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Laser scanning estimation of relative light interception by canopy components in different grapevine training systems*)

by

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S u m m a r y : The fractional light interception by different parts of vines trained to various systems was estimated by a modified point-quadrat method using an over-row solar arc positioning device equipped with a laser to simulate sunbeam position and angle at any latitude and time of the day. Laser readings were also combined with total vine light interception estimates via a line sensor to calculate the total light intercepted by specific canopy components. At each sampling date (late June and September, corresponding to fruit set and full canopy), type and position of organs were directly detected by the laser beam. Regardless of sampling date, the relative amount of light captured by the renewal-fruiting area (nodes 1 to 6) of simple cordon (SC) and double curtain (GDC) was considerably higher than that of spur-pruned cordon (SPC), whose vegetative area (distal to node 6) received about two-thirds of the incoming light. Relative light interception by main and lateral leaves was rather constant for GDC, thus reflecting the negligible regrowth after topping. By contrast, SC and SPC showed a much stronger response to topping which caused an increase of light interception by laterals (+19 % for SC and +21 % for SPC). Frequencies of relative intercepted light by main leaves as a function of node position showed a peak around nodes 6-8, a zone where maximum leaf size is attained in all systems and on all dates. Instead, lateral leaves predominantly exposed to light were within the three basal nodes of the lateral shoots. Estimates of relative and total light for different vine parts at any time during the season as detected by laser scanning can objectively assess important characteristics of grapevine training systems, e.g. cluster and basal node exposure to light.

K e y w o r d s : light interception, leaf area, canopy microclimate, training systems.

Introduction

The amount of sunlight intercepted by a vineyard throughout the season depends on canopy size and density, the amount of trellis fill, spacing and orientation of rows and canopies, earliness of leaf formation, leaf area development and duration. Studies of apple productivity have established that total dry matter production is related to the amount of solar energy captured by the foliage over the season (PALMER 1986; LAKSO 1994). Although some light interception models are based on hedgerow height, row spacing and orientation (BALDINI and INTRIERI 1987; MAGNANINI and INTRIERI 1987), total light interception has been used more rarely in viticulture as an indicator of maximum vine capacity; emphasis has been laid on grape quality rather than total yield. Total leaf area (WILLIAMS 1987), total leaf area per canopy surface area (SMART 1985; INTRIERI 1987), leaf layer counts (SMART 1985) and exposed leaf area (CARBONNEAU 1983) have been extensively used to characterize the light interception patterns and the light microclimate within a vine canopy.

SMART (1974) estimated that the share of external leaf layers is ca. 70 % of total vine photosynthesis. This is also demonstrated by a study in which the removal of up to 30 % of the total leaf area from the interior of the canopy had no detectable effects on fruit ripening (WILLIAMS *et al.* 1987). Therefore it can be assumed that maximum vine canopy efficiency requires a leaf area development up to trellis fill, whereas further vegetative growth would primarily cause internal shade with small contributions to photosynthesis and fruit quality.

The importance of optimum light exposure of specific vine organs to improve grape yield and quality has also been stressed by BALDINI and INTRIERI (1986), INTRIERI (1987), KLIEWER and SMART (1989) and SILVESTRONI *et al.* (1994). The beneficial effect of light exposure of the basal parts of shoots, with regard to the next year's crop has been demonstrated for Concord grapes (SHAULIS 1966), and, after veraison, high light exposure of the rapidly growing apical leaves is considered to have positive effects. Thus, it appears that information on the relative light interception by specific vine sections or organs should be integrated within the traditional measurements of total light interception by single vines and direct measurements of radiation in different zones of the canopy. Therefore, in the present study a modified point-quadrat method with a solar arc positioning device and a laser to simulate sunbeams was used to estimate relative light interception of canopy components.

