Seasonal growth and gas exchange of conventionally and minimally pruned Chardonnay canopies

S. PONI, C. INTRIERI and E. MAGNANINI

Dipartimento di Colture Arboree, Bologna, Italia

Summary

The net CO₂ gas exchange rate (NCER) of hand-pruned (HP) and minimally pruned (MP) potted Chardonnay canopies was continuously monitored from about 20 d after budburst until post-harvest. Single-leaf gas exchange readings were taken 4 times throughout the season and non-destructive estimates of leaf chlorophyll at veraison. Canopy leaf area development was registered, yield components and grape soluble solids were recorded at harvest; samples were taken to determine dry matter partitioning into clusters, leaves and canes.

The MP vines showed higher shoot number, distinctly reduced leaf and shoot size, and a higher cluster number with smaller berries and less berries per cluster compared to HP vines. The MP vines exhibited a 4-6-fold higher CO₂ fixation than HP vines from about three weeks after budbreak till bloom. Canopy NCER started to recover in HP vines concurrently with the transition to a faster shoot growth phase, although by canopy completion NCER was still 13 % higher in MP. Sugar concentration of berries was not significantly lower in MP compared to HP despite a yield increase of about 70 %. The overall results indicate minimal pruning as a valuable tool to improve the performance of Chardonnay vines under our experimental conditions.

Key words: pruning, shoot growth, photosynthesis, yield components, crop load.

Introduction

The minimal pruning system of cordon trained vines (MPCT) was originally developed for grapevines in irrigated vineyards of Australia corresponding to climatic regions IV and V of the Winkler scale (CLINGELEFFER 1984). In these warm areas, cultivars such as Riesling, Chardonnay, Shiraz and Cabernet-Sauvignon have been successfully managed with no pruning and almost no further control of the cropping level. Yields have increased by about 20-40 % compared with conventionally (hand) pruned vines, whereas ripening has been delayed by about one week with a similar grape composition being attained (CLINGELEFFER and POSSINGHAM 1987; POSSINGHAM 1996). The MPCT has also been tested in cooler areas of Australia (similar to regions II and III on the Winkler scale) characterized by higher rainfall, increased vine vigor and a shorter ripening season. Trials have shown that vineyards are exposed to over-cropping and delayed or incomplete ripening unless techniques to limit crop size are employed (CLINGELEFFER 1993; POSSINGHAM 1994). Crop level adjustment can be achieved by trimming significant amounts of a canopy’s low hanging canes, either as dormant canes or as green shoots. An alternative method of crop adjustment for minimally pruned vines has been successfully tested in eastern New York State (POOK et al. 1993) using mechanical crop thinning applied 20-30 d after bloom with a horizontal impactor harvester.

Regardless of the adjustments needed to achieve the best balance in MPCT vines according to cultivar and site conditions, minimally pruned vines as compared to conventionally pruned vines normally show on average a 3-10 times higher shoot number; earlier leaf area formation in spring and less prolonged shoot growth in summer; shorter shoots with few or no laterals and smaller leaves; smaller, less compact clusters with fewer and smaller berries; generally higher yields with slightly lower soluble solid concentrations. These characteristics cause very different growth and development patterns on the minimally pruned vines compared to conventionally pruned ones and urge a better understanding of MPCT physiology to improve management. As a matter of fact, the data sets available for the viticultural performances of MPCT (see review by POSSINGHAM 1994, and lit. cited therein) prevail over the physiological evaluations, the latter being primarily based on readings taken on single leaves (DOWNTON and GRANT 1992; SOMMER and CLINGELEFFER 1993; IACONO et al. 1998). However, some of the most typical effects induced by minimal pruning (e.g. alteration of canopy photosynthesis and structure due to earlier canopy filling) would also need an evaluation on a whole-plant basis. DOWNTON and GRANT (1992) report estimates of whole-vine photosynthesis of spur-pruned and minimally pruned grapevines based on single-leaf measurements corrected as a function of light attenuation through the canopy. More recently, LAKSO et al. (1996) have initially reported whole-
canopy gas exchange directly measured over the season on conventionally pruned vs. minimally pruned Concord grapevines by enclosing half-vine canopies in clear plastic chambers.

