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Traditional and innovative summer pruning techniques for vineyard management

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Abstract: This review paper highlights physiological and vine performance effects of widely adopted summer pruning operations such as leaf removal, shoot trimming and positioning and cluster thinning. Leaf removal is addressed either under its traditional configuration, i.e. removing in dense canopies some or all leaves around clusters usually pre-veraison to improve fruit microclimate and facilitate spraying and early (pre-flowering) defoliation primarily aimed at inducing looser clusters via a concurrent reduction of fruit-set and berry size. Time consuming and still non mechanisable cluster thinning is evaluated primarily in terms of response variability *vs.* season and intensity with emphasis on lack of significant reduction of final yield per vine in thinned treatments when large crop compensation occurs. Variability of expected final grape composition improvements in thinned vines is also discussed based on the actual vine balance when the operation is performed. Although fully mechanisable, shoot trimming is still a debated choice in terms of timing and severity. While severe (i.e. fewer than six or seven main leaves retained) and late (i.e. several weeks after bloom) cuts should possibly be avoided, the effects of shoot trimming on final grape composition is discussed as a function of seasonal changes in leaf area development, demography, fraction of lateral leaves from the total and leaf to fruit ratio. It is indicated that, for vertically shoot-positioned trellises, if the support trellising is correctly designed and vine vigour is balanced, timing and severity of trimming are dictated by the vine "itself" rather than by grower choices. Overall, this review underscores the importance of leading the vineyard to a "natural" control of vegetative growth, which would minimise the need for an extensive use of summer pruning. In other words, such vineyard operations should be viewed not just as something the growers "have to do", instead as specific tools used to achieve targeted final grape composition.

1. Introduction

Summer pruning is a fairly broad term comprising a set of practices performed on the canopy during the growing season with an array of aims, including regulation of size, vigour and crop and reduction of the susceptibility to biotic and abiotic stress. If it is considered that at least two such operations, e.g. selective shoot and cluster thinning, still require manual execution, the total amount of necessary seasonal labour, calculated as man × hr/ha, readily exceeds the demand for winter pruning and becomes a primary determinant of vineyard economics (Intrieri and Poni, 1995). While it is commonly heard that the 'perfect' vineyard needs no summer pruning, perfect in reality has proved to be a very rare occurrence. Yet, we should certainly like to see vineyards of the future moving towards a more focused application of summer pruning operations. The major change is that a given summer cut is not solely or exclusively seen as something the grower "has to do", say, to accommodate adjustments for excessive shoot growth or canopy density. Rather it should also be viewed as something that the grower may 'use' to head vine and cluster growth towards better grape composition or to specific features consonant with adjustments needed because of climate change.

Along with traditional summer pruning operations, which define the grapevine canopy management strategy and include cluster and shoot thinning, shoot positioning and hedging, elimination of lateral shoots and late season basal leaf removal, over the last few years innovative summer techniques such as pre-flowering leaf removal (Poni *et al.,* 2006; Intrieri *et al.,* 2008; Poni *et al.,* 2008; Diago *et al.*, 2010 a; Palliotti *et al.*, 2011 b) or early and late season anti-transpirant sprays (Palliotti *et al.,* 2010 and 2011 a) have been introduced. These latter management practices are useful in any situation where the main aims are to reduce the vine yield and improve both technological and phenolic maturation. Moreover, global warming is leading to a progressive shift toward sub-tropicalization of several viticulture areas, shorter time intervals between phenological stages (Schultz, 2000; Jones *et al.,* 2005) as well as increased probability for berry sunburn (Spayd *et al.,*

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2002; Tarara and Spayd, 2005; Greer *et al.,* 2006). Finally, clear evidence does exist for faster ripening leading to significant increases in grape sugar concentration at harvest (Dokoozlian, 2009).

2. Leaf removal

This operation has been historically defined as "the removal of some leaves from the fruiting area between fruit set and veraison" (Smart, 1973) with the prevailing aim to ameliorate bunch microclimate and reduce rot incidence in canopies that are too dense (Gubler *et al.,* 1991). Ongoing research has provided knowledge to distinguish two types of leaf removal aimed at quite distinct goals.

Traditional leaf removal

Although this practice may have different purposes, it is usually employed from fruit set to veraison on high-density canopies to improve light exposure and air circulation around the clusters, with substantial benefits in terms of pigmentation and tolerance to rot (Smart, 1985; Bledsoe *et al.,* 1988; Gubler *et al.,* 1991; Percival *et al.,* 1994; Reynolds *et al.,* 1996). This operation can be done manually, requiring up to about 60 hr/ha, although increasing labour costs nowadays strongly advise a mechanical approach which can be easily performed in less than 2 hr/ha. The best timing for machine use is about one to two weeks prior to veraison when berries are still hard while specific bunch weight is already much higher than that of leaves.

Yield may not change (Bledsoe *et al*., 1988; Smith *et al.,* 1988; Hunter *et al.,* 1995) or might even occasionally increase as compared with non-defoliated vines (Zoecklein *et al.,* 1992). The variability of the impact that leaf removal has on yield and their components is likely dependent upon the negative effects on fruit set and berry growth in the current year and positive effects on bud induction and differentiation for the next year's crop via an improvement in canopy microclimate. Although this type of leaf removal usually leads to undeniable improvements in fruit composition, which more frequently are a slight increase in sugars and ripe fruit characters and a decreased malic acid content and attenuated herbaceous and grassy wine characters (Smart, 1985; Reynolds *et al.,* 1996; Zoechlein *et al.,* 1992; Scheiner *et al.,* 2010), its popularity has probably decreased over the last two decades due to either advancement in leaf and whole-canopy physiology and new pressure from global warming.

A study from Petrie *et al*. (2003) found that leaf removal from the lower quarter of the canopy during the lag phase of berry growth caused a significant decrease of whole-vine photosynthesis, even on a per-unit leaf area basis, thus suggesting that the lower portion of the canopy contributed more than the upper portion to the whole-vine carbon budget. A possible explanation of this finding is that although basal, and hence older leaves are removed by defoliation, they are also the largest leaves along the shoot and their size can offset lower photosynthetic rates (Poni *et al.,* 1994). Therefore, lowering shoot photosynthesis might not be negligible especially for leaf removals performed after fruit set.

Removal of all the leaves from the fruiting area, which thereby exposes the clusters to full sun, might lead in warm climates to compromised fruit composition because of excessive berry temperatures, which can hinder colour formation and cause a sharp drop in malic acid concentrations (Spayd *et al.,* 2002; Tarara *et al.,* 2008). For such reasons and in association with increasing concern for berry sunburn, criteria for applying leaf removal have become more restrictive and more often conceive retaining some leaf cover around the fruiting area. Differentiation in the actual need and/or severity of leaf removal also depends upon specific planting choices. For instance, no or very light defoliation is usually applied on the south facing side of an east-west oriented row, whereas more severe leaf stripping might be required on the north facing row side; basically the same applies for west- and east facing sides of north-south oriented rows, respectively.