Materials and methods

P l a n t m a t e r i a l s : Measurements were performed in 1992 on vines in a 10-year-old Sangiovese clone 12 T on SO 4 vineyard located at Cadriano (near Bologna,

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Italy, N 44°23'), with grapevine training systems arranged in NE-SW rows. The vines were trained to simple cordon (SC) and double curtain (GDC), vine spacing in the row: 1 m, and to bilateral, spur-pruned cordon (SPC), vine spacing in the row: 2 m. Between-row spacing varied from 3 to 4 m since the planting had single rows of each system and the GDC required wider spacing. In all systems winter-pruning was based on 2-bud spurs above the cordon to give ca. 12-15 nodes per m of canopy. Bud number per vine was thus double in GDC and SPC compared to SC as a consequence of 2 m of cordon per vine versus 1 m. The structure of the supporting trellis and the position of the canopy for each system are shown in Fig. 1.

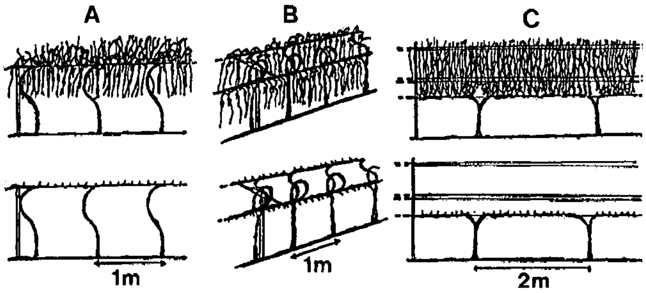

Fig. 1: Row sections trained to simple cordon (SC) (**A**), Geneva Double Curtain (GDC) (**B**) and spur-pruned cordon (SPC) (**C**) before (top) and after pruning (bottom). Vine distance in the row corresponds to actual distances in the field trial. Row spacing varied from 3 to 4 m, 12-15 buds per meter of cordon.

Device description: A series of simulated sunbeams were used to quantify the relative light interception of different vine parts. The basic concept of this laser scanning method is reported by WÜNSCHE *et al.* (1996). The device used in the present study has three main components (Fig. 2): (1) a semi-circular steel arc to represent the sun's arc, (2) a supporting structure which can be positioned to raise the arc to an inclination equal to the latitude of the specific site and to align the device N-S (thereby making the arc parallel to the solar track) and (3) a laser beam mounted on a metal pipe that can slide along the arc. The laser is attached by a swivel joint to adjust it to the angle corresponding to the correct solar declination and solar elevation at any given time. The device was designed for over-row measurements of a grapevine training system having a maximum height of about 3 m. The arc can be moved N-S and positioned to align its axis to true north. Once the latitude inclination is set, the movement of the laser along the arc will match that of the sun. This condition was verified before the onset of measurements by moving the laser along the arc to confirm that the red laser spot remained within the shadow the arc projected on the ground. The laser source was a compact 0.5 mW unpolarized Oriel Helium Neon (Scorpio Optics, Milan, Italy).

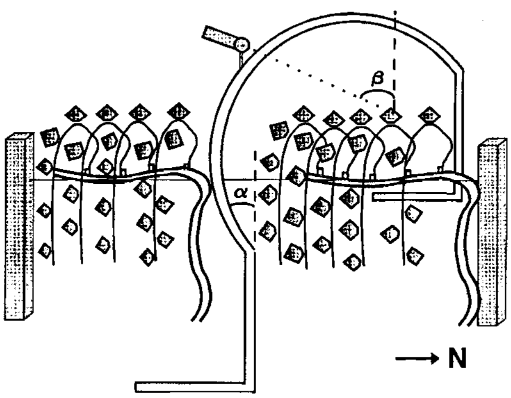

Fig. 2: Laser scanning of a full grapevine canopy. The device has a semi-circular steel arc (representing the sun's track), a supporting structure (that can angle the arc to the latitude of the specific site (α) and align the device NS), and a laser beam attached to the arc by a swivel joint for adjustment to solar declination at the given time of the year (β). Once the latitude inclination is set, the movement of the laser along the arc matches that of single sunbeams.

