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Scientia Horticulturae 87 (2001) 21–32

**SCIENTIA
HORTICULTURÆ**

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Ecophysiology and vine performance of cv. “Aglanico” under various training systems

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Accepted 17 March 2000

Abstract

A 2-year study was conducted to evaluate ecophysiological characteristics and yield–quality performance of cv. “Aglanico” (*Vitis vinifera* L.) grapevines trained to three different trellises at the same intrarow vine spacing and bud load per meter of row length. Bilateral guyot (BG) showed the lowest vine capacity and bilateral spur-pruned cordon (BSPC), with a vertical shoot positioning had the highest total leaf area (LA) and pruning weight. Despite very comparable crop levels among trellises, quality decreased considerably in the bilateral free cordon (BFC) vines with respect to the systems with upright shoot growth. BFC vines showed significantly lower sugar concentration (°Brix), anthocyanins and phenols, and higher pH and K⁺ according to a pattern frequently associated with excessive within-canopy shading. Shading was aggravated in the BFC vines by canopy rotation, which probably resulted in an increase of LA density per volume unit. Moreover, the BFC canopies had more close-to-horizontal oriented leaves and from veraison onward, placed the most functional median and apical leaves in the lower or less illuminated portion of the canopy. These factors may have combined to diminish total vine photosynthesis in BFC-trained vines. The data also pointed out that the differences among trellises could not have been predicted simply on the basis of widely accepted indicators of crop load (e.g. the yield-to-pruning weight ratio) or canopy density (e.g. leaf area-to-canopy surface area (LA/SA)). © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Light interception; Gas-exchange; Shoot growth; Yield; Crop load; Leaf area index

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1. Introduction

Labor intensive operations such as harvesting and pruning are affecting an increasing number of Italy's grapevine districts, regardless of geographical location. Training systems which allow partial or full mechanization and facilitate hand management due to their simpler structure and pruning are therefore becoming more appealing to growers (Intrieri et al., 1998). The introduction of any new trellis in a given area requires both agronomic and ecophysiological evaluations to determine its viability over time and how canopy structure interacts with the local climate. Unfortunately, most of the comparisons among different trellises performed under various Italian environments have been based on traditional growth yield–quality assessments (Lisa and Cargnello, 1991; Sottile et al., 1991; Intrieri et al., 1992; Novello, 1994), whereas the interactions of training systems with the environment (namely, light) have been either neglected or oversimplified by calculation of basic indices such as the exposed canopy surface area (SA) (Smart, 1985; Carbonneau, 1995) or the leaf area-to-canopy surface area (LA/SA) ratio (Smart, 1985). These indices are essentially based on geometrical features of the canopy and their use has been recently questioned by Mabrouk and Sinoquet (1998) and Calò et al. (1999).

A more focused approach designed to evaluate directly light interception and distribution for a given trellis can be anticipated to lead to a better interpretation of the yield–quality performance of vines, in addition to building a body of data useful to characterize each training system type regardless of the influence exerted by other factors (year, location, rootstock, etc.).

The purpose of the present study was to compare different trellises for the cv. “Aglanico” with emphasis on their agronomic performance and interactions with light availability. The trellises were the bilateral guyot (BG), the bilateral spur-pruned, vertically shoot-positioned cordon (BSPC) and the bilateral free cordon (BFC), which also differ with respect to an increasing adaptability to the mechanization of harvesting and pruning.