More physiological insights have also been provided about "why" a traditional leaf removal might become mandatory. Backward to the still shareable rule indicated from Dr. Shaulis in that "no leaf removal is needed if while standing in front of a canopy at veraison about 50-60% of the clusters are visible", other more recent findings have shown that in a significant number of cases, excessive canopy crowding in the bunch zone leading, in turn, to the need of stripping leaves, is caused by other wrong or rushed vineyard management choices (Fig. 1). One example is worthwhile above all: spur pruned vertically shoot positioned (VSP) cordon-trained canopies are usually prone to leaf removal due to too high shoot density per meter of canopy length. Yet, this often happens as vines burst many either secondary or base bud originated shoots casting additional shade in the bunch area. More equilibrated vines would better comply with the shared requirement that, on average, one shoot is expected from each single retained node and, if so, the subsequent leaf removal would become quite likely unnecessary.

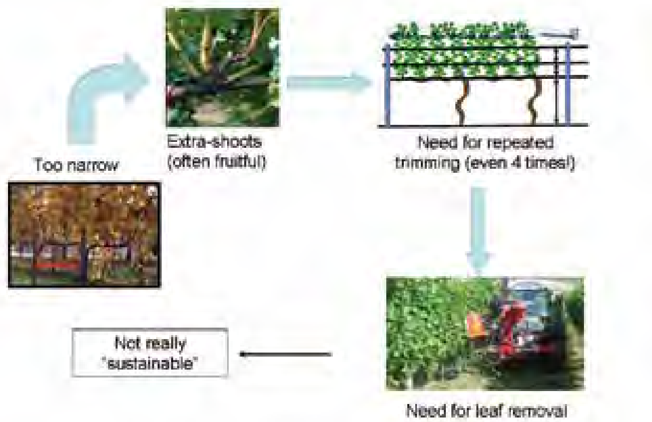

Fig. 1 - Interrelationships of excessive shoot vigour stimulated by a too narrow within-row vine spacing and related consequences on summer pruning needs (drawn by Authors).

Early leaf removal

This practice has mainly been inspired from long-standing knowledge according to which carbohydrate supply at flowering is a primary determinant of fruit set (Coombe, 1959; May *et al.,* 1969). The temporary source limitation induced by removing an average of six main basal leaves before flowering has led, under a broad array of genotypes and growing conditions, to a significant decrease in fruit-set, which in turn increases cluster looseness and tolerance to rot (Gubler *et al.,* 1991; Poni *et al.,* 2006; Intrieri *et al.,* 2008; Poni *et al.,* 2008; Diago *et al.,* 2010 a). Yet, the most important outcome is that, irrespective of genotype, this early leaf removal markedly improves grape composition and wine sensory properties as compared to non-defoliated shoots (Poni *et al.,* 2006; Diago *et al.,* 2010 a; Palliotti *et al.,* 2011 b).

There are multiple mechanisms involved in such a positive response. Defoliated shoots generally have a higher final leaf-to-fruit ratio than control, thus implying that the yield reduction induced by defoliation was more than proportional to the leaf removal constraint due to a fruit-set and berry-size effect (Poni *et. al.,* 2006). Furthermore, it is known that a precocious source limitation carried out in the form of defoliation or darkening the basal shoot zone hastens translocation of assimilates towards the cluster (Quinlan and Weaver, 1970). Improved grape composition in the defoliated shoots also relates to the 'quality' of the source. For example, it is indeed true that removing the main six basal leaves at pre-bloom causes an abrupt and severe decrease in vine photosynthesis [75% less than with not-defoliated (ND) according to Poni *et al.,* 2008]. However, removing source leaves around bloom also triggers a series of dynamic changes in canopy growth, age and photosynthesis. Defoliated vines have a 'younger' canopy at veraison since median and apical shoot leaves at this time are now mature and more lateral leaves may be present as a compensating reaction to early main leaf removal, while some, albeit temporary, photosynthetic compensation usually occurs in both main and lateral leaves of defoliated plants. Poni *et al.* (2008) have recently shown that whole canopy net CO_2 exchange rates (NCER) monitored uninterruptedly for three months in defoliated (D) vs. non-defoliated Sangiovese vines indicated no differences in data expressed on a per-vine basis. Yet when the same data were given on a per-unit leaf area basis, defoliated vines showed higher rates than ND vines (4.75 μmol $m^{-2} s^{-1}$ *vs*. 4.16 μmol $m^{-2} s^{-1}$) and, most importantly, NCER/yield increased by 38% in D vines, thus resulting in enhanced carbohydrate supply for ripening (Table 1).

However, the most intriguing outcome from these early-season defoliation tests is that a significant increase in relative skin mass has consistently been found in separate field studies conducted on a three-year basis in cv. Barbera (Poni and Bernizzoni, 2010), regardless of absolute berry mass (Fig. 2). It is reasonable to think that such an early

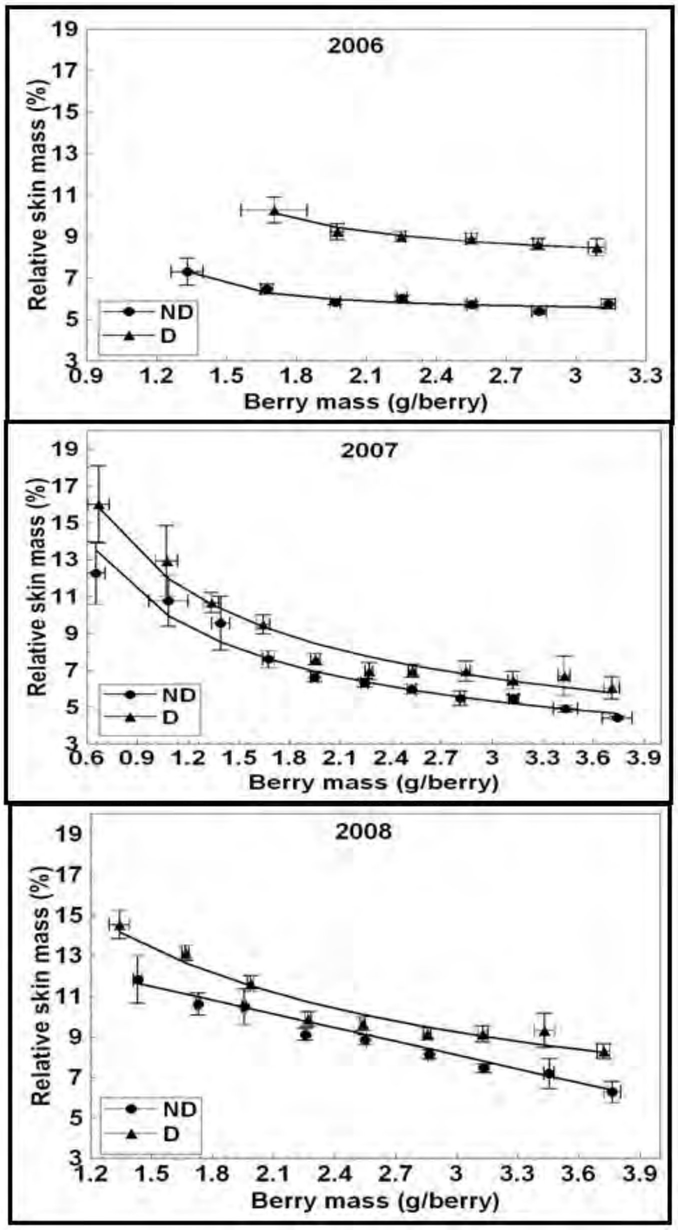

Fig. 2 - Correlation between relative skin and berry mass in 2006, 2007 and 2008 for non defoliated and defoliated Barbera grapevines (from Poni and Bernizzoni, 2010).

