

## Vine performance and leaf physiology of conventionally and minimally pruned Sangiovese grapevines

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### Summary

**A three-year-study (1996-1998) was carried out on field-grown Sangiovese grapevines under the temperate, humid climate of the Po Valley (northern Italy) to assess their degree of adaptation to minimal pruning (MP) as compared to conventional pruning (CP). Evaluation included canopy growth, yield, berry ripening and grape rot incidence. In 1996 leaf function was determined as net assimilation (A); seasonal total canopy light interception and percentage of canopy gaps were also measured.**

**As compared to CP, over the 3-year period MP showed typical features of a more rapid canopy development and earlier growth cessation, higher shoot number with shorter shoots and smaller leaves, higher yields with smaller and looser clusters less susceptible to bunch rot. Must sugar concentration was significantly lowered.**

**Seasonal rates of A recorded on single leaves of the two pruning treatments at different shoot positions were overall similar except for higher A in young MP leaves having a chronological age of about 8-10 d. MP also showed the tendency of retarded leaf senescence. The seasonal total light interception trends indicated a linear increase with formation of leaf area in CP, whereas total light interception in MP augmented until about 50 % of canopy filling and then remained constant with further leaf area development. This suggests that about half the leaf area produced in the MP vines contributed mostly to mutual shading rather than enhancing light interception capability, and, hence, photosynthetic capacity.**

**The overall data indicate that a satisfactory balance in the minimally pruned Sangiovese grapevines can only be reached with further adjustments of crop level to be performed either as partial winter and/or summer pruning. Nevertheless, in MP vines the consistent feature of looser clusters which are much less susceptible to bunch rot is crucial in an area usually characterized by abundant rainfall at pre-harvest.**

**Key words:** pruning, bud load, gas exchange, grape quality, light interception.

### Introduction

Minimal pruning of cordon-trained vines (MPCT) is a canopy management system originally developed and cur-

rently adopted in several warm, irrigated grape districts of Australia (CLINGELEFFER 1983, 1984; POSSINGHAM 1994). In such areas, work done on Riesling, Chardonnay, Shiraz and Cabernet Sauvignon (CLINGELEFFER and POSSINGHAM 1987; POSSINGHAM 1996) has shown that a satisfactory balance between vegetative growth and crop level can be reached with almost "no pruning" since the increase in leaf area achieved by retaining more buds with MPCT can usually meet the demand for the additional 20-40 % yield increase as compared to conventionally (hand) pruned vines. Further investigation conducted in cooler Australian districts (CLINGELEFFER 1993; SOMMER and CLINGELEFFER 1993) and in Upstate New York (POOL *et al.* 1993) have indicated that MPCT is still feasible provided that supplementary crop size control is ensured through winter and/or summer pruning, the latter including mechanical cluster thinning applied at fruit set. Within the same climatic area, the need for crop adjustment is more urgent if late ripening cultivars or vigorous rootstocks are chosen; lack of appropriate crop control under such circumstances may lead to severely delayed or incomplete ripening (POSSINGHAM 1996).

The general impression obtained from the large body of work mainly conducted in Australia on MPCT is that of a technique which is highly sensitive to parameters like climate and season, soil type, grape variety, rootstock, and cropping level. However, there are two major features triggered by the MPCT which appear extremely consistent and therefore rather independent of both, site and management factors; a) an earlier canopy filling in spring leading to higher total canopy assimilation (A) rates from budbreak till about fruit set; and b) an altered cluster structure, *i.e.* bunches that are smaller in size, less compact, having smaller berries with an increased skin-to-pulp ratio. These features may help to explain why well-balanced MPCT vines show both increased yield and grape quality.

The MPCT technique has also been tested in Europe with somewhat contradictory results, which essentially confirm its sensitivity to both environmental and cultural conditions. Long-term trials carried out in northern Europe (SCHULTZ *et al.* 1999) have shown the potentialities of MPCT for Riesling and Pinot noir to produce quality wines even with vines of moderate vigor. In other cases, results on MPCT were judged unsatisfactory with respect to yield (OLLAT *et al.* 1993) and quality (CARBONNEAU 1991; MARTINEZ DE TODA and SANCHÀ 1998).

A preliminary three-year comparison of the physiological and viticultural behavior of minimally versus conven-

tionally pruned Chardonnay grapevines carried out in a hot, irrigated area of Sicily (IACONO *et al.* 1998) proved to be promising since grape quality of MPCT vines was but slightly affected despite a yield increase of 60 % compared with conventional pruning. To our knowledge, no results of long-term experiments with MPCT have been published for locations in the cooler districts of northern Italy with medium-to-late ripening varieties.

The purpose of the present study was to evaluate compensation mechanisms, vine balance and grape quality of minimally pruned Sangiovese grapevines versus conventional pruning within the environment of the Central Po Valley in northern Italy, *i.e.* a medium-to-high vigour district usually marked by late season rainfall.