When the laser positioning device was placed and aligned over the row of vines to be measured, the laser was slid along the solar track in 5 degree increments, from 30 (SE direction) to 150 degrees (SW direction). The laser was always pointed towards the vine canopy. Experimental units were 2 m row panels (including both row sides in the GDC for a total of 4 m of canopy); measurements were replicated 4 times along single rows per system. For different laser scans of the 2 m row panels, the laser was set at two different positions along the row for a total of 8 scans per system corresponding to a minimum of 150 measuring points. To facilitate spotting within the canopy, the laser beam was tracked using white paperboard on bright, sunny days. When a laser beam was aimed into the canopy the type of grape organ encountered was recorded. Contact data also included position along the shoot for leaves and clusters, leaf type (main or lateral), leaf age (immature (I), recently matured (RM) or mature (M)); the insertion node was recorded on the main axis and on laterals. Measuring points within the canopy showing no contact were classified as gaps.

System comparison: Laser scanning was performed twice during the season, the first in late June, about three weeks after bloom and just before mechanical topping of the main shoots in all systems. At that time average leaf number per main shoot was 26, 27 and 25 for SC, GDC and SPC, respectively. Due to the high vigor shoot topping is a common practice in that area and tends to retain a minimum of 14-16 mature leaves per main shoot. The GDC-trained vines had been shoot-positioned before the first scanning, showing typical downward growth. The second scanning was done 10 d before harvest when post-topping lateral regrowth was completed.

Light interception estimates: Scanning on both dates was combined with estimates of the fraction of light intercepted by each 2 m-row section of each system. According to JACKSON (1980), light interception was calculated as 100 (total incident light measured simultaneously above the canopy by an elevated PAR sensor) less the estimated fractional light transmission at the vineyard floor (%T). Measurements were taken almost concurrently on. Light readings were recorded three times a day, 2 h before solar noon, at solar noon and 2 h after solar noon under a completely clear sky by a specially designed line sensor equipped with 11 single cosine-corrected PAR sensors, 7 cm spacing and linked to a CR10 Campbell data logger. A built-in level assured that the sensors were properly set before each reading. The line sensor was moved on a below-vine canopy grid of 2 m x 3 m to 15 locations per canopy section (165 individual points) in approx. 2 min. To account for the wider canopy dimensions of the GDC, 5 extra readings were taken by extending the line 1 m off the 2 m x 3 m standard grid size. This yielded a total of 220 single readings per GDC canopy section. The readings were not taken early or late in the day to avoid shadows from adjacent rows. Since the total light transmission to the ground (T) is representative of light passing between (T_f) and through canopies (T_c) and that grid width was nearly equivalent to standard between-row spacing of the tested trellises, total intercepted light (100 – T %) can be taken as an acceptable estimate of light interception per hectare. However, 100 – $\%T_c$ was also estimated by contouring the mean ground area shaded by each vine and including in the calculation light readings falling only within that area.

Relative light interception estimates: The percentage of total light intercepted by different vine parts was determined as the product of total light interception (*via* line sensor) and the fractional light interception (*via* laser "sunbeam" interception). This parameter was also calculated separately for the fruiting-renewal (nodes 1-6 in each system) and the vegetative area (distal node to node 6 in each system).

Leaf area estimates: Average size of main and lateral leaves (determined destructively from samples of 30 leaves taken from the basal, median and apical shoot zones of extra-vines), total shoot number and total number of leaves per shoot (counted on two tagged shoots per meter of cordon of each system) were recorded during the season to estimate total leaf area per meter of canopy.

Statistical analysis: The variation of contact frequency with main and lateral leaves *vs.* node position on the stem was analyzed by regression. A log-linear model was used to test the differences among proportions of individuals occurring in different categories (Mead *et al.* 1993). This model is recommended if more than two classification factors are involved in the definition of the categories (e.g. trellis type, time and shoot zone or vine organ).