Table 1 - Effects of early defoliation on yield components and whole shoot net CO_2 exchange rate (NCER)/fresh fruit mass

Treatment	Flowers/cluster (no.)	Fruit set (%)	Total berries/ cluster (no.)	Cluster weight (g)	Berry weight (g)	NCER shoot/yield (nmol/s x g)	Cluster compactness (rating)
Control	435	38.8	169	334	1.98	2.43	6.60
Defoliated	487	21.0	103	207	2.01	3.31	4.25
Significance	NS	**	**	**	NS	**	**

**, NS= significant at P ≤ 0.05 or not significant, respectively.

basal leaf removal, besides favouring berry hardening in the long run, would also impose more favourable microclimate conditions for cell division and berry skin deposition, which typically takes place within four to five weeks after flowering. Mescalchin *et al*. (2008) have shown in Pinot Gris that the earlier the defoliation, the lesser the incidence of skin burning on VSP and pergola-trained varieties due to both more time allowed for cluster cover after treatment and adaptation towards the formation of a thicker skin.

Mechanization is feasible by preferably using at pre-flowering (i.e. closed-flower stage) an air pressure blowing machine which can run two passages per row in about 5-7 hr/ha (Intrieri *et al.,* 2008). Best performance is obtained on canopies characterized by vertical and well positioned shoots and on cultivars having mostly erect inflorescences.

It has to be kept in mind that early leaf removal is specifically recommended in highly productive vineyards which often present heavy, thick bunches very susceptible to rot. Based on the constancy of the results obtained under the above circumstances, this practice is nowadays an interesting alternative to traditional methods of crop control such as bunch thinning. Advantages are feasibility of mechanization, hence cost saving, and different mechanisms by which the crop level on the vine is adjusted. If early leaf removal is chosen, the primary regulation for crop restriction is via a decrease in fruit set with or without a significant reduction in berry size. Therefore, cluster number is unchanged, yet each bunch is smaller and looser. Conversely, hand bunch-thinning, besides being time consuming, drastically lowers bunch number per vine and favours undesirable yield compensation mechanisms such as larger berries and heavier clusters (Ough and Nagaoka, 1984; Keller *et al.,* 2005).

Anti-transpirant applications

A very recent development of the above work investigated whether the precocious, albeit temporary, source limitation sought with early leaf removal can be induced through the non-invasive and easy-to-do application of anti-transpirants (Palliotti *et al.,* 2010). Their use could sort out the inherent limitations of high labour demand for manual work while eliminating the risks of direct damage to the inflorescences linked to the use of a leaf plucker. Results reported for cvs. Sangiovese and Ciliegiolo subjected to pre-bloom treatment of anti-transpirant Vapor Gard® (a.i. di-1-*p*-menthene at 3% concentration, Intrachem Bio Italia, Grassobbio, BG, Italy) show similar reductions of net photosynthesis (from 30% to 70%) over several weeks after spraying as compared to control vines (Fig. 3). The treated Sangiovese vines showed reduced yield, berry weight, cluster compactness and, on a two-year basis, lower vigour and unchanged vine capacity per year. At harvest, the treated vines showed higher °Brix in all seasons and higher anthocyanin concentration two years out of three. Overall, early-season applications of a film-forming anti-transpirant caused a leaf function limitation strong enough to reduce yield and cluster compactness through smaller final berry size.

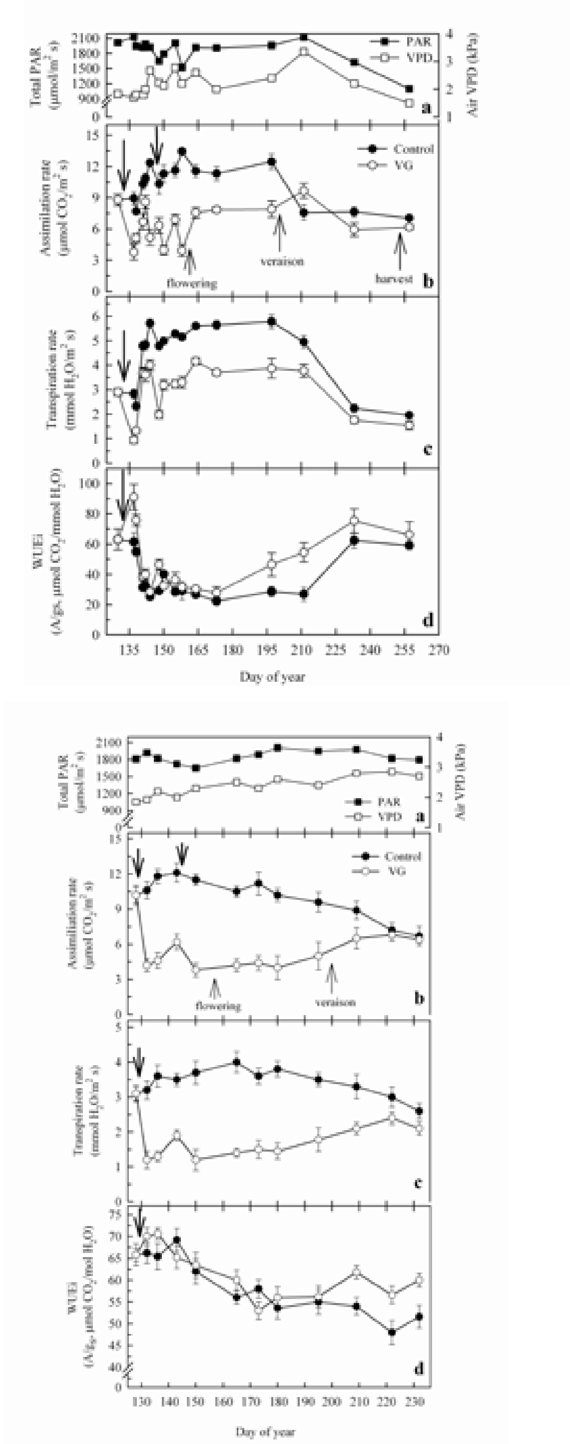

Fig. 3 - Seasonal trends of air vapour pressure deficit (VPD) and total photosynthetic active radiation (PAR) (a), assimilation rate (b), transpiration rate (c) and intrinsic water use efficiency (d) recorded on fully expanded, median Sangiovese (top image) and Ciliegiolo (bottom image) leaves sprayed twice with anti-transpirant Vapor Gard® at 3% (T) or left unsprayed (C). Bold arrows indicate the time of application. Data are means ± SE (from Palliotti *et al.,* 2010).

Over the last decade, climate change along with improvements in vineyard management and clonal selection have exerted a strong impact on vine yield and grape and wine composition. Among the most important effects, the increase in grape sugar concentration at harvest, is to be considered, which resulted in wines with high alcohol content (Vierra, 2004; Duchêne and Schneider, 2005; Godden and Gishen, 2005). There is a surge of interest from the wine industry in tools suitable to lower wine alcohol content such as the de-alcoholisation process which also agrees with the EU legislative measure No 606/2009. Conversely, it would thus be helpful to find strategies able to reduce grape sugar concentration in the vineyard, thus limiting the need to operate in the winery without detrimental effects on wine characteristics. In association with traditional management practices which can be used to slow down the accumulation of sugars in the grape berry, interest is growing in late season applications of anti-transpirants. In a recent contribution by Palliotti *et al.* (2011 a), the anti-transpirant Vapor Gard® sprayed about one month before harvest significantly delayed sugar accumulation in Sangiovese, Tocai rosso and Trebbiano Toscano berries which, at harvest, had -1.2 to -2.7 less °Brix than the un-sprayed control according to genotype and crop load. The temporary reduction of photosynthesis, due to the film formed by the anti-transpirant, limited the amount of assimilates translocated into the ripening berry, thus lowering must sugar concentration with a potential effect on wine alcohol content.