### Material and Methods

**Plant material and experimental layout:** A single, north-south oriented row of 12-year-old Sangiovese (clone 12 T) grapevines grafted to SO 4 was used. Vines were planted at 1 m intrarow spacing and trained to a narrow T trellis featuring two parallel cordons spaced at 35 cm and placed 1.7 m above the ground without foliage wires. In winter 1995 four 10 m long row sections were randomly assigned to either conventional pruning (CP) and minimal pruning (MP) and 4 vines per treatment (two per row section) were tagged. To increase MP node number the next season (1996, trial year 1), the MP row sections were lightly pruned in winter 1995. Data recording started in spring 1996 and continued till 1998. CP consisted in retaining 8-10 two-node spurs per meter cordon (16-20 spurs per vine), whereas MP was applied in 1996 as a low winter canopy skirting and in 1997-1998 as a more severe cut performed 70 cm above and on the side of the cordons. A mechanical summer canopy skirting was applied each year when CP's vigorous hanging shoots started to reach the ground (mid to late July). Cutting was performed in both treatments at approximately 50 cm above the ground and resulted in negligible leaf removal for the MP vines.

**Vegetative growth and leaf age determination:** Total nodes per vine were counted each year after winter pruning; no distinction was made in MP between nodes borne on one-year-old or lateral wood. Date of budbreak was visually estimated when at least 50 % of total nodes per vine had passed the "woollen bud" stage (BAGGIOLINI 1952). Shoot number was assessed on each vine about two weeks after budbreak in 1996 and 1998, while in 1997 shoot counting was performed much later (about 40 d after budbreak) due to a severe spring frost which caused a staggered sprouting.

Ten shoots per vine, evenly distributed on both sides of the row, were selected each year on the canopy exterior when they had formed about 3-4 expanded leaves; they were used for both, vegetative growth and physiological assessment (the latter being limited to 1996). Total shoot elongation and the number of unfolded leaves (including laterals) were measured at varying intervals throughout the season. Lamina length and maximum width were also recorded for each leaf of the marked shoots. Leaf area was then calcu-

lated from a linear regression ( $y = 3.3 + 0.78 x$ ;  $r^2 = 0.98$ ) established between length  $\times$  maximum width and actual leaf area (determined by a portable Li-Cor area meter) of a leaf sample made up of 4 shoots per treatment removed on 5 May and 16 June 1996 from extra-vines. The age of each leaf along the stems (either main or lateral) was estimated by plotting for each node position the calculated leaf area versus time and extrapolating the date of leaf appearance back to the x-axis.

**Gas exchange and light interception:** The assimilation rate (A) of main and lateral leaves inserted on two well-exposed shoots per vine was measured in 1996 on 12 dates throughout the season starting on 6 May when shoots had formed 6-7 fully expanded leaves. The measurements were conducted at saturating light with a portable, flow-through CIRAS-1 (PP-System, Hertfordshire, UK) gas exchange featuring a broad leaf chamber having a window of 2.5 cm<sup>2</sup>. Airflow was adjusted to 300 ml min<sup>-1</sup> and all readings were taken at ambient relative humidity. On the first two dates (6 and 14 May) all leaves were measured from the shoot base towards the apex, whereas on all remaining dates every other main leaf was checked beginning with the first normally developed basal leaf. This procedure enabled us to complete the readings within a maximum of 3 h (usually 10:00 to 13:00) thereby minimizing variability due to diurnal fluctuation of photosynthesis. Lateral leaf readings regarded CP only, since almost no laterals developed in MP. All measured leaves were generally well exposed to sunlight at the time of measurements.

On July 25, 4 fully expanded but not yet senescent leaves per treatment were selected in well-exposed mid-shoot zones and their assimilation rate was measured at saturating light ( $> 1200 \mu\text{mol m}^{-2} \text{s}^{-1}$ ) and at varying levels of shading by placing neutral filters of differing density above the chamber window and the light sensor. Light response curves were recorded for each leaf in a "round trip" way (from maximum light to compensation point and vice versa).

Total canopy light interception was also measured in 1996 on 5 dates from budbreak to canopy closure on four 2-m row sections of each pruning system so as to include the 1 m long cordons of the test vines. A 105 cm long, custom-built ceptometer equipped with 16 single cosine-corrected sensors at 7 cm spacing was moved on a below-vine canopy grid of 2 m  $\times$  2 m to 10 locations per canopy (160 individual points) in approximately 2 min and data were recorded and stored by a CR10 Campbell data logger. The total incident light above the canopy (100 %) was also simultaneously measured by an elevated, horizontal PAR sensor; total light interception was calculated as 100 minus the estimated fractional light transmission to the vineyard ground (% T). Light readings were recorded three times a day, 2 h before solar noon, at solar noon and 2 h after solar noon on cloudless days.