2. Material and methods

The trial was carried out in 1997 and 1998 in a 10-year old experimental vineyard planted with cv. “Aglanico” grafted onto 1103 P in the Melfi area (Basilicata, southern Italy). The vineyard had been planted in single rows spaced 3 m apart and trained to three different trellises: BG, BSPC and BFC (Fig. 1). The BG and BSPC canopies have a typical upright shoot growth supported by catch wires, whereas the BFC's shoots hang freely. To ensure a uniform bud load among trellises, one eight-node cane and two two-node spurs were retained on the BG vines; 7–8 short spurs were maintained on both the BSPC and BFC to yield

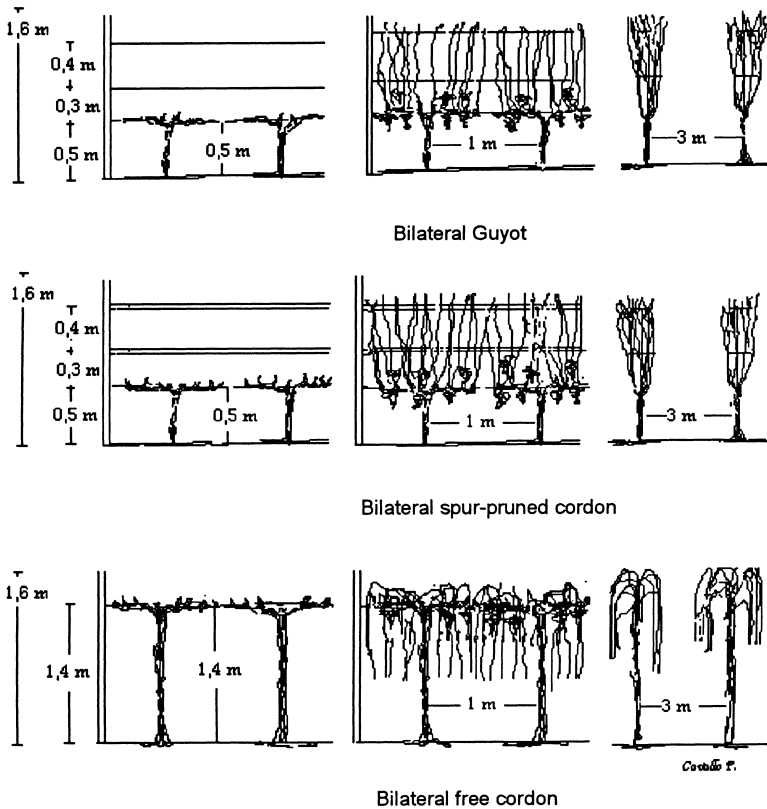


Fig. 1. Diagrams reporting trellis features, cordon heights and vine spacings of the three training systems.

approximately 20 nodes per vine per trellis. Vines did not receive supplemental irrigation during the trial, and pest control was administered on a calendar basis. Shoot thinning was done each year at the phenological stage of “separated clusters” (Baggiolini, 1952) to lower canopy density without altering the shoot number ratios among trellises.

2.1. Vegetative growth, yield and must quality

Budbreak date was estimated after Baggiolini (1952), i.e. when at least 50% of the nodes retained at pruning had crossed the “swollen bud” phase. Shoot number per vine and number of inflorescences per shoot were recorded at the “visible cluster” stage. At the same stage of growth, two shoots per vine (one for each cordon or cane) were tagged and monitored for the number of expanded leaves (both main and laterals) at varying intervals until growth cessation. For 1997 only, the lengths of each burst shoot on the spurs and canes of the test vines

were recorded at weekly intervals from the stage of “first expanded leaf” until fruit set. All shoots were trimmed at fruit set to retain a minimum number of 12–14 main leaves. Concurrently with the dates of shoot measurements, samples of main and lateral leaves representative of different positions along the shoot were taken from extra-vines on each trellis, and the LA for each leaf was measured with a LI-COR 3000 portable area meter. Combining mean LA assessment with leaf counts made it possible to estimate LA per vine on the different dates as well as the extent of LA removed by topping. The vegetative growth measurements ended with the weight of 1-year old pruning wood.

At harvest, besides recording the crop weight and cluster number of each test vine, two 100-berry samples (one per cordon or cane) were taken from the same vines, weighed and processed for sugar concentration ($^{\circ}$ Brix), titratable acidity (TA), malate, tartrate, phenols and anthocyanins. The latter two parameters were measured on berry skin disks after Iland (1988). Potassium concentration of berries was measured by atomic absorption.