3. Cluster thinning

The achievement of an adequate balance between growth and fruiting can be obtained by the regulation of crop level through cluster thinning treatments. Despite additional labour costs, cluster thinning might play an important role in all cases where over cropping occurs (e.g. excess of vigour due to cultivar and rootstock, high soil fertility, low planting density, use of drip fertigation, etc.) and in cases where winter pruning severity has not overcome cropping due to high bud fertility. The negative effects of over cropping include delay in grape maturation, worsening of overall grape quality, increased susceptibility to biotic disease and poor wood maturity (Winkler *et al.,* 1974). Furthermore, different environmental parameters, particularly air temperature, light intensity, photoperiod and soil water content, together with phyto-hormones and the availability of mineral ions are known to influence bud fertility and fruit-set (Srinivasan and Mullins, 1981). Therefore, it is not always possible to regulate the yield level by solely adjusting bud load, especially in vineyards with low planting density and in years and areas characterized by unfavourable environmental conditions.

However, the results regarding the effects of high yield levels on fruit composition (sugar, acidity, colour, etc.) and wine quality (taste, flavours, colour and potential for aging) are quite contradictory. For example, some authors found an increase in anthocyanin concentration upon cluster thinning (Bravdo *et al*., 1984 a, Reynolds, 1989; Guidoni *et al.,* 2002), whereas no improvement in anthocyanin content or wine colour in cluster-thinned vines were found by Bravdo *et al*. (1984 b) and Ough and Nagaoka (1984). Location, application time and intensity of cluster thinning treatment significantly affected the results and can therefore justify, at least in part, the discrepancy of the experimental results in literature.

The results of a three-year trial on the effects of three levels of cropping (0%, 20% and 40% cluster thinning treatments) applied just before veraison in Sangiovese, Merlot and Cabernet Sauvignon showed that this management practice caused a significant reduction of yield only at the 40% severity and in two out of the three seasons studied (Table 2) (Palliotti and Cartechini, 1988). In each cultivar, in 1995 and 1996, yield was linearly correlated with cluster thinning intensity. Cluster thinning treatment at the 40% level caused a reduction of vine yield that ranged from 22% to 47%. The reduction of yield observed was, in general, not proportional to the cluster thinning intensity due to a significant increase of berry and clus-

Table 2 - Effects of cluster thinning on yield and cluster characteristics in Sangiovese, Merlot and Cabernet Sauvignon grapevine cultivars

Cultivar	Thinning	Yield (kg/vine)			Cluster/vine (n°)			Cluster weight (g)			Berry weight (g)		
		1995	1996	1997	1995	1996	1997	1995	1996	1997	1995	1996	1997
Sangiovese	0%	12.4	11.3	10.1	40.6	46.4	39.9	306	245	251	2.30	2.36	2.33
	20%	11.8	9.5	10.0	35.1	34.3	32.9	340	271	300	2.47	2.60	2.68
	40%	9.5	6.9	9.5	25.2	22.6	24.3	381	308	387	2.70	2.82	3.38
Significance		**	***	NS	**	***	**	***	***	***	***	***	***
r^2		0.76	0.92	---	0.76	0.94	0.75	0.90	0.89	0.92	0.87	0.94	0.96
Merlot	0%	8.1	8.7	8.7	57.8	64.1	60.5	147	137	149	1.70	1.82	2.03
	20%	7.7	8.0	8.2	49.5	52.1	50.5	159	154	160	1.76	1.83	2.12
	40%	6.1	6.6	7.9	35.4	38.8	37.5	172	170	212	1.92	1.94	2.53
Significance		*	***	NS	***	***	***	***	***	***	***	*	**
r^2		0.47	0.87	---	0.84	0.91	0.83	0.89	0.91	0.84	0.85	0.46	0.73
Cabernet S.	0%	7.2	7.9	6.2	56.1	58.9	51.6	131	135	123	1.35	1.94	1.39
	20%	7.4	7.0	6.1	44.2	47.6	42.2	167	146	146	1.60	2.02	1.57
	40%	5.6	4.2	6.0	32.2	27.9	30.5	176	154	198	1.70	2.06	1.89
Significance		*	***	NS	***	***	***	***	***	***	**	**	***
r^2		0.42	0.84	---	0.90	0.93	0.92	0.85	0.87	0.84	0.72	0.70	0.84

*,**,***, NS= linear component significant at $P \leq 0.05, 0.01, 0.001$, or not significant, respectively.

ter weight. At the 20% intensity of cluster thinning, vine self-regulation warranted full yield compensation through significantly increased berry size and cluster weight. In 1997, due to quite favourable environmental conditions for ripening, +156 and +143 degree-days, base 10°C, as compared to 1995 and 1996, respectively, and lower rainfall during the two months prior to harvest, the impact of the 40% cluster thinning on vine yield was negligible.

Total soluble solids, anthocyanins and phenolics increased linearly with thinning severity in two out of the three seasons (Tables 3 and 4). Juice pH and titratable acidity (TA) were rather variable, although cluster thinning tended to reduce TA and increase pH (Table 3). In 1995 and 1996, improvements in soluble solids content in cluster-thinned vines were consistent with lower yield levels (Table 3) whereas the reduction of titratable acidity and the slight increase of juice pH were probably attributable to an earlier ripening. Similar results have also been reported by Looney (1981), Bravdo *et al*. (1984 a) and Reynolds (1989).

Table 3 - Effects of cluster thinning on soluble solids, titratable acidity and pH at harvest in Sangiovese, Merlot and Cabernet Sauvignon grapevine cultivars

Cultivar	Thinning	Soluble solids (°Brix)			Titratable acidity (g/l)			Juice pH		
		1995	1996	1997	1995	1996	1997	1995	1996	1997
Sangiovese	0%	17.3	17.1	21.4	8.5	8.2	6.3	3.01	3.08	3.26
	20%	18.0	18.9	21.8	8.8	7.5	6.1	3.04	3.11	3.22
	40%	18.4	21.1	22.0	8.0	7.2	5.9	3.04	3.12	3.21
Significance		*	***	NS	NS	**	NS	NS	NS	NS
r^2		0.54	0.94	---	---	0.71	---	---	---	---
Merlot	0%	20.6	21.0	21.4	9.7	6.8	6.5	3.13	3.29	3.32
	20%	21.4	21.2	22.8	9.5	6.7	6.3	3.15	3.27	3.28
	40%	22.6	22.8	22.6	8.8	6.5	6.4	3.18	3.44	3.36
Significance		**	**	NS	**	NS	NS	***	NS	NS
r^2		0.79	0.67	---	0.64	---	---	0.85	---	---
Cabernet S.	0%	20.2	21.0	21.6	9.7	8.0	7.6	3.05	3.21	3.22
	20%	20.0	21.4	22.2	9.5	7.9	7.1	3.09	3.19	3.23
	40%	22.0	23.2	22.0	8.8	7.5	7.2	3.13	3.25	3.27
Significance		*	**	NS	*	NS	NS	*	NS	NS
r^2		0.55	0.74	---	0.55	---	---	0.46	---	---

*,**,***, NS= linear component significant at $P \leq 0.05, 0.01, 0.001$, or not significant, respectively.

