:55-63.

Reynolds, A.G., S.F. Price, D. Wardle, & B. Watson. 1994c. Fruit environment and crop level effects on Pinot noir. I. Vine performance and fruit composition in British Columbia. Am. J. Enol. Vitic. 45:452-459.

Reynolds, A.G., and D.A. Wardle. 1989. Impact of several canopy manipulation practices on growth, yield, fruit composition, and wine quality of Gewurztraminer. Am. J. Enol. Vitic. 40:121-129.

Reynolds, A.G., D.A. Wardle, and M. Dever. 1994d. Shoot density effects on Riesling grapevines: interaction with cordon age. Am. J. Enol. Vitic. 45:435-443.

Reynolds, A.G., S. Yerle, B.T. Watson, S.F. Price, and D.A. Wardle. 1996. Fruit environment and crop level effects on Pinot noir. III. Descriptive analysis of Oregon and British Columbia wines. Am. J. Enol. Vitic. 47:329-339.

Roberts, D. 1994. Cluster thinning experiments on Pinot noir. Am. J. Enol. Vitic. 45:470 (Abstr.).

Smart, R.E. 1988. Shoot spacing and canopy light microclimate. Amer. J. Enol. Vitic. 39:325-333.

Weaver, R.J., and R.M. Pool. 1973. Effect of time of thinning on berry size of girdled, gibberellin-treated 'Thompson Seedless' grapes. Vitis 12:97-99.

II-Canopy Management

A useful reference book on this subject is "Sunlight into Wine" (Smart and Robinson 1991). For this course, I'll confine my remarks to some of my own ideas and research. Dealing with a problem canopy can go one of two directions: towards an **enlightened solution** or towards a **bandaid solution**. These two categories include the following:

ENLIGHTENED SOLUTIONS	BANDAID SOLUTIONS
Canopy division	Hedging
Deficit irrigation	Leaf removal
Rootstocks	Growth regulators
Vine spacing	Increased node numbers
Reduced fertilization	
Cover crops	

Enlightened Solutions to Problem Canopies

1. Deficit irrigation. After canopy division, the most effective tool for vigor control is perhaps the use of **deficit irrigation**. Irrigation is covered in our morning session.

2. Rootstock. The choice of **rootstock** is an important one where vigor may later become a problem. Here is a review of relative rootstock vigor (Howell 1985):

Very weak	Moderate vigor	High vigor	Very high vigor
333 EM	**Riparia Gloire** 420A Mgt 41B Mgt **101-14 Mgt** 101-15 Mgt 1616 Couderc **3309 Couderc** 3306 Couderc	**SO 4 Teleki** **5BB Kober** **5C Teleki** 110 Richter 1103 Paulsen 4453 Maleague 1613 Couderc 1202 Couderc	Salt Creek Dog Ridge Rupestris St. George AxR 99 Richter 140 Ruggeri

3. Vine spacing. Spacing can be a controversial topic in some circles. One of the most abused European practices is the concept of narrow rows and tight spacing. Our experience has shown that giving a grapevine more room will ultimately reduce vine size per linear measure of row or canopy, may display a slight reduction in soluble solids, but under some circumstances may produce fruit with higher monoterpene flavorants (Reynolds et al. 1996b). It is important to accommodate anticipated high vigor through wider vine spacing; the concept of root competition among grapevines is unproved at best and lousy physiology at worst. It is generally accepted now that tight vine spacing will have no impact on vigor unless soil conditions are limiting to begin with.

4. Reducing fertilizer. Decreasing nitrogen inputs is an obvious solution to over-vegetative vines.

5. Cover crops. Use of cover crops is a wise choice where high vigor is a consistent problem, or where excess soil moisture and fertility cause autumn re-growth.

Bandaid solutions

That's a short discussion of enlightened solutions to canopy problems. There are, however, other short-term solutions I call **bandaid solutions**. To put this in the proper context, a good example of a bandaid solution would be a grower who applies excess fertilizer every spring, then spends half the summer hedging, slashing, pulling leaves, and otherwise fighting with the monster vines that he alone has created. I have seen far too many examples of this type of viticulture, enough to conduct some research into the possible benefits of all this cutting and slashing. Surprisingly, some of it works, but at a high cost to the grower. The main bandaid solutions are **hedging and leaf removal**.