2.2. Leaf gas-exchange, light interception and distribution

Assimilation (A) and transpiration (E) were measured at fruit set and veraison on eight, mature, healthy leaves per treatment, four of which were well-exposed while the other four were located in shaded parts of the canopy. Measurements were recorded at 2 h intervals from 8:00 a.m. to 4:00 p.m. with an ADC-LCA 4 portable gas-exchange system. Leaf gas-exchange records were paralleled by leaf water potential readings taken with a pressure chamber on well-lit and shaded leaves adjacent to the ones sampled for gas-exchange. Pre-dawn leaf water potentials were also measured at the same dates on eight leaves per trellis.

Total canopy light interception (TCLI) was estimated at three dates throughout the season (pre-shoot and post-shoot toppings, and veraison) on 2 m row sections of each trellis type including the cordons or canes of the test vines. The amount of light transmitted to the vineyard floor was measured under clear-sky conditions using a multiple line sensor equipped with 10 single cosine-corrected, photosynthetically active radiation (PAR) sensors (10 cm spacing) and linked to a CR10 Campbell data logger. The line sensor was moved over a level, below-canopy grid of 2 m \times 2 m to 10 locations per grid so as to yield a total of 100 individual light readings taken in approximately 2 min. Considering diurnal variation in light interception, the light readings were taken at three different sun angles (2 h before solar noon, solar noon and 2 h after solar noon) by moving the grid over the ground to intercept the entire ground area shaded by the canopies. Percent canopy light interception was estimated by subtracting total vine light transmission from incident radiation measured simultaneously above the canopy by an elevated, horizontal PAR sensor. An adjusted leaf area index (LAI') was then calculated by dividing total vine LA by the mean ground area shaded by the

canopy. The light extinction coefficient (K , otherwise defined as the amount of light intercepted per unit LA) was calculated as the slope of the logarithm of light transmission vs. LAI' after Beer's law of light attenuation throughout a canopy (Jones, 1992). Concurrently with the dates of light interception, SA was estimated after Smart (1985); LA/SA was also calculated.

Light distribution was evaluated under clear-sky conditions on the same experimental units on days adjacent to those chosen for light interception estimates. Five locations, at 40 cm spacing, were marked along the 2 m long row sections with bamboo stakes, and nine different measuring levels from cordon height were identified as follows: 20, 40, 60, 80, 100 and 120 cm above cordon, and 20 and 40 cm below cordon for BG and BSPC; 20, 40 and 60 cm above cordon, and 20, 40, 60, 80 and 100 cm below cordon for BFC. Measurement levels were adapted to the canopy geometry of the trellises featuring a top fruiting area for BFC and the reverse for BG and BSPC. Light readings were taken at each level using the same multiple sensor, which was held perpendicular to the vine row and inserted horizontally into the canopies so that its mid-point was centered along the row axis. The sensor was then quickly moved to the next location so as to complete the measurement for a single unit in less than 1 min. Light availability was given as a percent of the incident radiation measured concurrently by the elevated, horizontal PAR sensor. Data were also averaged over the "fruiting" and the "vegetative" zone of each trellis as defined in the table captions.

2.3. Statistical analysis

Data were taken in both years on three replicates per treatment represented either by single vines or 2 m row sections. Data were subjected to analysis of variance and mean separation performed by Duncan multiple range test (DMRT). Values are presented as means over the 2 years, unless a significant year \times trellis interaction occurred.