Table 4 - Effects of cluster thinning on anthocyanins, polyphenols and total nitrogen content at harvest in Sangiovese, Merlot and Cabernet S. grapevine cultivars

Cultivar	Thinning	Anthocyanins (mg/cm^2 berry skin)			Polyphenols (mg/cm^2 berry skin)			Total nitrogen (% s.s.)	
		1995	1996	1997	1995	1996	1997	1996	1997
Sangiovese	0%	0.412	0.453	0.602	1.42	1.95	1.34	0.35	0.56
	20%	0.580	0.596	0.652	1.89	2.37	1.84	0.56	0.56
	40%	0.610	0.692	0.639	1.94	2.42	1.87	0.49	0.70
Significance		***	***	NS	**	*	NS	NS	**
r^2		0.83	0.96	---	0.80	0.57	---	---	0.65
Merlot	0%	0.491	0.487	0.576	1.51	1.63	1.24	0.42	0.49
	20%	0.571	0.554	0.641	1.73	2.00	1.46	0.63	0.49
	40%	0.824	0.742	0.653	2.10	2.37	1.56	0.49	0.53
Significance		***	***	*	**	**	NS	NS	NS
r^2		0.90	0.91	0.49	0.68	0.77	---	---	---
Cabernet S.	0%	0.652	0.786	0.691	1.80	1.91	2.08	0.38	0.29
	20%	0.670	0.772	1.021	2.10	2.60	2.52	0.70	0.42
	40%	1.024	0.942	1.073	2.70	2.84	2.55	0.56	0.56
Significance		**	*	***	***	**	NS	NS	***
r^2		0.78	0.62	0.83	0.81	0.79	---	---	0.95

*,**,***, NS= linear component significant at $P \leq 0.05, 0.01, 0.001$, or not significant, respectively.

Data pooled from cultivars and years resulted in negative correlations between total soluble solids and yield level, while positive linear relationships were found between anthocyanins in berry skin and soluble solids in berry juice (Fig. 4). Overall, regulation of yield through cluster thinning is strictly dependent on year; the grape composition is generally improved and this assumes particular importance in seasons marked by unfavourable environmental conditions or in very productive vineyards due to either high fertility cultivars (i.e. Sangiovese) or soils. The increase of polyphenols and anthocyanin content recorded in both 20% and 40% cluster-thinned vines is of great significance for the production of high quality red wine, especially when targeted to aging. Since manual cluster thinning is a very expensive operation due to large labour requirements, its mechanization is a very needed, yet largely unresolved issue. In Grenache and Tempranillo grapevines trained to vertical, shoot-positioned mechanical berry thinning performed with a grape harvester was effective to reduce yield while achieving more ripened grapes and wines with higher alcohol and pH values, more intense colour and increased phenolic compounds (Diago *et al.,* 2010 b).

4. Shoot hedging

Practices aimed at manipulating vegetative growth during late-spring and summer, particularly in vigorous vineyards, can substantially influence yield and grape composition (Intrieri *et al*., 1983; Kliewer and Bledsoe, 1987; Reynolds and Wardle, 1989). Hedging is a common management practice used to maintain canopy shape, reduce vine vigour, improve the microclimate in the fruiting zone, increase the efficiency of disease treatments and facilitate harvest and access of machines to the vineyard rows. Compared with other summer management practices used for similar purposes, such as leaf removal and pulling of lateral shoots, hedging is commonly used because it can

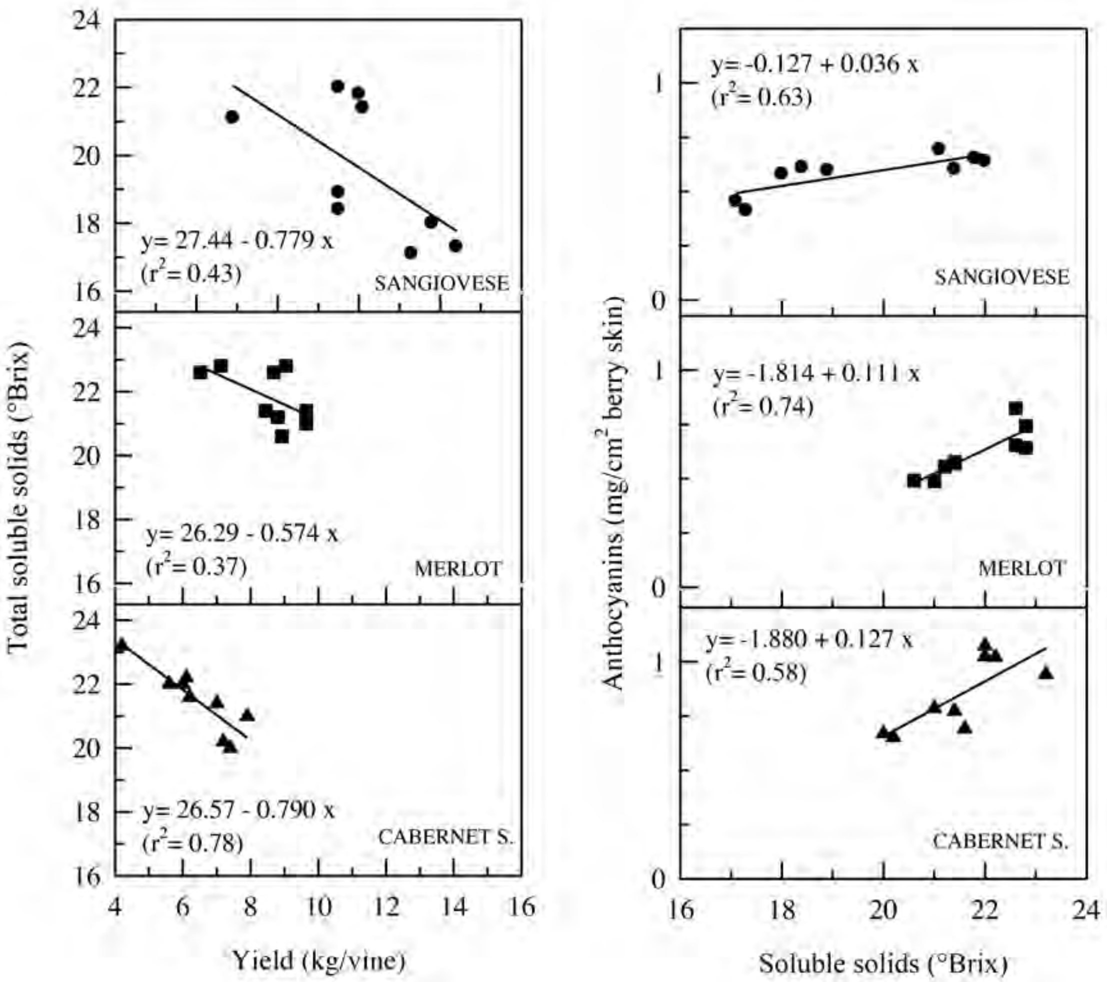

Fig. 4 - Relationship between yield per vine and total soluble solids (left) and total soluble solids and anthocyanins content in the berry skin at harvest (right).

be done completely mechanically and therefore is easy, fast and cheap. The effects of hedging on yield and fruit quality, considering the variables of timing and severity of application, are strictly associated to the ability of the cultivar to develop lateral shoots and their photosynthetic capacity from veraison to harvest (Cartechini *et al.,* 1998).