Results and discussion

Relative light interception by different canopy components: The relative amount of light intercepted by the fruiting-renewal (node 1 to 6) and the vegetative (node > 6) zones of the three trellis systems already differed by late June (Tab. 1), SC and GDC showing that about half the incoming light was intercepted by the fruiting zone of the vine *vs.* 27 % for the SPC. These figures did not change substantially even after completion of canopy regrowth. The results quantify the effects of the reversed canopy geometry of the SC and GDC, where the downward growing habit progressively places the clusters and the renewal zone on top of the canopy. This effect is even more pronounced in the GDC possibly as a result of shoot positioning, as many shoots expose basal and median leaves to more light. The SC and GDC appear to better satisfy the local light requirement of specific zones (basal part of shoots) considered to be critical in optimizing canopy efficiency (Shaulis 1966). The additional labor caused by shoot positioning in the GDC system, however, resulted in a higher fruiting zone light interception compared to the natural bending of the SC shoots.

The percentage of light intercepted by main and lateral leaves over time was relatively constant with the GDC (Tab. 1), reflecting a negligible lateral regrowth subsequent to shoot topping (Fig. 3) which confirms the devigorating effects of this trellis. A stronger vegetative response was found in the SC and the SPC, yielding a considerable in-

Table 1

Proportions of relative light intercepted by different shoot zones (nodes 1-6 and nodes > 6) and single vine organs in three grapevine training systems (simple cordon, SC; Geneva Double Curtain, GDC; spur-pruned cordon, SPC) before shoot topping (late June) and at full canopy (late September)

Trellis system	Time of estimation	Node 1-6[y]	Node > 6[y]	[z]Main	[z]Lateral	[z]Clusters	[z]Others[x]	[z]Gaps
SC	Pre-topping	48	52	74	17	0	3	6
	Full canopy	43	57	55	36	1	4	4
GDC	Pre-topping	56	44	61	26	4	4	5
	Full canopy	59	41	63	22	7	2	6
SPC	Pre-topping	27	73	66	24	3	6	1
	Full canopy	31	69	45	45	1	4	5

[x] Stems, petioles, peduncles, cordons.
[y] Significant trellis x shoot zone interaction (χ^2 test, $p \leq 0.05$)
[z] Significant trellis x vine organ and shoot zone x vine organ interactions (χ^2 test, $p \leq 0.05$)

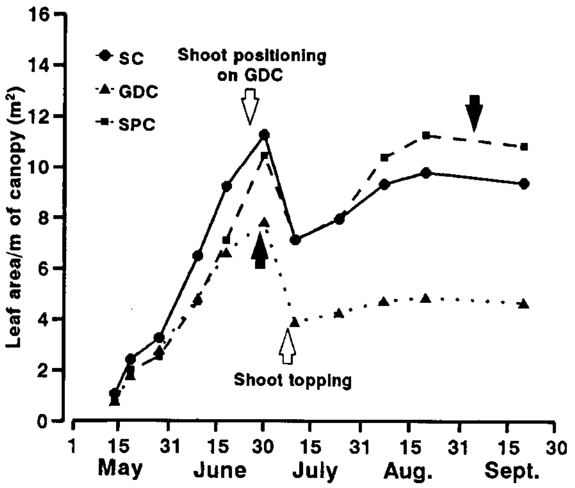

Fig. 3: Seasonal leaf area development per meter of canopy in vines trained to simple cordon (SC), Geneva Double Curtain (GDC) and spur-pruned cordon (SPC). Bold arrows indicate laser scanning dates.

crease in the relative light interception by laterals (+19 and +21 % for SC and SPC, respectively). This may be interpreted as a positive feature since more light is directed to younger but nevertheless mature leaves enabling a high photosynthetic efficiency (KRIEDEMANN *et al.* 1970; INTRIERI *et al.* 1992). It is speculated that the SC's response results from the lower bud load, whereas the enhanced vigor of SPC vines, having the same bud load as GDC vines, appears to result from a combination of the upward shoot growth and the absence of manual shoot positioning.