In 1996 canopy filling was also assessed at 4 dates by a photographic method. A white rigid cardboard (1.5 m  $\times$  1.3 m) was placed underneath the canopy and held perpendicular to the sun to minimize interference with penumbral effects. The shade cast on the cardboard by the canopy was photographed with a black and white film at three different times during the day; enlarged prints were scanned to calculate

the percentage of the "dark surface" (*i.e.* intercepted light) against the white background. The percent of canopy gaps (*i.e.* light passing through the canopy and reaching the ground) was estimated as well.

**Yield, berry ripening and quality:** Yield and number of clusters per vine were recorded at harvest. Berry development was monitored by collecting 100-berry samples per vine at 7-10 d intervals beginning before veraison until harvest. To warrant random sampling, either exterior and interior berries were taken as well as berries located in the top, middle and bottom part of the cluster. Since in 1997 spring frost markedly lowered crop in both treatments, berry samples were reduced in both, frequency (7 sampling dates) and size (50 berries per sample).

In 1996 veraison date was assessed by measuring deformability of all sampled berries at 4 dates from pre- to post-veraison. Deformability was measured with a modified digital caliper by exerting one Newton (N) on a berry ( $\text{mm N}^{-1}$ ); veraison was set at the threshold of  $0.4 \text{ mm N}^{-1}$ . In 1997 and 1998 the date of veraison was extrapolated from the curve of sugar accumulation in berries, *i.e.* the beginning of the steep increase in sugar concentration (COOMBE 1992). Juice was extracted from berry samples and total sugar concentration ( $^{\circ}\text{Brix}$ ) was determined using a temperature compensating Atago desk refractometer. Berry weight and cluster compactness were yearly evaluated at harvest on 20 clusters per treatment according to the rating recommended by the IBPGR (1983). The same clusters were used to estimate the percentage of rotten cluster surface over total.

**Weather data and statistical analysis:** Weather data (daily mean air temperature and total rainfall) were recorded by an automated weather station located 0.3 km away from the experimental site.

Data analysis was performed as a factorial strip-plot design where "year" was the strip factor. Data of cluster compactness and incidence of rot were transformed into square root and arcsine prior to analysis.

## Results and Discussion

**Vegetative growth and light interception:** The MP vines had a significantly lower budburst rate (0.4 shoots per node) than CP (1.0 shoots per node) on a three-year basis which led to a 7-fold increase in shoot number versus an initial 17-fold difference in the number of retained nodes (Tab. 1). Although the number of retained nodes varied markedly among years (Tab. 2), the shoot:node ratio was quite constant for two years (*i.e.* in 1997 the percentage of budbreak was similar to that in 1996 in spite of a reduction in bud load by 50%), suggesting that the number of retained nodes was not always a reliable indicator of vine capacity under the conditions of the present study.

Shoot and internode length, main leaf size and total leaf area per shoot were much lower for MP than for CP (Tab. 1); this agrees with the expected dwarfing effects which are usually seen when a very high shoot number is let to develop. Nevertheless the high shoot number per vine in MP was able to more than compensate for the reduced vigor of individual shoots and the final total leaf area was 90% higher

Table 1

Growth, yield and ripening parameters for conventionally and minimally pruned Sangiovese canopies: \* indicates significant differences between pruning systems at the 5% level. NS indicates non-significance. Data are 3-year means

	Conventional Pruning (CP)	Minimal Pruning (MP)	t-test
Nodes per m of row	38	644	*
Shoots per m of row	38	266	*
Shoots per node	1.0	0.4	*
Shoot length (cm) <sup>a</sup>	150	44	*
Total nodes per shoot <sup>b</sup>	26.1	14.7	*
Internode length (cm)	5.7	3.0	*
Single main leaf area (cm <sup>2</sup> )	127	62	*
Shoot leaf area (dm <sup>2</sup> )	33.1	9.1	*
Leaf area per m of row (m <sup>2</sup> )	12.6	24.2	*
Yield per m of row (kg)	4.3	10.0	*
Clusters per m of row	31	129	*
Clusters per shoot	0.83	0.46	*
Cluster weight (g)	136	83	*
Berry weight (g)	2.62	1.94	*
Berries per cluster	52	43	NS
Leaf-to-fruit ratio (m <sup>2</sup> kg <sup>-1</sup> )	2.9	2.4	*
Total soluble solids ( $^{\circ}\text{Brix}$ )	20.2	18.2	*
Total sugar per m of row (kg)	0.87	1.82	*
pH	3.39	3.34	NS
Titrateable acidity (g·l <sup>-1</sup> )	7.9	7.1	NS
Rating of bunch density <sup>c</sup>	6.5	2.6	*
Rot incidence (%)	65.5	17.6	*

<sup>a</sup> Values recorded before shoot trimming. <sup>b</sup> Laterals included.