The impact of hedging severity on vine performance is well known; severe hedging, i.e. less than six main leaves retained per shoot, generally reduces grape quality (Kliewer and Bledsoe, 1987; Reynolds and Wardle, 1989; Palliotti, 1992), whereas the time of application is rather controversial because other factors may also influence these effects such as bud load, shoot orientation, training system, environmental conditions, soil characteristics, water availability, and so on (Intrieri *et al*., 1983; Reynolds and Wardle, 1989).

Vertical shoot positioned (VSP) training systems are normally trimmed when their shoots exceed the wires placed at the top of the canopy. Therefore, the timing is poorly dependent on grower's decisions and it is instead a function of intrinsic shoot vigour and vine balance. A balanced vineyard would reach the height suitable for trimming around fruit set, whereas an excessively vigorous one would get to the same growth stage much earlier, therefore making shoot trimming more likely to be repeated again later in the season. Timing of trimming follows different rules when performed on sprawl canopies (i.e. a single high wire trellis) where an early (pre-flowering) shoot trimming might be made necessary by the need to induce mostly upright shoot growth habits.

A two-year trial, aimed at assessing the effect of timing of hedging (one and five weeks after full bloom, AFB) on yield and grape composition in different red and white grapevine cultivars grown on fertile clay soil and trained to a single high wire trellis, showed that hedging at the 9-10th node on primary shoots, carried out one week AFB, markedly changed canopy characteristics, yield and grape composition (Fig. 5 and Tables 5, 6, 7 and 8) (Cartechini *et al.,* 1998). In untrimmed Sangiovese, Cabernet Sauvignon and Verdello vines, leaf area build up progressed rapidly from about 30 to 120 days after bud burst (Fig. 5). The development of laterals and relative leaf area occurred from 60 to 110 days after bud burst in Sangiovese and from 60 to 140 days after bud burst in Cabernet Sauvignon and Verdello.

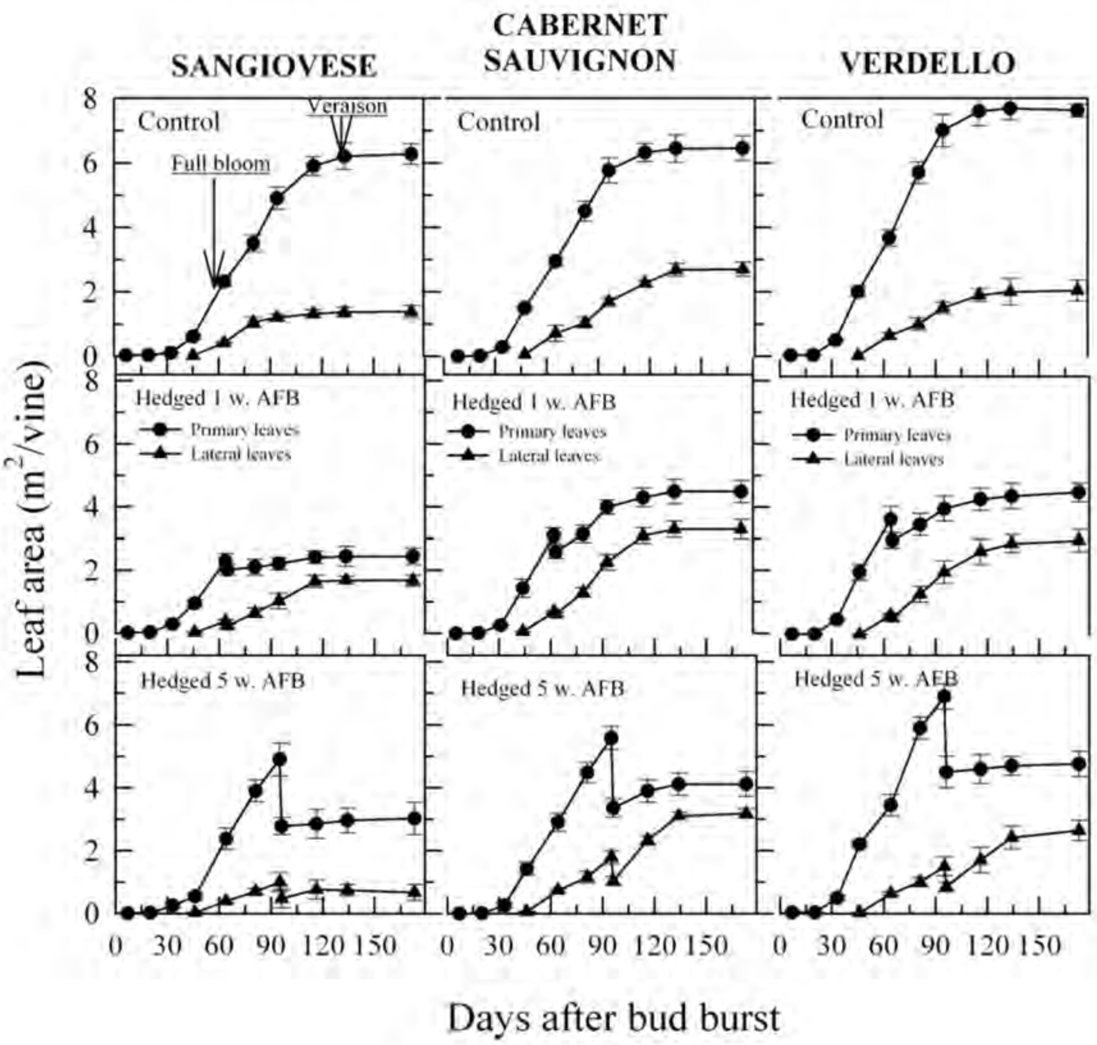

Fig. 5 - Development of primary and lateral leaves in Sangiovese, Cabernet Sauvignon and Verdello grapevine cultivars hedged one and five weeks after full bloom (AFB) as compared to the untrimmed control (n = 3 ± SE).

In all the cultivars, from flowering to veraison, the total leaf area increased more than three-fold. At the end of canopy growth, the Sangiovese had less total leaf area than Cabernet Sauvignon and Verdello (-1.5 and -2.0 m^2/vine, respectively) and the laterals represented 18, 32 and 22% of the total leaf area in Sangiovese, Cabernet Sauvignon and Verdello, respectively. Up to the end of canopy growth, Sangiovese, Cabernet Sauvignon and Verdello hedging one and five weeks AFB produced about 1.1, 3.9 and 3.5 and 0.9, 3.4 and 3.1 m^2 of new leaves per vine, respectively, derived mainly from lateral development.

In all cultivars, early-hedging, one week AFB, generally increased the contents of soluble solids, total nitrogen and total polyphenols (Tables 6, 7 and 8) as well as anthocyanins content in the red cultivars (Table 8). Early-hedging significantly reduced the titratable acidity and juice pH in all the cultivars (Table 6 and 7). Late-hedging, five weeks AFB, instead significantly reduced yield in Sangiovese and, except for Sauvignon blanc, the soluble solid content was significantly reduced as well as anthocyanins content in both red cultivars.