Although canopy laser scanning is not the best method to estimate light exposure of canopy components like clusters that do not intercept much light, data on cluster light interception can provide estimates. The percentage of fruit intercepting light was generally higher in the GDC, an effect that became more pronounced when canopies became filled (Tab. 1). This seems to be closely correlated with the effects induced by manual shoot positioning, by which many clusters are moved to the top of the canopy.

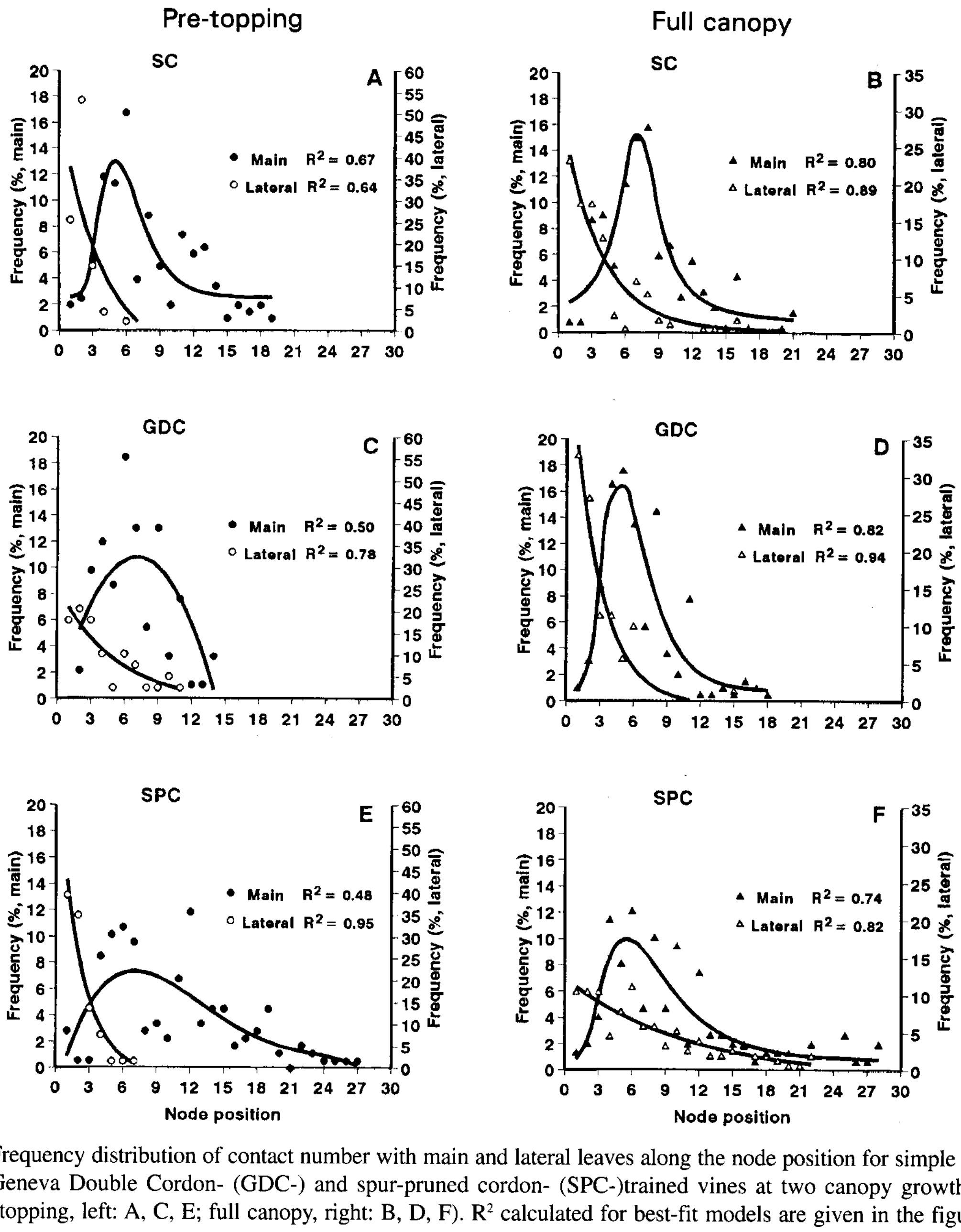

Fig. 4: Frequency distribution of contact number with main and lateral leaves along the node position for simple cordon- (SC-), Geneva Double Cordon- (GDC-) and spur-pruned cordon- (SPC-)trained vines at two canopy growth stages (pre-topping, left: A, C, E; full canopy, right: B, D, F). R^2 calculated for best-fit models are given in the figures.

Light distribution patterns along the shoot: In the SC system the frequency of relative intercepted light as a function of main leaf position on the shoot was highest for nodes 6-8 (Fig. 4 A). The sharper peak found at full canopy (Fig. 4 B) is probably due to the increased probability of light interception by basal leaves after the removal of the more apical leaves by topping. A few contacts with main leaves located at more apical nodes still persisted simply because few long shoots growing along the row axis remained untopped. Pre-topping laser scanning in GDC confirmed a maximum frequency peaking around node 8 (Fig. 4 C). A more distinct but similar pattern was found 2 months later in an almost identical canopy since there was no re-growth on the external parts of the canopy (Fig. 4 D). The SPC response was very similar to that found in SC, again confirming a reduction of the variability during full canopy scoring (Fig. 4 E and F).