The objective of the present study is to provide a seasonal evaluation of the growth and gas exchange patterns of conventionally and minimally pruned Chardonnay canopies in the warm climate of the Po Valley, Italy. This type of information is deemed important for a better assessment of the correct cropping level needed for a specific location to optimize both wine quality and overall vineyard profitability of minimally pruned vines.

Material and Methods

The study was carried out in 1997 on 5-year-old, own-rooted Chardonnay grapevines grown in 120-l pots filled with peat, sand and soil (1.5:2:1 v:v:v). Experimental units were established by adjoining vines in pairs to form single canopies of about 2 m in length (Fig. 1). Two canopies were assigned to the hand-pruned (conventional) treatment (HP), which retained about 15 two-node spurs per meter of permanent cordon, and two were used for the minimal pruning treatment (MP), which received no pruning. The vines forming the two MP canopies had been left unpruned the previous season to allow a significant increase of bud load the following year. The 4 canopies were aligned in two rows (two canopies per row) spaced 2.5 m apart to avoid interference due to mutual shading. Both treatments featured three catch wires for upright shoot growth, which was maintained within a maximum height of 1.0-1.2 m by rolling the outgrowing shoots along the top wire. At growth completion, the HP vines had an average canopy diameter of about 30 cm with both internal and external clusters. Final canopy shape in MP was more elliptical due to shorter and more flexible shoots, maximum canopy diameter was about 60 cm and clusters were predominantly located at the outside of the canopy.

Vines were fertilized with urea (10 g per pot) just prior to budburst (in both treatments on March 18). Vines were watered daily with a drip system delivering about 8 l·h⁻¹ and pest management was carried out regularly.

Growth, yield and must quality: Shoot leaf area development was monitored at approximately 10-d intervals from April 11, till the end of shoot growth (mid-July) by recording the number of unfolded leaves and the lamina length x maximum width of each leaf on a sub-sample of pre-tagged shoots equivalent to about 25 and 10% of total shoots for HP and MP, respectively. Leaf area was estimated by regression of lamina length x width vs. actual leaf area ($R^2 > 0.95$) destructively measured with a portable LI-COR 3000 area meter on a subsample of 60 and 100 leaves (including both, main and laterals) for HP and MP, respectively. At different dates total leaf area per vine was then calculated on the basis of the correspondingly estimated mean shoot leaf area and the total shoot number per vine recorded at leaf fall.

Vines were harvested on August 19, and yield and total cluster number per canopy were recorded. Five 30-berry samples per canopy (300 berries per treatment) were used to determine fresh weight and sugar concentration (°Brix) by standard methods. Five fresh fruit samples (about 100 g each) per canopy were also taken and freeze-dried. Concurrently, the chlorophyll content of 20 and 30 mid-shoot, well-exposed leaves of HP and MP vines, respectively, was

---

**Fig. 1:** Pruning trials with Chardonnay. Conventionally pruned (A) and minimally pruned (B) after budbreak before measurement. Conventionally pruned (C) and minimally pruned (D) test units seven days later at gas exchange measurement.
estimated with a portable Minolta SPAD-502 spectrometer based on three readings per leaf at different lobes. These leaves were then detached, their fresh weight and leaf area were recorded immediately, and then the leaves were dried in a ventilated oven at 80 °C until constant weight was reached. At leaf fall all the main and lateral nodes formed during the current growing season were counted and the one-year-old pruning wood was carefully separated from the older wood, weighed and dried at 80 °C in a ventilated oven until constant weight was reached. Differences between the two treatments were analyzed by t-test.

Gas exchange patterns: Gas exchange of the test vines was evaluated on a single-leaf and a whole-canopy basis. Single-leaf assimilation (A) rates were measured 4 times throughout the season (pre-bloom, fruitset, veraison and post-harvest) using a CIRAS-1 flow-through portable system fitted to a leaf chamber fed with a 300 ml·min⁻¹ air flow and featuring a window of 2.5 cm². Measurements were taken on clear days in the morning and afternoon on 5 well-exposed shoots per canopy. To provide adequate sampling with regard to variation of leaf age, every second leaf along each shoot was sampled starting with the first normally formed basal leaf (usually identified as leaf two or three).