The positive outcomes of the early-hedging were likely dependent upon a cultivar's ability to develop lateral shoots after trimming (Fig. 5). All the cultivars with a good capacity to produce laterals, such as Cabernet Sauvignon, Verdello, Drupeggio and Sauvignon blanc, responded better to early summer pruning as shown by the increased cluster weight and yield and improved contents of soluble solids, total polyphenols and nitrogen content. Trimming vines increased lateral growth and

Table 5 - Yield and average cluster weight at harvest in vines of different grapevine cultivars hedged one and five weeks after full bloom (AFB) and control (n= 60)

Cultivar	Yield (kg/vine)			Cluster weight (g)		
	Control	Hedged 1 week AFB	Hedged 5 weeks AFB	Control	Hedged 1 week AFB	Hedged 5 weeks AFB
Sangiovese	7.4 b	7.3 b	6.0 a	279.8 b	292.4 b	253.5 a
Cabernet S.	6.0 a	7.8 b	5.5 a	122.9 a	143.7 b	110.5 a
Verdello	7.0 a	8.2 b	6.9 a	215.6 a	276.6 b	218.7 a
Drupeggio	7.4 a	9.1 b	7.2 a	238.7 a	275.7 b	235.4 a
Sauvignon b.	4.0 a	5.2 b	3.9 a	106.5 a	129.3 b	103.8 a

For each grapevine cultivar, the means followed by different letters are significantly different at $P \leq 0.05$.

Table 6 - Soluble solids content and titratable acidity at harvest in different grapevine cultivars hedged one and five weeks after full bloom (AFB) and control

Cultivar	Soluble solids (°Brix)			Titratable acidity (g/l)		
	Control	Hedged 1 week AFB	Hedged 5 weeks AFB	Control	Hedged 1 week AFB	Hedged 5 weeks AFB
Sangiovese	23.2 b	23.9 b	21.8 a	6.6 b	6.1 a	6.8 b
Cabernet S.	23.4 b	23.7 b	22.9 a	7.1 b	6.6 a	7.3 b
Verdello	19.4 b	21.0 c	17.8 a	8.5 b	8.0 a	8.6 b
Drupeggio	20.3 b	21.9 c	18.1 a	8.4 b	7.8 a	8.3 b
Sauvignon b.	20.5 a	23.1 b	20.4 a	8.8 b	8.2 a	9.0 b

For each grapevine cultivar, the means followed by different letters are significantly different at $P \leq 0.05$.

Table 7 - Juice pH and berry nitrogen content at harvest in vines of different grapevine cultivars hedged one and five weeks after full bloom (AFB) and control

Cultivar	Juice pH			Total nitrogen (% d.w.)		
	Control	Hedged 1 week AFB	Hedged 5 weeks AFB	Control	Hedged 1 week AFB	Hedged 5 weeks AFB
Sangiovese	3.42 b	3.35 a	3.36 a	0.48 a	0.63 b	0.45 a
Cabernet S.	3.40 b	3.22 a	3.29 a	0.63 a	0.98 b	0.55 a
Verdello	3.06 b	3.00 a	2.99 a	0.42 a	0.59 b	0.41 a
Drupeggio	3.08 b	3.03 a	3.04 a	0.44 a	0.68 b	0.38 a
Sauvignon b.	3.07 b	3.01 a	3.02 a	0.51 a	0.66 b	0.45 a

For each grapevine cultivar, the means followed by different letters are significantly different at $P \leq 0.05$.

Table 8 - Anthocyanins and total polyphenol content at harvest in the berry skin of different grapevine cultivars hedged one and five weeks after full bloom (AFB) and control

Cultivar	Anthocyanins (mg/cm^2 berry skin)			Polyphenols (mg/cm^2 berry skin)		
	Control	Hedged 1 week AFB	Hedged 5 weeks AFB	Control	Hedged 1 week AFB	Hedged 5 weeks AFB
Sangiovese	0.754 b	0.958 c	0.412 a	1.65 b	2.24 c	1.09 a
Cabernet S.	1.095 b	0.998 b	0.773 a	2.07 a	2.96 b	1.90 a
Verdello	---	---	---	0.88 a	1.25 b	0.80 a
Drupeggio	---	---	---	0.91 a	1.19 b	0.81 a
Sauvignon b.	---	---	---	0.82 a	1.12 b	0.75 a

For each grapevine cultivar, the means followed by different letters are significantly different at $P \leq 0.05$.

the total final leaf area was always less than that recorded in control vines (from 15 to 49% less). At harvest, in all the grapevines tested, early-hedging reduced the leaf/fruit ratio from 33 to 45% in comparison to the control vines and improved the soluble solids content (from 0.3 to 1.6°Brix), whereas late-hedging caused a reduction of both leaf/fruit ratio and soluble solid accumulation in the berries (Fig. 6). The rejuvenation of leaf area in the canopy following early-hedging and their high photosynthetic efficiency from veraison to harvest of the newly formed lateral leaves (Fig. 7) likely reduced the leaf area per gram of fruit required to achieve adequate ripeness. These laterals also translocate assimilates to the subtending clusters very efficiently (Candolfi-Vasconcelos and Koblet, 1990). Negative results found on late-hedged vines, also reported by other authors (Intrieri *et al.*, 1983; Palliotti, 1992), are probably linked to the fact that lateral shoots compete with the developing grapes for carbohydrates, causing delayed berry growth and sugar accumulation.

Early-trimming reduced titratable acidity as compared to control vines due to greater cluster exposure to sunlight

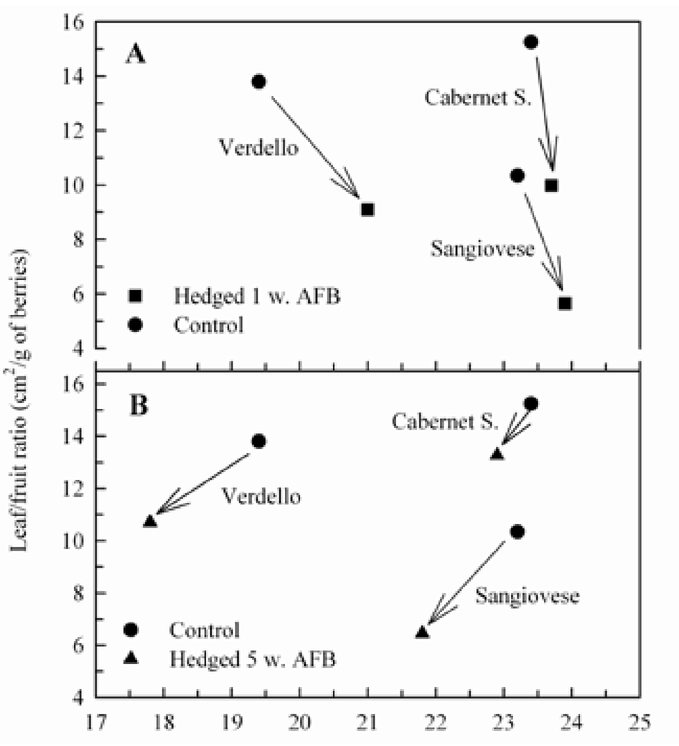

Fig. 6 - Relationship between must total soluble solids and leaf/fruit ratio at harvest in vines of Sangiovese, Cabernet Sauvignon and Verdello either untrimmed or trimmed one (A) and five (B) weeks after full bloom (AFB).