<sup>c</sup> Rated according to IBPGR (1993): 1 = very loose; 3 = loose; 5 = medium; 7 = dense; 9 = very dense.

than CP (24.2 m<sup>2</sup> m<sup>-1</sup> vs. 12.6 m<sup>2</sup> m<sup>-1</sup> of row, respectively). Thus, our data agree with Winkler's general principles (WINKLER *et al.* 1974) according to which pruning has a depressing or stunting effect on the vine and vine capacity varies directly with the number of shoots that develop. However, the latter correlation should not be taken for granted in studies on minimal pruning; there are reports in which, at MP:CP shoot number ratios similar to our study, the total leaf area of MP vines was either comparable (LAKSO *et al.* 1996) or even lower (DOWNTON and GRANT 1992) than conventionally pruned vines.

In 1996 the seasonal development of total leaf area was much faster in MP (Fig. 1, bottom) which had already formed 3 m<sup>2</sup> of leaf area per m of row 18 d after budbreak (DAB) with respect to 0.4 m<sup>2</sup> only for CP (Fig. 1, top). The slope of leaf area increment became similar between the two treatments from about 40 DAB onward due to a recovery of CP caused by faster shoot growth rates (data not shown). Leaf area development proceeded well beyond bloom in both pruning regimes although MP vines showed an earlier canopy closure (Fig. 1, bottom). Final maximum leaf area was about 29 m<sup>2</sup> m<sup>-1</sup> in MP versus 19 m<sup>2</sup> m<sup>-1</sup> reached by CP.

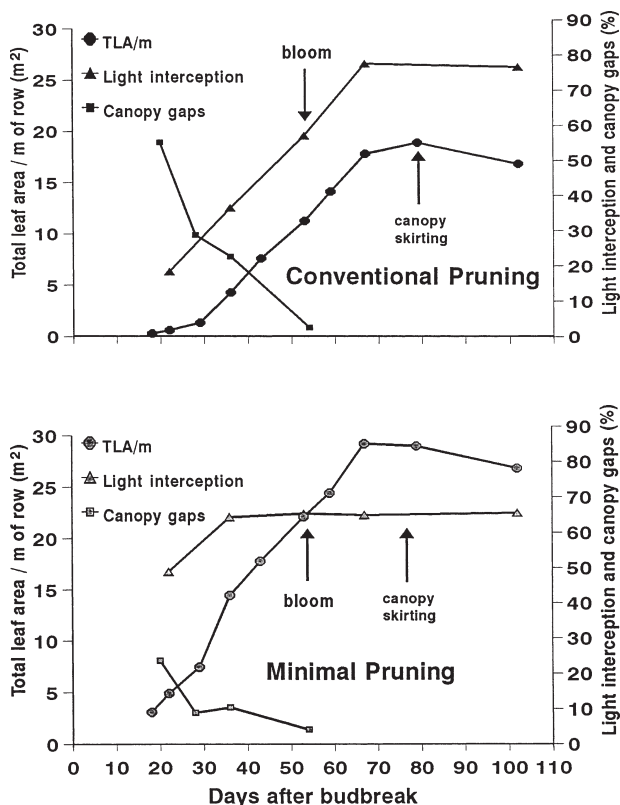


Fig. 1: Seasonal development of total leaf area (TLA) per meter of row, canopy light interception and canopy gaps recorded for conventionally (top) and minimally pruned (bottom) Sangiovese grapevines in 1996.

Total canopy light interception was linearly correlated with leaf area development in conventionally pruned vines, a correlation that was not found in MP. Minimally pruned canopies already reached their maximum light interception (65 % of incoming light) 35 DAB, when the vines had formed only 50 % of their final leaf area (Fig. 1, bottom) and further leaf area production in MP (up to 29 m<sup>2</sup> m<sup>-1</sup>) was not reflected in any additional increment in light interception. The main physiological implication of this effect is that the foliage produced in MP in excess of 14 m<sup>2</sup> m<sup>-1</sup> contributed mostly to mutual within-canopy shading and, as a consequence, very unlikely resulted in significant gains of whole-canopy photosynthesis. Given that the two pruning systems share the same free shoot growth habit, the low vigor of the shoots formed in MP and their insertion on thin, flexible one-year-old canes hinder the lateral expansion of the canopy which tends to assume a downward growing habit with leaf layers overlapping along a vertical plane. By contrast, the more vigorous CP shoots produced by short spurs inserted on a rigid framework (the cordon) allowed a widening of the canopy, which in turn enables more light to be intercepted.

The much faster canopy filling in MP is also attested by the seasonal evolution of the canopy gaps (*i.e.* light passing through the canopy) which were estimated to be 55 % in CP (Fig. 1, top) versus 22 % of MP (Fig. 1, bottom) on the first sampling date. In accordance with the light interception patterns, the percentage of canopy gaps dropped to close-to-minimum in MP by the second date (May 11), whereas a linear decrease was seen in CP. The earlier canopy filling

pattern with MP was also confirmed in 1997 and 1998 (data not shown).