Canopy net CO₂ exchange rate (NCER) was monitored with the flow-through system advocated by Corelli and Magnanini (1993). On April 7 (20 d after budbreak) the entire canopies were enclosed in transparent polyethylene chambers that were kept in place except for temporary removals for canopy sampling and sprays or due to wind gusts during thunderstorms, which severely damaged the chambers. The chambers were dismantled on October 5, when canopies had already started to show visual symptoms of leaf senescence. The air flow through the chambers was progressively adjusted to final values of about 40 and 30 l·s⁻¹ for MP and HP vines, respectively, according to the leaf area development. These rates resulted in an air flow of at least 25 ml·min⁻¹·cm⁻² leaf area, sufficient to keep the air heating inside the chambers below 2.5 °C of the outside temperature even on hot summer days. Inlet and outlet CO₂ concentration readings were automatically stored at 10-min intervals by a CR10 Campbell data logger. Additional details about the system’s set-up, functioning and data processing are reported in Poni et al. (1997) and Intrieri and Poni (1998).

Results and Discussion

Growth, yield and ripening: The minimally pruned vines showed most of the typical effects to be expected without pruning. Compared to HP, the number of MP canopy shoots was about 6 times higher; they were shorter and much less vigorous, had very few laterals, and leaf size was markedly reduced (Tab. 1). Despite the large increase in shoot number, the total leaf area of the minimally pruned canopies was not significantly higher (8.1 m²) than the conventionally pruned canopies (6.8 m²). This increase of vine capacity was moderate when compared to the vegetative growth registered in the field at the same location (Intrieri et al., unpubl.). The MP canopies showed a linear leaf area development phase from about 20 d after budbreak (DAB) to about 80 DAB (Fig. 2), whereas the HP treatment induced an exponential shoot growth pattern until bloom followed by a linear growth until veraison. The weight of one-year-old pruning wood was 2.7-fold higher in the HP compared to the MP canopies (Tab. 1).

Although care was taken to assure optimum water and nutrient supply to the vines, restricted root growth in the pots may have limited growth capacity of vines. No pruning had pronounced effects on important components of total leaf area (namely nodes per shoot and leaf size) and an almost concurrent arrest of shoot growth was observed.

Table 1

<table>
<thead>
<tr>
<th></th>
<th>HP</th>
<th>MP</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of shoots/canopy</td>
<td>62</td>
<td>366</td>
<td>*</td>
</tr>
<tr>
<td>Number of main nodes/shoot</td>
<td>13.0</td>
<td>4.6</td>
<td>*</td>
</tr>
<tr>
<td>Leaf area/shoot (cm²)ᵃ</td>
<td>1103</td>
<td>222</td>
<td>*</td>
</tr>
<tr>
<td>Leaf size (cm²ᵇ)</td>
<td>80.2</td>
<td>46.5</td>
<td>*</td>
</tr>
<tr>
<td>Leaf area/canopy (m²)</td>
<td>6.83</td>
<td>8.12</td>
<td>NS</td>
</tr>
<tr>
<td>Pruning weight/canopy (g)</td>
<td>622</td>
<td>230</td>
<td>*</td>
</tr>
<tr>
<td>Yield/canopy (kg)</td>
<td>4.9</td>
<td>8.4</td>
<td>*</td>
</tr>
<tr>
<td>Number of clusters/canopy</td>
<td>44</td>
<td>285</td>
<td>*</td>
</tr>
<tr>
<td>Cluster weight (g)</td>
<td>92.3</td>
<td>30.9</td>
<td>*</td>
</tr>
<tr>
<td>Berry weight (g)</td>
<td>2.15</td>
<td>0.90</td>
<td>*</td>
</tr>
<tr>
<td>Number of berries/cluster</td>
<td>43</td>
<td>33</td>
<td>-</td>
</tr>
<tr>
<td>Sugar concentration (°Brix)</td>
<td>21.1</td>
<td>20.3</td>
<td>NS</td>
</tr>
<tr>
<td>pH</td>
<td>3.45</td>
<td>3.53</td>
<td>NS</td>
</tr>
<tr>
<td>Titratable acidity (g·l⁻¹)</td>
<td>6.2</td>
<td>5.4</td>
<td>NS</td>
</tr>
<tr>
<td>Dry-to-total leaf weight (%)</td>
<td>33.6</td>
<td>35.9</td>
<td>NS</td>
</tr>
<tr>
<td>Dry-to-total wood weight (%)</td>
<td>49.8</td>
<td>53.7</td>
<td>*</td>
</tr>
<tr>
<td>Dry-to-total cluster weight (%)</td>
<td>23.7</td>
<td>22.9</td>
<td>NS</td>
</tr>
<tr>
<td>Leaf-to-fruit ratio (cm²·g⁻¹)</td>
<td>13.1</td>
<td>9.7</td>
<td>*</td>
</tr>
</tbody>
</table>