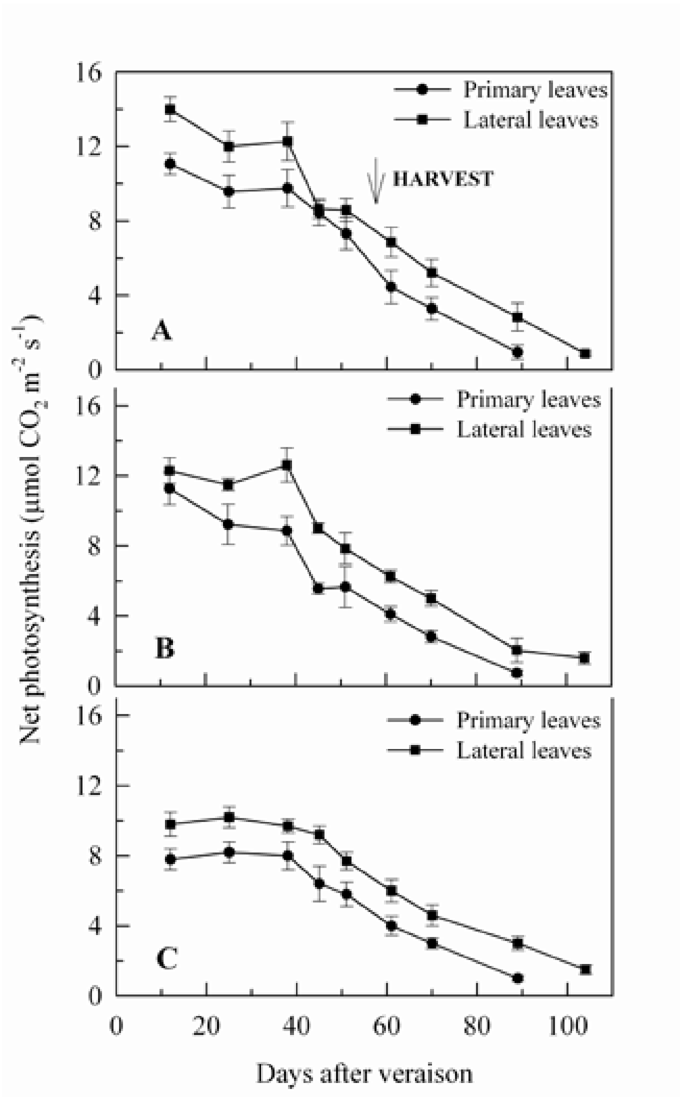

Fig. 7 - Evolution of net photosynthesis of primary and lateral leaves from veraison to leaf fall in Sangiovese, Cabernet Sauvignon and Verdello grapevine cultivars (n = 8 ±SE).

and a consequent decrease of malic acid content due to respiration activity. In addition, the reduced must pH with early-hedging is probably linked to the reduction of both the malic acid and potassium contents in the must in association with lower total leaf area. Bledsoe *et al.* (1988) found a significant positive correlation between these two parameters and juice pH.

In all the grapevine cultivars that develop many laterals after hedging, the greater transpiration rate (from +15 to 35%, data not shown) assessed in these leaves, compared with primary ones, particularly in August and September, may aggravate susceptibility to vine water stress especially in hot environments and in particularly dry years. During the first two weeks of November, the laterals on the vines had net photosynthesis values that ranged from 0.7 to 1.6 μmol CO_2 m^{-2} s^{-1} (Fig. 6), in a period when all the carbohydrates fixed are very useful for the reserve accumulation, and therefore for increased cold hardiness (Wample and Bary, 1992) and even for budbreak and initial shoot growth the following season. Thus, at the end of the season care must be taken to maintain the integrity of these leaves until total abscission occurs. Early winter pruning, practiced in some viticulture areas, should be avoided.

5. Shoot positioning

In VSP canopy trellis systems, shoot positioning is performed to maintain canopy form and shoot separation, to create a uniform distribution of leaves that minimizes cluster shading as well as to optimize canopy light interception and allowing the transit of mechanical equipment between rows. Shoot positioning also exerts a positive effect on disease incidence and severity; usually disease pressure is lessened due to increased air flow and sunlight penetration inside the vine canopy. Another important effect of this canopy management technique is that it has a positive impact on the development of fruitful buds and therefore for the vine yield in the following year.

The way shoot positioning is performed depends mainly on the training systems. In a VSP system the process consists of directing the shoots growing up between a set of catch wires as they develop. The vertically positioning of shoots can be done manually or using movable wires and done several times during the growing season. Mechanical shoot positioning on VSP trellis systems with specialized equipment has undergone a notable increase in recent years.

On Geneva Double Curtain (GDC) training system the shoots are positioned downward and separated out from the permanent cordon in order to reduce the vigour of shoots and attain optimal canopy density. In the GDC trellis, shoot positioning is performed on the interior part of the canopy to maintain two distinct canopies avoiding excessive shading in the central part of the canopy. Usually, in most training systems, shoot positioning is performed one or two weeks after bloom, before tendrils have become firmly attached. For best results, however, two or three shoot positioning runs during the season are needed.

6. Conclusions

Vineyard management should aim to achieve and maintain high efficiency over time, which is closely dependent on the ability to control the competition both between-and intra-vine. This approach would warrant a fair and fruitful balance between vegetative and productive activity of the vines and the best expression of grape quality (Smart and Robinson, 1991) without costly additional inputs. Since the “perfect” vineyard able to reach and maintain this equilibrium in a natural way during the season is generally utopia, summer pruning often plays a crucial role.

In light of the climate change in progress, an important challenge for old and new vineyards will be the matching of tradition and innovation. This raises the question of new techniques of canopy management, availability of rootstocks of low-to-moderate vigour, new cultivars better adapted to higher temperatures and water shortage and more intense mechanization. The latter assumes particular importance especially when the wines produced must be sold in un-bottled form or within large organized distribution (LOD) chains, like supermarkets, hypermarkets and discount markets. Currently, at least in Italy, LOD commercialize about 70% of the entire Italian wine production (which corresponds to about 48-50 million hl per year) (ISMEA, 2007), where the binomial “adequate quality”-“moderate selling price” is still dominant.

Global warming requires rapid adaptation and poses the crucial question of ripening modulation. In white grape varieties, the major challenge is the preservation of organic acids and primary grape flavours; whereas in black-berried cultivars the priority is producing wines with moderate alcohol content without modifying colour intensity and wine sensory. Some traditional and innovative canopy management practices can help to achieve these results, such as light pruning (Petrie *et al.,* 2003), early leaf removal (Poni *et al.,* 2006; Palliotti *et al.,* 2011 b), late defoliation and severe summer pruning (Stoll *et al.,* 2010), use of anti-transpirants (Palliotti *et al.,* 2010, 2011 a), canopy treatment of exogenous auxins (Böttcher *et al.,* 2010) and brassinosteroid and brassinazole steroidal hormones (Symons *et al.,* 2006). However, such lines of research will require more data inputs to better clarify the causes responsible for variability in vine yield, grape composition and wine quality according to seasons and grapevine varieties and to develop the best operative strategy for crop regulation.

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