**Gas exchange:** Mean A rates from all sampled leaves increased steadily till bloom in both systems, although MP showed significantly higher values on most dates (Fig. 2). Mid-season A was generally higher in CP, although it had a faster A decline late in the season. This decline was not observed in MP, which maintained comparable A rates from 60 DAB (post-bloom) till harvest. The trends reported in Fig. 2 suggest that leaf function of young leaves and leaf longevity is altered by pruning regimes. However, more insight into this matter is provided if A rates are plotted against leaf age (Fig. 3) to show a similar pattern for both treatments in the intermediate 20-100 d age span and higher assimilation rates for both, younger and older leaves in MP. At the age of 8 d, MP leaves had already had a positive net assimilation rate (2.1 μmol m<sup>-2</sup> s<sup>-1</sup>) while coeval CP leaves were still below the CO<sub>2</sub> compensation point. The same effect was intensified if mean A was calculated at each sampling date

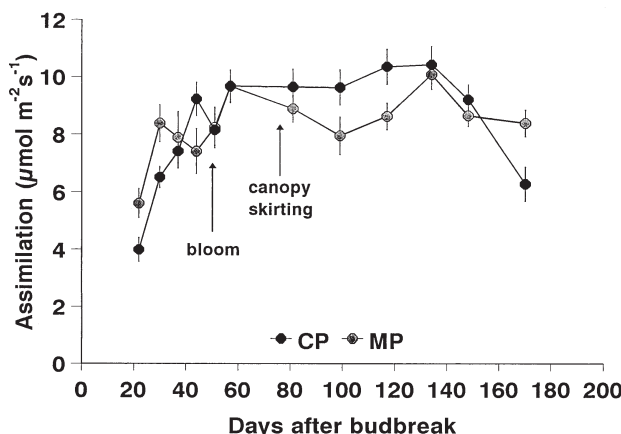


Fig. 2: Seasonal variation of CO<sub>2</sub> assimilation recorded at saturating light on well-exposed main leaves of conventionally (CP) and minimally pruned (MP) Sangiovese grapevines in 1996. Data are means of readings taken at different leaf positions along the main stem. Vertical bars indicate 2 x standard error (SE).

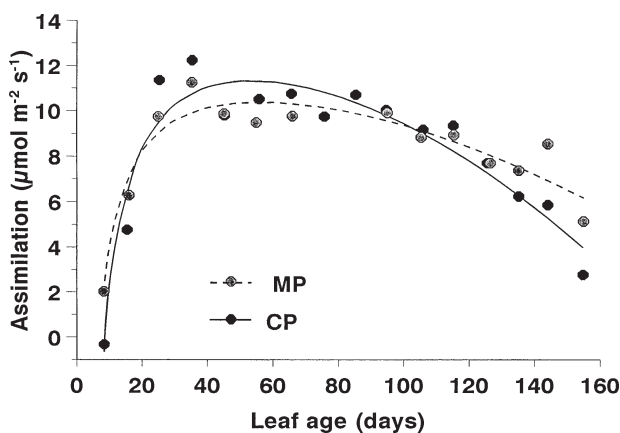


Fig. 3: Relationship between CO<sub>2</sub> assimilation at saturating light and chronological age for main leaves of conventionally (CP) and minimally pruned (MP) Sangiovese grapevines. Regression equations were:  $y = 14.96 - 0.00042x^2 - 130.83x$ ,  $r^2 = 0.91$  for CP;  $y = 12.74 - 0.00025x^2 - 89.62x$ ,  $r^2 = 0.88$  for MP.



for different shoot zones (Fig. 4). From budbreak to bloom the A rates measured in the apical shoot zone of MP (Fig. 4, bottom) were consistently higher than the rates recorded in the corresponding CP shoot zone (Fig. 4, top). Thereafter, the late-season drop in A was faster in CP regardless of leaf insertion at the main shoot.

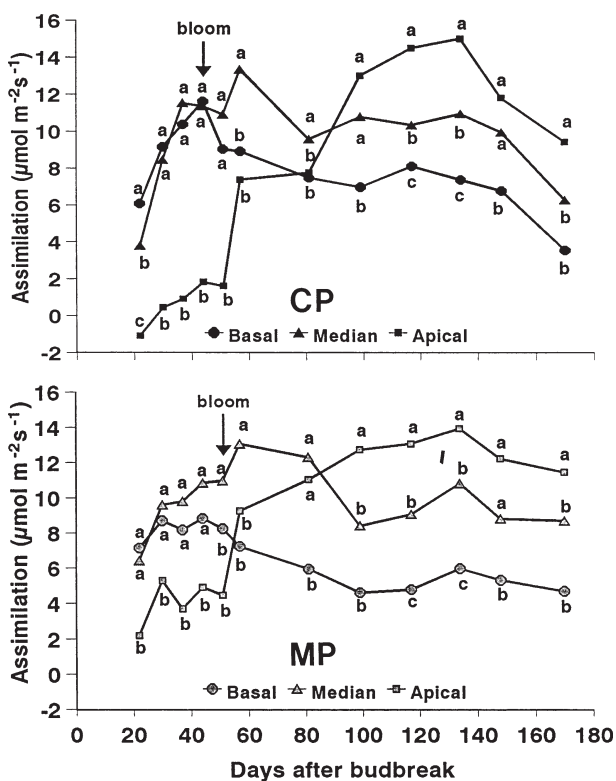


Fig. 4: Seasonal variation of CO<sub>2</sub> assimilation rates at saturating light averaged over different shoot zones for conventionally (CP, top) and minimally pruned (MP, bottom) Sangiovese grapevines. Mean separation within each date performed by the Student-Newman-Keuls test, 5% level.