1. Hedging. Hedging seems like a relatively universal practice among growers of French-American hybrids, *V. vinifera*, and to a lesser extent, *V. labruscana*. It has both advantages and disadvantages:

Advantages	Disadvantages
Reduced fruit shade	Reduced soluble solids.
Reduced vine vigor	Reduced winter hardiness.
Ultimately, more manageable vines	Enhanced lateral shoot growth, and potentially more fruit shading.

Some work we conducted on De Chaunac between 1985 and 1987 clearly showed that hedging, especially severe and/or late hedging, substantially reduced node hardiness (Reynolds &Wardle 1989a), while delaying sugar accumulation and reducing anthocyanins (Reynolds & Wardle 1989d). Some of the potentially-negative aspects of these hedging treatments may have been obscured by the good management; all vines were shoot positioned twice annually, cluster-thinned, shoot-thinned, and suckered numerous times.

V. vinifera canopies trained on vertical trellises are customarily hedged one or more times each growing season. The benefits of this practice may simply be cosmetic on small and medium-sized vines. Our work between 1984 and 1986 on Riesling (Reynolds 1988) showed quite clearly that hedging had no effect on soluble solids in two of three years, no effect on titratable acidity, and no consistent effect on pH. In larger vines, hedging may delay sugar accumulation by removal of too much photosynthetic leaf surface, or through the encouragement of lateral shoots (Reynolds and Wardle 1989b; Reynolds et al. 1996a). The general recommendation would be to start hedging early, remove as little as possible each time, and withhold irrigation, if possible, to prevent late season lateral shoot growth.

2. Leaf removal. Leaf removal (or, more correctly, **basal leaf removal**) has become a popular viticultural practice in North America over the past few years. It has many benefits:

- ·Increased flavor compounds (Reynolds 1990; Reynolds & Wardle 1989b, 1989c; Reynolds et al 1995, 1996a, 1996b; Smith et al. 1988)
- ·Reduced titratable acidity (Wolf et al. 1986; Reynolds & Wardle 1989b; Reynolds et al 1995, 1996a, 1996b)
- ·Reduced pH and potassium (Kliewer et al. 1988; Reynolds et al. 1995, 1996a)
- ·Reduced bunch rot (Wolf et al. 1986; Smith et al. 1988)
- ·Higher bud fertility in spurs (Reynolds et al. 1989b, 1996a)
- ·Better spray penetration
- ·Reduced vegetative aromas in some cultivars, e.g. Semillon (Smith et al. 1988)

As with any viticultural practice, leaf removal is not without faults:

- Bird damage
- Slightly lower soluble solids (Reynolds & Wardle 1989b; Reynolds et al. 1996a)
- Hot, vegetative, or cooked flavors in wines of some cultivars, e.g. Gewurztraminer

The time of leaf removal can be significant. Post veraison leaf removal appears to be largely unsuccessful, and can result in sunburned clusters. On the other hand, very early leaf removal may ultimately prove uneffective once fruit maturation begins, due to all the regrowth that may recur. I have found the most effective "window of opportunity" occurs 10 to 20 days after hedging, when lateral shoots in the fruit zone are growing, can be easily visualized, and can be efficiently removed along with the basal leaves. As to severity, be sure to retain >12 leaves per shoot, and preferably more. It is of greater consequence to note leaves retained, not leaves removed. Do remember, however, that leaf removal can slightly reduce sugar accumulation, so moderation is the key.

i) Early ripening cultivars. Leaf removal may have very little effect on standard harvest indices of very early ripening cultivars. Bacchus, Pearl of Csaba, Schonburger, and Siegerrebe ripen at the very beginning of our season when the air temperatures are at their maximum. Removing a

few basal leaves did not appear to have a big influence on malic acid degradation, pH, or sugar accumulation. Significant effects did occur, however, in the free volatile terpenes (FVT) and potentially-volatile terpenes (PVT) in the juices of these cultivars in response to basal leaf removal, and these responses were detected in the wines as well (Reynolds et al. 1995).