ᵃ Lateral contributed to 16% and 3% for HP and MP, respectively.
ᵇ Main leaves.

Fig. 2: Seasonal changes of total leaf area in conventionally and minimally pruned Chardonnay canopies.
in both treatments (Fig. 1). These features indirectly support the assumption that, regardless of the pruning method, maximum vine capacity was primarily a function of the allotted soil volume. Therefore, minimal pruning was more effective in inducing a redistribution of total vegetative growth among the various components rather than enhancing growth potential. Interestingly, the difference in final canopy development observed in the present study is similar to that found in field pruning trials carried out in Upstate New York (Lakso et al. 1996), where climatic factors are likely to limit the vegetative potential of grapevines.

Minimal pruning led to an increase of yield per canopy by about 70 % as a result of a 7-fold increase in cluster number (Tab. 1). Yield compensation occurred in the MP canopies primarily as a function of a markedly reduced berry weight and cluster size. Although cluster compactness was not directly assessed in this experiment, clusters on MP canopies clearly looked less compact than those on the HP canopies. The marked difference in yield between treatments did not proportionally affect sugar concentration of berries, which was slightly, but not significantly, lower in MP (Tab. 1). Titratable acidity and pH did not statistically differ between treatments despite a tendency for MP to show higher pH and lower TA. This pattern may reflect in part the better light exposure of the MP clusters, which may have led to increased depletion of malic acid. The dry matter accumulated in leaves, clusters and canes did not differ between the two pruning systems except for dry mass of one-year-old wood, which was significantly higher in the minimally pruned canopies (Tab. 1). The total leaf-to-fruit ratio increased significantly under conventional pruning, reaching 13.1 cm²·g⁻¹ as compared to 9.7 cm²·g⁻¹ for MP. The overall yield pattern of the minimally pruned canopies was consistent with the typical effects triggered by no or very light pruning. It is worth noting that the yield equivalents on a ha basis for the two pruning systems (interrow spacing: 2.5 m) were about 10 and 17 t for HP and MP, respectively, and that the degree of ripening of HP canopies are very pronounced (Downton and Grant 1992). A related consequence of this outcome is that the difference in whole-canopy photosynthesis between the two pruning systems primarily depends on the dynamics of canopy filling, leaf distribution (hence degree of canopy shading) and respiratory losses.

From about 3 weeks after budbreak to bloom, the MP canopies showed a 4-6-fold higher CO₂ fixation rate than conventionally pruned vines (Fig. 3). Most of this gain was clearly due to the faster rate of canopy development (Fig. 2) rather than a higher average photosynthetic rate per leaf (see Tab. 2, pre-bloom). Notably, the whole-vine gas exchange monitoring of HP vines started when the canopies were still at the compensation point for photosynthesis, which corresponded to a canopy leaf area of about 0.5 m², or 7 % of final leaf area. Canopy NCER began to recover in the HP treatment immediately after bloom, concurrently with the transition from a slower to a faster canopy growth phase (Figs. 2 and 3). However, by the time of canopy completion (about 80 DAB), NCER was still 13 % higher in MP, and the average NCER gain of MP vines was 19 % in the remaining measuring period.

Seasonal mean dark respiration rates were 8.8 and 10.9 % of the corresponding diurnal rates of photosynthesis for HP and MP, respectively. Due to the high nocturnal CO₂ fluctuations and the impossibility of adjusting flow rates at night, the system’s sensitivity was not sufficient to detect the physiological changes brought about by the minimal pruning technique. This applies also to cases in which the differences in total vine leaf area between MP and HP canopies are very pronounced (Downton and Grant 1992). A related consequence of this outcome is that the difference in whole-canopy photosynthesis between the two pruning systems primarily depends on the dynamics of canopy filling, leaf distribution (hence degree of canopy shading) and respiratory losses.