The capacity of young (<15-d-old) leaves developing on minimally pruned vines to carry higher A rates than coeval leaves produced on conventionally pruned vines has not been reported previously in literature and should be regarded as an additional positive feature of minimal pruning. Thus, early season, whole-canopy photosynthesis typically detected on MP vines (LAKSO *et al.* 1996; PONI *et al.* 2000) does not appear to be due simply to faster canopy filling but also to an improved net photosynthesis of young leaves. The most likely explanation for such an effect may be inferred from Fig. 5 where the growth curves of leaf blades inserted at a given node (8<sup>th</sup> from basal) are shown for both treatments. Due to faster lamina expansion rates, full size was reached in about 30 d by the CP leaves as compared to 55 d for MP. The increased respiration costs associated with such high rates might be the main cause for lower net assimilation rates recorded on the youngest CP leaves.

In agreement with previous work (SOMMER and CLINGELFFER 1993; LAKSO *et al.* 1996), our data also provide evidence that leaf senescence is not accelerated by minimal

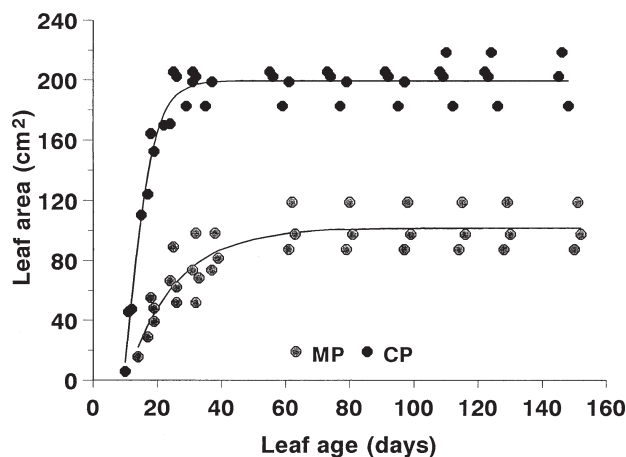


Fig. 5: Trends of lamina expansion for leaves located at the same position (8<sup>th</sup> from the shoot base) in conventionally (CP) and minimally pruned (MP) Sangiovese grapevines. Regression equations were:  $y = -168.65 + 368.14 / (1 + \exp(-(x-10.16)/4.33))$ ,  $r^2 = 0.94$  for CP;  $y = -4658.28 + 4760.07 / (1 + \exp(-(x-46.66)/14.90))$ ,  $r^2 = 0.75$  for MP.

pruning; indeed, they suggest that the lifespan is somewhat prolonged in MP. This may be correlated to the lower 'costs' for maintenance respiration of smaller-sized mature leaves in MP (see Tab. 1 for leaf size comparison between treatments) or may reflect the effect lateral development has on the assimilation rate of the main leaves of the same shoot. CANDOLFI-VASCONCELOS and KOBLET (1991) have convincingly shown that main grapevine leaves are able to retain higher A rates if laterals do not develop or develop but weakly on the same shoot (case of MP), whereas main leaf function is hindered if more vigorous lateral shoots are allowed to grow (as with CP).

In accordance with minimal pruning trials conducted with Riesling (DOWNTON and GRANT 1992), Cabernet Sauvignon (SOMMER and CLINGELFFER 1993) and Concord (LAKSO *et al.* 1996) maximum A rates recorded on mature but as yet non-senescent Sangiovese leaves of the two pruning systems were quite similar. Thus, it appears that the maximum photosynthetic capacity per unit leaf area does not change very much despite large variation in total leaf area. This suggests that physiological performance of minimally pruned vines has to be more closely related to effects that depend upon canopy structure and development (*i.e.* canopy filling, leaf exposure, leaf area expansion rate) rather than to changes in the photosynthetic performance of single leaves. This is also corroborated by the fact that no differences were found between treatments with regard to the assimilation rate of fully expanded leaves at varying levels of shading (data not shown).