ii) Midseason cultivars. With midseason cultivars such as Gewurztraminer, the effects of leaf removal are more far reaching. In most years, we have observed decreases in titratable acidity, pH, and potassium, as well as increases in FVT and PVT (Reynolds 1990; Reynolds & Wardle 1989b, 1989c; Reynolds et al 1996a). Naturally-exposed fruit also contain higher FVT and PVT concentrations than shaded fruit (Reynolds and Wardle 1989c). Tasters can distinguish between non-hedged wines and either hedged or leaf-pulled wines, but recognizing a leaf-pulled wine among two hedged ones is a somewhat more difficult task.

iii) Late season cultivars. Late season cultivars such as Riesling clearly benefit from leaf removal. In BC, leaf removal reduced Riesling titratable acidity in each of three years, while increasing PVT (Reynolds et al. 1996b). No effects were observed on pH or soluble solids. FVT were increased in one year by leaf removal as well. In this trial, we had hoped that leaf removal would have no effect on the divided canopies, but FVT and PVT were highest in alternate double crossarm canopies that had undergone leaf removal (Reynolds et al. 1996b). Leaf removal also improved fruit composition and wine quality of Semillon, and tasters found the wines from leaf-pulled plots much more floral than the non-leafed treatments (Reynolds, unpubl.).

Literature Cited—Canopy Management

Christensen, L.P. 1986. Fruitfulness and yield characteristics of primary and lateral canes of Thompson Seedless grapevines. Am. J. Enol. Vitic. 37:39-43.

Howell, G.S. 1985. Factors to consider in rootstock selection. Proc. Ark. State Hort. Soc. 106:132-135.

Howell, G.S., and N.E. Shaulis. 1980. Factors influencing within-vine variation in the cold resistance of cane and primary bud tissues. Am. J. Enol. Vitic. 31:158-161.

Kliewer, W.M., J.J. Marois, A.M. Bledsoe, S.P. Smith, M.J. Benz, and O. Silvestroni. 1988. Relative effectiveness of leaf removal, shoot positioning, and trellising for improving winegrape composition. In: Proc. 2nd Int. Symp. Cool Climate Vitic. Oenol. (R.E. Smart, R.J. Thornton, S.B. Rodriguez, and J.E. Young, eds.), NZ Soc. Vitic. Oenol., Auckland, pp. 123-126.

Reynolds, A.G. 1988. Inhibition of lateral shoot growth in summer-hedged 'Riesling' grapevines by paclobutrazol. HortScience 23:728-730.

Reynolds, A.G. 1990. Monoterpenes--key to Gewurztraminer winegrape quality. Practical Winery & Vineyard 11(1):33-37.

Reynolds, A.G., C.G. Edwards, D.A. Wardle, D.R. Webster, and M. Dever. 1994a Shoot density effects on 'Riesling'. I. Vine performance. J. Am. Soc. Hort. Sci. 119:874-880.

Reynolds, A.G., C.E. Edwards, D.A. Wardle, D.R. Webster, and M. Dever. 1994b. Shoot density effects on 'Riesling'. II. Wine composition and sensory response. J. Am. Soc. Hort. Sci. 119: 881-892.

Reynolds, A.G., D.A. Wardle, and M. Dever. 1994c. Shoot density effects on Riesling grapevines: interactions with cordon age. Am. J. Enol. Vitic. 45:435-443.

Reynolds, A.G., and D.A. Wardle. 1989a. Effects of timing and severity of summer hedging on growth, yield, fruit composition, and canopy characteristics of De Chaunac. I. Canopy characteristics and growth parameters. Am. J. Enol. Vitic. 40:109-120.

Reynolds, A.G., and D.A. Wardle. 1989b. Impact of various canopy manipulation techniques on growth, yield, fruit composition, and wine quality of Gewurztraminer. Am. J. Enol. Vitic. 40:121-129.

Reynolds, A.G., and D.A. Wardle. 1989c. Influence of fruit microclimate on monoterpene levels of Gewurztraminer. Am. J. Enol. Vitic. 40: 149-154.