3. Results and discussion

Budbreak occurred within a 2-day span over trellises, although average date of budburst was estimated on April 14 in 1997 and April 9 in 1998. The BSPC had the highest vegetative growth for total LA and pruning weight (Table 1). All vegetative parameters indicated BG as the weakest trellis, although pre-topping shoot growth was more reduced in BFC — as might be expected because of its free hanging (rather than upright) shoots. Nevertheless, BFC vine capacity offset this drawback by a higher, albeit not significantly, shoot number per vine and resulted in not being significantly different from BSPC (Table 1).

Table 1
Vegetative growth of vines trained to various trellises^a

Trellis	Nodes (No.)/m	Shoots (No.)/m ^b	Shoot length ^c (cm)	Total leaf area (m ²)/m	Lateral leaf area (m ²)/m	Removed leaf area (m ²)/m ^d	Pruning weight (kg)/m
BG	18.5	10	114 b	5.74 b	0.91 b	0.67 b	0.80 b
BSPC	19.5	11.5	170 a	7.40 a	1.78 a	1.02 a	1.01 a
BFC	22.5	13	104 b	7.01 a	1.69 a	0.87 ab	0.96 ab
Trellis	NS	NS	*	*	*	*	*
Trellis×year	NS	NS	NS	NS	NS	NS	NS

^a Mean separation within columns by DMRT test. Data are given on a per meter of cordon or cane basis. NS denotes nonsignificance. * $P < 0.05$.

^b Recorded after manual shoot thinning.

^c Maximum values recorded before topping.

^d Removed with topping.

The variability in pre-topping shoot development along the cane (1997 data only) was higher in BG (coefficient of variation=12%) as compared to that recorded in BSPC and BFC (coefficient of variation of 6% for both trellises) for the shoots bore on spurs at different positions along cordon. Interestingly, the BFC vines reacted to shoot topping with a considerable number of laterals (Table 1). Although this response was also affected by the higher shoot number, note that the period immediately following shoot cut (July) was characterized by 18 mm of rain in 1997 and no rain in 1998 (data not reported). It appears likely that soil moisture may have limited regrowth by shifting the dependence of lateral formation onto the amount of vine reserves (i.e. more abundant in BSPC and BFC due to the presence of a permanent cordon).

Yield components varied, giving very similar crop levels per meter of row over treatments (Table 2). BSPC vines offset the lower cluster number by increased cluster weight; berry size did not differ among trellises. Given the comparable yields, the calculated crop load indices essentially reflected variations in vine capacity (Table 2). BSPC showed the highest source availability per unit of fruit mass (18.8 cm²/g), which also corresponded to the lowest yield-to-pruning weight ratio (3.5 kg/kg).

The must quality of the BFC vines differed from that of the trellises with upright shoot growth (Table 3) — significantly lower sugar concentration, anthocyanins and phenols and higher pH and K⁺. This ripening pattern has often been associated with increased canopy shading (Smart, 1987; Kliewer and Smart, 1989), which in the present study does not seem attributable to a higher LA (values were similar for both BSPC and BFC) and should have actually been offset by the progressive spreading of the BFC canopies, leading to a “dilution” of LA in a larger canopy volume. A more likely explanation for

Table 2

Yield, components of yield and crop load indices recorded on vines trained to various trellises^a

Trellis	Clusters (No.)/shoot ^b	Cluster weight (g)	Berry weight (g)	Cluster number (g/m)	Yield (kg)/m	Yield-to- pruning weight ratio	Leaf area/yield (cm ² /g)
BG	1.75 a	230 ab	2.22	18.0 a	4.13	5.8 a	13.9 b
BSPC	1.56 b	251 a	2.20	16.0 b	3.99	3.5 b	18.8 a
BFC	1.68 a	212 b	2.37	19.5 a	4.14	4.9 ab	16.7 ab
Trellis	*	*	NS	*	NS	*	*
Trellis×year	NS	NS	NS	NS	NS	NS	NS

^a Mean separation within columns by DMRT test. Cluster number and yield given on a per meter of cordon or cane basis. NS denotes nonsignificance. * $P < 0.05$.