**Yield, ripening and grape quality:** Yield per meter of row doubled in MP as compared to CP on a three-year-basis (Tab. 1) despite MP vines showing large yield compensation *e.g.* lower budbreak, shoot fruitfulness and cluster weight. Smaller clusters in MP were primarily the result of reduced berry size rather than reduced berry number per cluster. Yield variation over years clearly showed an alternate bearing pattern in MP which was triggered by a very high yield in 1996 (13.8 kg m<sup>-1</sup> of row) that resulted in a very low crop the next season (Tab. 2). Although in 1997 yields

Table 2

Variation over years of key vegetative, yield and grape quality parameters for which a significant year x pruning regime occurred. Data are means of 4 replicates. SEM= standard error of interaction means

	Conventional pruning			Minimal pruning			SEM
	1996	1997	1998	1996	1997	1998	
Nodes per m of row	44	25	45	902	419	611	39
Shoots per m of row	54	28	30	376	150	273	35
Shoots per node	1.24	1.14	0.66	0.38	0.36	0.45	0.06
Yield per m of row (kg)	6.7	2.8	3.5	13.8	4.8	11.3	1.56
Berry weight (g)	2.61	2.72	2.53	1.72	2.19	1.92	0.116
Clusters per shoot	0.79	0.75	0.96	0.41	0.33	0.66	0.18
Clusters per m of row	43	21	29	156	49	182	13.4
Total soluble solids ( $^{\circ}$ Brix)	20.0	21.1	19.6	15.0	21.5	18.0	0.48
Rating of bunch density <sup>a</sup>	8.1	5.5	6.0	2.4	4	1.5	0.50
Rot incidence (%)	62.9	38.7	95.0	32.2	11.6	8.9	4.26

<sup>a</sup> See explanation in Tab. 1.

were adversely affected by frost damage in both treatments, the key-factor for low yield in MP (Tab. 2) was bud fruitfulness (down to 0.33 clusters per shoot) which quite likely reflects lack of adequate source (*i.e.* effective leaf area) during bud induction and differentiation the previous season. It also should be pointed out that in 1997 and 1998 yields of CP were considerably lower (Tab. 2) than the average crop level of standard T-trellised spur-pruned Sangiovese grapevines at the specific site, ranging between 6-8 kg m<sup>-1</sup> of row (3-4 kg m<sup>-1</sup> of cordon). Especially in 1998, rot incidence also contributed to a lowering of CP yields.

The course of sugar accumulation in berries (Fig. 6) and the total sugar concentration ( $^{\circ}$ Brix) in berries at harvest of MP vines showed large year-to-year fluctuations which essentially paralleled yield levels (Tab. 2). The worst result was obtained in 1996 when MP vines showed a 4 d delay at the onset of veraison and final sugar concentration was that of unripe berries despite the late harvest date (October 3). Interestingly, the 5  $^{\circ}$ Brix difference in grape maturity of the two treatments at harvest 1996 was not reflected in the final titratable acidity (Fig. 6, top). Thus, berry sugar accumulation and degradation of total acidity proceeded as mostly uncoupled phenomena, the former being driven by a severe source limitation and the latter being quite likely affected also by microclimatic factors. Clusters of MP vines were predominantly at the canopy exterior whereas those of CP vines were mostly shaded. Therefore, better light exposure of MP clusters may also have caused higher berry temperature and, in turn, more rapid degradation of malic acid.

The significant year x treatment interaction which occurred for the rating of bunch compactness (Tab. 2) indicated that MP clusters were particularly loose in years with a high crop level (1996 and 1998). Low cluster compactness was paralleled by a spectacular reduction in rot incidence (as shown in Fig. 7 for 1996) in spite of the wet season recorded in both years. The total amount of rain from veraison to harvest was 238 and 234 mm in 1996 and 1998,

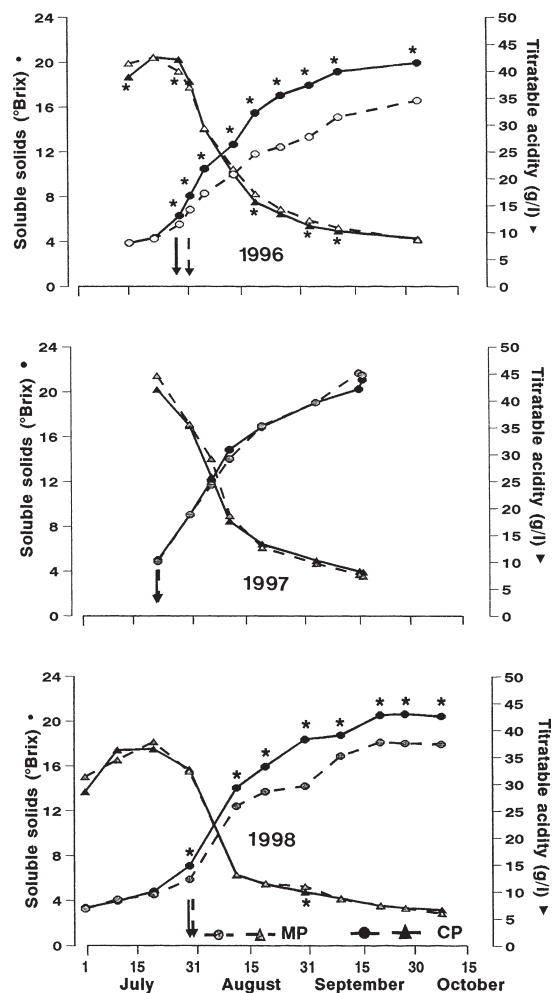


Fig. 6: Ripening pattern (total soluble solids,  $^{\circ}$ Brix, and titratable acidity, g l<sup>-1</sup>) of must in 1996, 1997 and 1998 in conventionally (CP) and minimally pruned (MP) Sangiovese grapevines. Arrows indicate veraison; \* indicates a significant difference (t-test, 5 % level) within each sampling date and pruning treatment.