The trends reported in Fig. 3 emphasize the remark-

<table>
<thead>
<tr>
<th>Pruning Regime</th>
<th>A (mol·m⁻²·s⁻¹)</th>
<th>SPAD⁸</th>
<th>DW⁹ (mg·cm⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-bloom</td>
<td>Fruitset</td>
<td>Veraison</td>
</tr>
<tr>
<td>Conventional</td>
<td>6.4</td>
<td>10.1</td>
<td>8.1</td>
</tr>
<tr>
<td>Minimal</td>
<td>7.4</td>
<td>8.9</td>
<td>10.7</td>
</tr>
<tr>
<td>t-test</td>
<td>NS</td>
<td>NS</td>
<td>*</td>
</tr>
</tbody>
</table>

⁸ SPAD: arbitrary unit of leaf greenness. ⁹ Dry weight per unit leaf area.

Leaf and canopy gas exchange: The mean photosynthetic rate (A) of single, well-exposed leaves of various ages showed no significant differences between the minimal and conventional pruning system except for leaves sampled at veraison, when the MP treatment had higher A rates than HP (Tab. 2). The other leaf function parameters (chlorophyll content estimated non-destructively and dry weight per unit leaf area) showed no significant variation in regard to the pruning system. Given that no significant changes of the maximum rates of leaf assimilation as a function of the pruning system have been previously reported (Downton and Grant 1992; Sommer and Clingel-Effer 1993; Lakso et al. 1996; Intrieri et al., unpub.), there is consistent evidence that photosynthesis measurements carried out on single leaves usually located on the upper shoulder of the canopy are not sensitive enough to detect the physiological changes brought about by the minimal pruning technique. This applies also to cases in which the differences in total vine leaf area between MP and HP canopies are very pronounced (Downton and Grant 1992). A related consequence of this outcome is that the difference in whole-canopy photosynthesis between the two pruning systems primarily depends on the dynamics of canopy filling, leaf distribution (hence degree of canopy shading) and respiratory losses.

From about 3 weeks after budbreak to bloom, the MP canopies showed a 4-6-fold higher CO₂ fixation rate than conventionally pruned vines (Fig. 3). Most of this gain was clearly due to the faster rate of canopy development (Fig. 2) rather than a higher average photosynthetic rate per leaf (see Tab. 2, pre-bloom). Notably, the whole-vine gas exchange monitoring of HP vines started when the canopies were still at the compensation point for photosynthesis, which corresponded to a canopy leaf area of about 0.5 m², or 7 % of final leaf area. Canopy NCER began to recover in the HP treatment immediately after bloom, concurrently with the transition from a slower to a faster canopy growth phase (Figs. 2 and 3). However, by the time of canopy completion (about 80 DAB), NCER was still 13 % higher in MP, and the average NCER gain of MP vines was 19 % in the remaining measuring period.

Seasonal mean dark respiration rates were 8.8 and 10.9 % of the corresponding diurnal rates of photosynthesis for HP and MP, respectively. Due to the high nocturnal CO₂ fluctuations and the impossibility of adjusting flow rates at night, the system’s sensitivity was not sufficient to highlight early-season differences in respiration with respect to differential canopy filling.

The trends reported in Fig. 3 emphasize the remark-
able photosynthetic gain by the minimally pruned vines during the early season. The data show (Fig. 2 vs. Fig. 3) that the total leaf area increments defined the time at which the HP treatment began to recover in terms of leaf area, hence canopy photosynthesis. Under such circumstances the MP technique offers better prospects than HP in a climate where cooler springs may retard individual shoot development because it would enable canopies to compensate the limiting temperatures by an increased shoot number per vine.