About 90 % of the main leaves contacted in SC and SPC at pre-topping were classified as mature. This percentage rose to 99 % on the GDC, which also showed the highest frequency (28 %) of hits on recently-matured lateral leaves. Contact frequencies with immature leaves were negligible (0-2 %) for both leaf types in all trellises. At full canopy, all the main and lateral leaves contacted by laser beam on each trellis were classified as mature.

Despite the variations within each system and date, the analysis of relative light interception by main leaves at different positions along the shoot indicated that in all systems the leaves between nodes 4-10 are preferentially intercepting light. Since these positions roughly match those at which maximum leaf size is attained, leaf size appears to be a key factor in regulating the pattern of relative light interception. However, recent work carried out with the same variety reports that the leaf position along the shoot associated with the maximum photosynthetic potential shifts gradually from the shoot base towards the apex during the season as a consequence of leaf senescence (INTRIERI *et al.* 1992; SILVESTRONI *et al.* 1994). Therefore, having the same main leaves predominantly exposed to high light may not represent the best combination for optimal light use, although the bigger size of basal leaves may offset their lower photosynthetic rates. This indicates that trellises with upright shoots exposing the apical but nevertheless mature leaves to the sun until ripening might be efficient.

Cultivar- or species-specific differences in leaf aging may also be of importance. The native American cv. Concord (*V. labruscana*), on which the GDC was developed, appears to have a much slower decline of photosynthesis due to leaf aging than *V. vinifera* (LAKSO, unpublished). Late season light interception by basal leaves may thus be more significant for photosynthesis in Concord than in *V. vinifera*. Furthermore, regardless of canopy form or measuring date, the lateral leaves intercepting more light were generally found within the 3 basal nodes of the lateral shoot. Like the main leaves, these leaves benefit from their larger size compared to the more proximal ones.