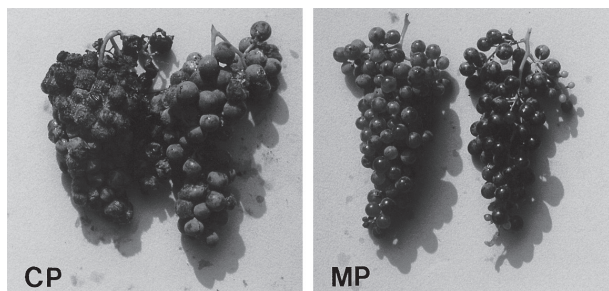


Fig. 7: Clusters of conventionally (CP) and minimally (MP) pruned vines harvested at mid-October in 1996 (about 2 weeks after the trial picking date). Note that clusters from CP vines show severe botrytis infection while clusters from MP vines are still perfectly healthy.

respectively, compared to only 79 mm in 1997 over the same period (Fig. 8). It has to be noted, though, that a significantly lower berry weight and bunch density was recorded in MP also in the "off" year, 1997 (Tab. 2). This suggests that minimally pruned Sangiovese vines can still maintain the highly desirable feature of loose or relatively loose clusters across a broad range of crop levels. Berry size and, to a lesser extent, berry number are likely to be negatively affected in MP by a source limitation (shoot basis) regardless of the final total amount of crop per plant.

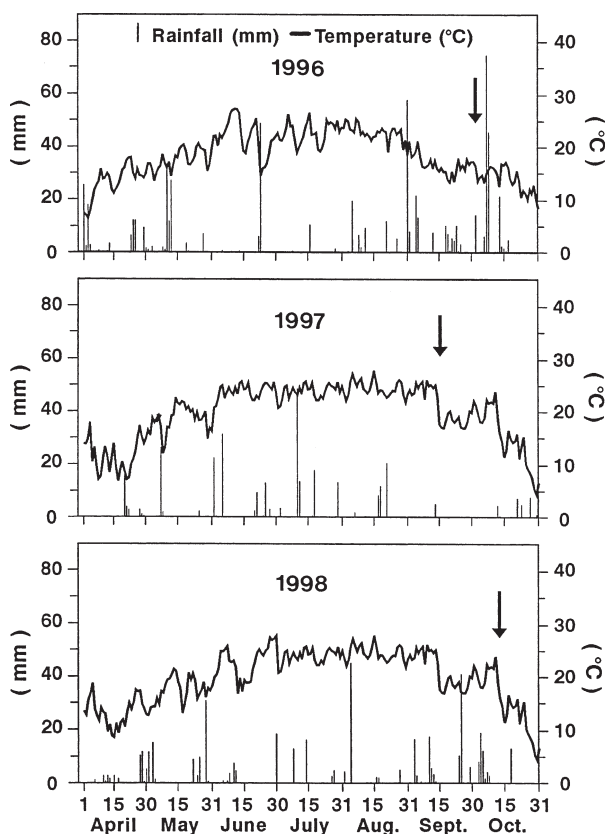


Fig. 8: Mean air temperature and total rainfall recorded near the experimental site (1 April to 31 October 1996, 1997 and 1998). Arrows indicate harvest date.

## Conclusions

Our overall data indicate a still unsatisfactory balance in MP Sangiovese grapevines (*i.e.* an alternate bearing pattern coupled with large crop-linked variation of grape quality) despite marked compensation registered for some yield components (namely lower shoot fruitfulness and cluster weight). They thus confirm that balancing MP vines is more troublesome if a medium-to-late ripening, highly fruitful cultivar like Sangiovese and a site allowing prolonged shoot growth well beyond bloom are chosen. However, the clusters of MP vines were distinctly less compact than those produced by CP and this feature was crucial in preventing massive bunch rot even in wet seasons (1996 and 1998). Since all Sangiovese clones are currently characterized by dense or very dense clusters, minimal pruning looks like an exceptionally effective, natural tool to induce looser clusters. In terms of wine quality, future work will have to assess if the increased concentration of aromatic precursors (glycosyl glucosides, G-G) expected in MP as a result of a higher skin:pulp ratio may fully counterbalance the drawbacks related to delayed or incomplete ripening. Thus, the main conclusion from this trial is that additional crop level control (*i.e.* mechanical flower thinning and/or cluster removal) will have to be implemented to bring the Sangiovese MP vines to a more satisfactory balance without losing the very attractive feature of less compact clusters.

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