^b Recorded after manual shoot thinning.

altered within-canopy shading in BFC is linked to the seasonal dynamics of canopy growth and movement for the different trellises (Fig. 2). Given the cordon's rotation along the supporting wire, BFC vines began to grow asymmetrically by mid-June, i.e. before shoot topping, in both years. This effect is quite often recorded in cultivars with heavy clusters and a natural downward growth habit (Intrieri and Poni, 1997), the latter feature applying to the great majority of the grape cultivars grown in Italy (Intrieri et al., 2000). Poni et al. (1996) investigated the incremental canopy density caused by asymmetric growth in free cordon trained vines and found a doubling in the mean leaf layer number as compared to a week earlier when growth was still symmetric.

Furthermore, shifting of canopy growth towards one side of the row would also lead to overexposure of clusters located in the "empty" side of the row, which subsequently may cause poor pigmentation. A similar effect has been reported for sun-exposed berry skins of Pinot gris (Price et al., 1992) which have shown an increase in flavonol concentration, particularly a quercetin glycoside, occurring at

Table 3

Must quality of vines trained to various trellises^a

Trellis	Soluble solids (°Brix)	TA ^b (g/l)	Tartrate (g/l)	Malate (g/l)	pH	K ⁺ (ppm)	Anthocyanins (mg/l)	Phenolics (mg/l)
BG	21.6 a	8.4	6.1	4.5	3.09 b	987 b	572 a	1863 a
BSPC	21.5 a	8.9	6.3	4.7	3.13 b	1009 b	483 ab	1728 ab
BFC	19.6 b	9.1	6.3	5.3	3.25 a	1290 a	426 b	1526 b
Trellis	*	NS	NS	NS	*	*	*	*
Trellis×year	NS	NS	NS	NS	NS	NS	NS	NS

^a Mean separation within columns by DMRT test. NS denotes nonsignificance. * $P < 0.05$.

^b TA, titratable acidity.

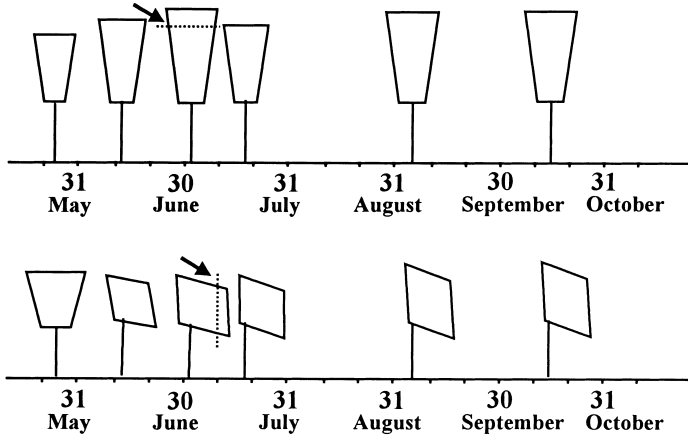


Fig. 2. Cross-section views of the BG–BSPC canopies (top) and of the BFC canopies (bottom) drawn at different times throughout the growing season. Asymmetry of the BFC canopies is apparent even before topping (indicated by arrows and broken lines). Date of topping was averaged over years (July 2).

the expense of anthocyanins synthesis. Although aggravated by the above effects, the mean canopy density of BFC-trained vines did not significantly differ from BSPC in terms of LAI' and the LA/SA ratio was actually significantly lower than the value calculated for BSPC (Table 4). According to Smart (1985), excessive within-canopy shading may occur when values of the latter index exceeds 1.5 (Smart, 1985).

Therefore, these indices proved to be unsuitable to predict and/or account for the differences in must quality highlighted by the two trellises. Additional insight into this matter is provided by looking at “local” canopy effects and “qualitative” canopy characteristics. For example, the higher values of the light extinction coefficient for the BFC vines indicate the predominance of close-to-horizontal oriented leaves, which can cause excessive light exposure of the uppermost leaf layers and prolonged diurnal shading of those located underneath.