Total light interception of whole vines and specific vine organs: Since light interception measurements were made on clear, sunny days with a low rate of diffuse light to avoid direct shadows from adjacent rows, the light interception of primarily direct light appears to be valid for comparison of training systems, even though the spacing varied. The total light intercepted at mid-season by each 2 m-row section was highest for GDC (48 %), which benefits from canopy division (Tab. 2). GDC and SC had similar light interception in late June and at harvest. This pattern differed for SPC, which increased light interception from 38 % in late June to 52 % at harvest due to vigorous regrowth after topping (Fig. 3). At both dates light extinction through canopies was higher in SPC, indicating increased leaf density as compared to the other trellises. This effect is related to canopy constriction imposed by foliage wires, which are absent in SC and GDC. In SPC, more than two-third of the

Table 2

Daily mean percent light (100-%T) intercepted by each 2 m-section of row and by different shoot zones and vine organs. 100-%T_c refers to interception by canopies calculated by contouring shadow areas on the ground. For details see Tab. 1

Trellis system	Time of estimation	[x]100-%T	[x]100-%Tc	[w]100-%T Nodes 1-6[y]	[w]100-%T Node > 6[y]	[w]100-%T Main[z]	[w]100-%T Lateral[z]	[w]100-%T Cluster[z]
SC	Pre-topping	43 ± 2.8	67 ± 2.2	21 (32)	22 (35)	32 (50)	7 (11)	0 (0)
	Full canopy	44 ± 7.0	61 ± 4.2	19 (26)	25 (35)	24 (33)	16 (22)	0.4 (0.6)
GDC	Pre-topping	48 ± 2.7	68 ± 1.8	27 (38)	21 (30)	29 (41)	12 (18)	1.9 (2.7)
	Full canopy	49 ± 4.6	59 ± 2.4	29 (35)	20 (24)	31 (37)	11 (13)	3.4 (4.1)
SPC	Pre-topping	38 ± 2.4	76 ± 2.6	11 (21)	27 (55)	24 (50)	9 (18)	1.1 (2.3)
	Full canopy	52 ± 2.9	65 ± 2.8	16 (20)	36 (45)	23 (29)	23 (29)	0.5 (0.6)

[x] Mean ± 2SE.
[y] Significant trellis by shoot zone interaction (χ^2 test, $p \leq 0.01$).
[z] Significant trellis effect. Proportions do not add up to total since gaps and contacts with other organs were not considered.
[w] Calculated as the product of relative light interception by 100-%T. Values in brackets are calculated as the product of relative light interception by 100-%T_c.

total light fraction is intercepted by the vegetative area (node > 6), whereas the amount of total light is equally split between main and lateral leaves (Tab. 2). A totally different pattern was found in GDC, where the majority of the incoming light was captured by the the main leaves in the renewal/fruiting area on both dates. SC was intermediate since it shares common features with both systems (top fruiting area like the GDC and capacity for considerable regrowth after topping like the SPC). The latter characteristic was also enhanced by the lower bud load of SC-trained vines.

In general, the data obtained by laser scanning indicate that, although at each location and date the laser is parallel to the sunbeam, only beams that are radial to the canopy are produced whereas in fact there are many parallel sunbeams penetrating all parts of a canopy. Maximum error will therefore occur in canopies having narrow, radially-oriented leaves, so that the cordon will intercept a disproportionate percentage of the laser hits (Wünsche *et al.* 1996). Technically, the limitations of having only radial sunbeams under the present configuration can easily be overcome by mounting the laser onto a support perpendicular to the arc which can slide along it and provide two-directional movement of the laser.

Conclusions

Estimating the percentage of relative light interception of different vine organs by laser beam can be combined with total light interception measurements per hectare or per vine to estimate the total light captured by given vine parts at any time during the season. As a result, important characteristics of grapevine training systems (e.g. canopy density, cluster and basal node exposure to light) can be objectively assessed and quantified. This should be helpful in evaluating many modern training systems which provide a good spatial separation of the fruiting and the vegetative zones in the canopy. In addition, the information about the light exposure of leaves with respect to their relative position and age will provide a better understanding of leaf distribution throughout the canopy and enable the development of corrections or new approaches. Since the method is designed to measure canopy components with high light interception, it is less suitable for assessing cluster exposure, which requires a concentration of beams within the fruiting zone (Smart 1984).

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