The seasonal dynamics of the NCER patterns also showed that, in spite of some variation between treatments on specific dates, the minimally pruned canopies maintained higher NCER from the attainment of full canopy size (about 80 DAB) until the end of the season. Quite interestingly, the average percentage of NCER gain for MP throughout the above period was 19 %, which is close to the difference in final total leaf area between treatments (+ 16 % for MP). It can be concluded that in the present study the total leaf area per canopy determined total photosynthesis and that the increment in leaf area promoted by minimal pruning resulted in a fairly proportional gain in photosynthesis rather than in aggravated internal shading. This implies that the MP vines were able to display their photosynthetic gain by the minimally pruned vines during the early season. The data show (Fig. 2 vs. Fig. 3) that the total leaf area increments defined the time at which the HP treatment began to recover in terms of leaf area, hence canopy photosynthesis. Under such circumstances the MP technique offers better prospects than HP in a climate where cooler springs may retard individual shoot development because it would enable canopies to compensate the limiting temperatures by an increased shoot number per vine.

The seasonal dynamics of the NCER patterns also showed that, in spite of some variation between treatments on specific dates, the minimally pruned canopies maintained higher NCER from the attainment of full canopy size (about 80 DAB) until the end of the season. Quite interestingly, the average percentage of NCER gain for MP throughout the above period was 19 %, which is close to the difference in final total leaf area between treatments (+ 16 % for MP). It can be concluded that in the present study the total leaf area per canopy determined total photosynthesis and that the increment in leaf area promoted by minimal pruning resulted in a fairly proportional gain in photosynthesis rather than in aggravated internal shading. This implies that the MP vines were able to display their greater leaf area at least as efficiently as the HP vines. This may depend either on leaf characteristics (much smaller leaf areas may allow more light to enter to the inner canopy layers) and/or the geometry of the supporting permanent vine frame (Iñtiewerie et al. 1997). While HP vines generally showed a restricted, vertical hedgerow pattern, the MP vines were elliptical in shape with a higher canopy surface allowing leaf displacement, especially on the sides. Although the level of foliage density was not directly assessed, the trends reported in Fig. 4 of leaf NCER over the whole canopy provide further insights into this matter.

Since the rates in Fig. 4 are calculated from canopy NCER, they are representative for all factors (age, light exposure, health) affecting leaf function per unit area. Note that leaf NCER was very similar between treatments from about 70 DAB onwards, indicating that despite the higher leaf area the MP vines maintained the same efficiency per unit leaf area and, apparently, leaf NCER was similarly affected by the limiting factors supra. Likewise, note that leaf NCER was consistently higher in MP until about 60 DAB despite the much larger leaf area of these vines. The level of shading does not seem to be linked to this response since we should have seen a decrease of leaf NCER in MP, which showed a more advanced canopy filling. The higher leaf NCER seen for MP early in the season is likely related to a canopy-age effect enabling more leaves to reach maturity earlier in the minimally pruned than in the HP vines. Yet, for the same reason, the minimally pruned vines could be expected to show a more rapid photosynthesis decline late in the season because of their ‘older’ canopy. This effect was not seen in the present study and is thus in accord with previous findings (Lakso et al. 1996, Iñtiewerie et al., unpubl.) suggesting that leaf longevity is not necessarily shortened in grapevine by minimal pruning.

**Carbon allocation and requirements:**

The total carbon that accumulated in fruit, new canes and leaves yielded about 790 and 1000 g for HP and MP, respectively; these amounts accounted for 44 and 45 % of the total estimated photosynthetic carbon gain of canopies from the onset to the end of season (Tab. 3). This calculation does not take into account carbon allocated to current-year growth of cordons, trunks and roots, which according to Mullins et al. (1992) is a minor fraction of the whole-vine carbon partitioning.

In both treatments, the similarity in the amounts of carbon allocated to new growth (clusters, canes and leaves) suggests that the type of pruning did not alter the dry matter accumulation pattern at the whole canopy level and that the other 55 % carbon gained during the season were required to support incremental growth of permanent vine structures and roots and to meet requirements for maintenance and growth respiration. Interestingly, the photosynthetic CO₂ fixation from veraison to harvest fully met the sugar requirements during berry ripening in both treatments (Tab. 3), although MP vines used 84 % of the total current photosynthates vs. 58 % of HP. Therefore, despite the con-
siderably higher crop, the MP did not seem to suffer any source limitation during the critical period of sugar accumulation in berries, suggesting also that translocation of carbohydrates from the rest of the vine may have been negligible. Thus, the next step is to repeat this type of study under field conditions to compare conventional and minimal pruning at higher levels of both total leaf area and crop.

References