The variations in TCLI for the different trellises reflected their canopy geometry and the vegetative flush after topping (Table 4). Pre-topping TCLI was the highest in BFC due to the canopy's widening, whereas higher TCLI for BSPC at full canopy as compared to BG relates to differences in vine vigor. Note that TCLI was not significantly affected by topping in any system. By contrast, the TCLI increment recorded at full canopy clearly matches that for lateral regrowth. The final TCLI values differed among trellises by up to 10% despite very comparable crop levels. Therefore, TCLI does not seem to be a good yield predictor in grapevine though this is at variance with the results shown for apple (Lakso, 1994). The lack of correlation between TCLI and yield in this study should also consider the fact that, due to the pruning type (short spurs retained in

Table 4

TCLI, adjusted LAI (LAI'), K, SA and LA/SA ratio calculated for vines trained to various trellises^a

Trellis	TCLI ^b (%)			LAI' (m ² /m ²)	K	SA (m ²)	LA/SA (m ² /m ²)
	Pre- topping	Post- topping	Full canopy				
BG	33.9 b	32.2 b	43.0 b	1.86	0.63 b	2.90 a	1.95 b
BSPC	38.5 ab	35.7 b	51.0 a	1.83	0.62 b	3.20 ab	2.42 a
BFC	46.9 a	46.4 a	53.5 a	1.75	0.85 a	3.40 a	1.96 b
Trellis	*	*	*	NS	*	*	*
Trellis × year	NS	NS	NS	NS	NS	NS	NS

^a LAI', K, SA and LA/SA values refer to the full canopy stage. Mean separation within columns by DMRT test. TCLI, total canopy light interception, LAI', adjusted leaf area index; K, light extinction coefficient; LA, leaf area; SA, canopy surface area. NS denotes nonsignificance. * $P < 0.05$.

^b Calculated as $100 - [(I_t/I_i)100]$, where I_t is transmitted radiation and I_i is incident radiation above canopy.

all systems), bud fruitfulness (one of the main yield components) may have been more closely affected by the light availability to the basal part of the cane retained at pruning rather than by the total amount of light intercepted by the whole canopy. Furthermore, other important yield components (i.e. berry size and berry number) are affected by canopy efficiency parameters such as the amount of effective LA per unit of fruit which are not inherently considered in the calculation of TCLI.

Light availability for the vegetative zones of each system showed higher values on almost any date for trellises with upright shoot growth and the lowest ones for BFC (Table 5). Although this outcome could have largely been predicted from their reversed canopy geometry (high vegetative zones for BG and BSPC, and low for BFC), it provides further insights into explaining the unsatisfactory grape quality reached by the latter trellis. In spite of a temporary increase due to the effects of topping, the light available to the vegetative zone of BFC at full canopy (corresponding to veraison, i.e. the time point from which berry sugaring begins) was considerably lower than that of BG (−22.9%) and BSPC (−11.3%).

This implies that the median and apical leaves of BFC shoots experienced a more limiting light microclimate than the corresponding leaves of the two remaining systems. It is well demonstrated that the contribution to vine photosynthesis of leaves located towards the shoot tip after veraison is predominant as these leaves are mature but not senescing (Hunter and Visser, 1988). Conversely, BFC benefitted from higher light availability to the fruiting-renewal area, where the older basal leaves are also located (Table 5). Since the rate of leaf senescence in *Vitis vinifera* is reported to be faster than the rate recorded for other *Vitis* species (Lakso, 1993) or fruit crops (Lakso, 1994), it is

Table 5

Light availability (percent of maximum incident radiation) for the vegetative-shoot and the fruiting-shoot zones of each trellis at different times of the season^a