Reynolds, A.G., and D.A. Wardle. 1989d. Effects of timing and severity of summer hedging on growth, yield, fruit composition, and canopy characteristics of de Chaunac. II. Yield and fruit composition. Am. J. Enol. Vitic. 40:299-308.

Reynolds, A.G., D.A. Wardle, and M. Dever. 1995. Effect of site and basal leaf removal on fruit composition and wine quality of four *Vitis vinifera* cultivars in response to vineyard location and basal leaf removal. Am. J. Enol. Vitic. 46:542-558.

Reynolds, A.G., D.A. Wardle, and M. Dever. 1996a. Vine performance, fruit composition, and wine sensory attributes of Gewurztraminer in response to vineyard location and canopy manipulation. Am. J. Enol. Vitic. 47:77-92.

Reynolds, A.G., D.A. Wardle, and A.P. Naylor. 1996b. Impact of training system, vine spacing, and basal leaf removal on the performance of Riesling. Vine performance, berry composition, canopy microclimate, and vineyard labor requirements. Am. J. Enol. Vitic. 47:63-76.

Reynolds, A.G., D.A. Wardle, A.C. Cottrell, and A.P. Gaunce. 1992. Advancement of 'Riesling' fruit maturity by paclobutrazol-induced reduction of lateral shoot growth. J. Am. Soc. Hort. Sci. 117:430-435.

Reynolds, A.G., S. Yerle, B.T. Watson, S.F. Price, and D.A. Wardle. 1996c. Fruit environment and crop level effects on Pinot noir. III. Descriptive analysis of Oregon and British Columbia wines. Am. J. Enol. Vitic. 47:329-339.

Shaulis, N.J. 1980. Responses of grapevines and grapes to spacing of and within canopies. In: Proc. U.C. Davis Cent. Symp. (A.D. Webb, ed.), Univ. of Calif. Press, Berkeley, pp. 353-361.

Smart, R.E. 1984. Some aspects of climate, canopy microclimate, vine physiology, and wine quality. In: Proc. 1st Int. Symp. Cool Climate Vitic. Enol. (D.A. Heatherbell, P.B. Lombard, F.W. Bodyfelt, and S.F. Price, eds.), OSU Agric. Expt. Sta. Tech. Public. 7628, pp. 1-19.

Smart, R.E. 1985. Principles of grapevine canopy microclimate manipulation with implications for yield and quality: a review. Am. J. Enol. Vitic. 36:230-239.

Smart, R.E. 1986. MKIV Vineyard Scorecard.

Smart, R.E. 1991. Canopy microclimate implications for nitrogen effects on yield and quality. In: Proc. Int. Nitrogen Symp. Grapes & Wines (J. Rantz, ed.). Am. Soc. Enol. Vitic., pp. 90-101.

Smart, R.E., and M.D. Robinson. 1991. Sunlight into Wine. Winetitles, Underdale, SA, Australia.

Smart, R.E., and K. Sharp. 1989. Handbook for Canopy Management Workshop. MAFTech North, Hamilton, New Zealand.

Smart, R.E., and S.M. Smith. 1988. Canopy management: identifying the problems and practical solutions. In: Proc. 2nd Int. Symp. Cool Climate Vitic. Oenol. (R.E. Smart, R.J. Thornton, S.B. Rodriguez, and J.E. Young, eds.), New Zealand Soc. Oenol. Vitic., Auckland, pp. 109-15.

Smart, R.E., J.K. Dick, I.M. Gravett, and B.M. Fisher. 1990. Canopy management to improve grape yield and wine quality--principles and practices. S. Afric. J. Enol. Vitic. 11: 3-17.

Smith, S., I.C. Codrington, M. Robertson, & R.E. Smart. 1988. Viticultural and oenological implications of leaf removal for New Zealand vineyards. In: Proc. 2nd Int. Symp. Cool Climate Vitic. Oenol. (R.E. Smart, R.J. Thornton, S.B. Rodriguez, & J.E. Young, eds.), New Zealand Soc. Oenol. Vitic., Auckland, pp. 127-133.

Wolf, T.K., R.M. Pool, and L.R. Mattick. 1986. Responses of young Chardonnay grapevines to shoot tipping, ethephon, and basal leaf removal. Am. J. Enol. Vitic. 37:263-268.