Trellis	Vegetative-shoot zone ^b			Fruiting-shoot zone ^c		
	Pre-topping	Post-topping	Full canopy	Pre-topping	Post-topping	Full canopy
BG	45.4 a	58.6 a	53.0 a	26.4 b	28.9 b	21.4 b
BSPC	40.5 a	50.2 ab	40.4 a	23.3 b	27.8 b	19.3 b
BFC	30.9 b	46.4 b	29.1 b	32.0 a	35.4 a	28.7 a
Trellis	*	*	*	*	*	*
Trellis×year	NS	NS	NS	NS	NS	NS

^a Mean separation within columns by DMRT test. NS denotes nonsignificance. * $P < 0.05$.

^b Average of readings taken at 40, 60, 80, 100 and 120 cm above the cordon in BG and BSPC, and at 60, 80 and 100 cm below the cordon in BFC.

^c Corresponding also to the renewal shoot zone in BSPC and BFC. Average of readings taken at the cordon level, 20 cm above and below the cordon in BG and BSPC and at the cordon level, 20 cm above the cordon, 20 and 40 cm below the cordon in BFC.

unlikely that the ameliorated light availability to the basal leaves may have fully offset the decreased radiation suffered by the median and apical leaves. This effect adds to the above discussion on altered leaf angles, suggesting that overall canopy photosynthesis may have been considerably lower in BFC as compared to BF and BSPC.

Diurnal trends and maximum values of *A* and *E* measured on exposed and shaded leaves at fruit set and veraison did not differ among trellises (data not reported). Pre-dawn and total leaf water potentials were slightly more negative at fruit set in accordance with the limited rainfall registered in both years during this period. However, minimum leaf water potential recorded in well-exposed leaves (−1.35 MPa) induced no apparent stomatal closure, and therefore did not limit photosynthesis.

4. Conclusions

This 2-year trial indicated that the upright, vertically shoot positioned trellises are both viable in achieving adequate ripening in “Aglianico” grapes. The choice between BG and BSPC should primarily involve their suitability to mechanization (BG is not adaptable to mechanical pruning) and cost savings under hand management (winter pruning in BG is more laborious and time consuming). Furthermore, the higher LA registered in BSPC did not induce any further improvement in grape quality, suggesting that excessive canopy density as related to intrarow vine spacing may have occurred in this system.

BFC does not appear to be a recommendable system on the basis of this preliminary evaluation, since grape quality was lowered markedly despite crop levels similar to the other trellises and total LA similar to the BSPC vines. However, the unsatisfactory performance of the BFC could not have been predicted simply on the basis of general estimators of crop load (i.e. the crop weight per weight of cane pruning or the total leaf-to-fruit ratio) and canopy density (LA/SA and LAI'). As a matter of fact, the values of these parameters calculated for BFC were either close to optimum or non-limiting according to the reference thresholds (Smart, 1985; Mabrouk and Sinoquet, 1998). The data show that vine performance in BFC was more closely related to such factors as leaf array (*K* values suggested more horizontally oriented leaves), shoot function (the more functional leaves were located in the bottom part of the canopy during the post-veraison stage) and local effects (asymmetry of canopy growth led to leaves and clusters being either too shaded or overexposed). Accordingly, given that cordon rotation leads to an asymmetric canopy growth, it could be taken as a primary factor in causing unsatisfactory grape quality. Maintaining a more erect canopy can be envisaged as a primary goal for upgrading the efficiency of BFC-trained vines under our conditions. This could be achieved either by using coiled support wires or trimming the shoots at a quite early stage (i.e. pre-bloom) to induce a more upright growth. If coiled wires are used, another option would be to form the cordon by training two twisted canes (instead of one), so that the time needed for the cordon to stick around the wire would be shortened accordingly. The overall data also indicate the urgent need to come up with a “physiological” expression of crop load (i.e. the balance of carbohydrate supplies to the demand of the clusters and the vine’s other organs) rather than indirect expressions such as yield-to-pruning weight.

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