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Canopy structure and radiation regime in grapevine. I. Spatial and angular distribution of leaf area in two canopy systems

by

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Summary: Grapevine canopies are discontinuous and spatially heterogeneous. Thus, their geometrical structure is difficult to characterize. A method based on a three-dimensional discretion of the volume occupied by foliage elements was used to assess spatial and angular distribution of leaf area. The method was applied to two canopy systems (Open Lyre and Geneva Double Curtain) exhibiting different vigor levels. Leaf area density (LAD, $m^2 \cdot m^{-3}$), leaf inclination and leaf azimuth distributions were presented for the canopy systems, as are the distributions of lateral shoot leaves within the canopy. An attempt was made to determine the consequences of the canopy system on the grapevine canopy structure. The canopy structure parameters determined in this study were used in a companion paper as input parameters for a radiation model to describe the grapevine light microclimate.

Key words: training system, vine vigor, canopy structure, leaf area density, leaf angle, radiation microclimate.

Introduction

Canopy management includes a range of techniques to alter the position and the amount of leaves, shoots and fruits in space (Carbonneau 1980; Smart 1985, 1990). Therefore, it determines to a large part the plant geometrical structure defined by Ross (1981) which includes parameters such as spatial distribution of leaf area and leaf orientation.

Canopy structure is widely considered to be a direct determinant of the amount and the distribution of radiation, and consequently of transpiration and photosynthesis inside the canopy. High light interception and uniform distribution inside the grapevine canopy favor yield and fruit quality (Carbonneau 1980; Smart 1985; Dokoozlian and Kliewer 1995).

Since grapevine canopies are discontinuous and spatially heterogeneous, their geometrical structure is difficult to characterize by common indices used for homogeneous crops, i.e. LAI (leaf area index expressed as leaf area per unit of soil surface area) or ground cover ratio. Other indices pertinent to isolated plants or row crops have been applied to define the grapevine canopy; e.g. shape and dimensions, foliage density expressed as the amount of leaf area comprised by the canopy volume and the canopy gap fraction assessed by the point quadrat method (Carbonneau 1979; Smart 1985; Reynolds *et al.* 1989 a and b). Other indices developed specifically for grapevines such as SFEp (surface foliaire exposée potentielle), i.e. potential exposed leaf area (Carbonneau 1980, 1989) and LLN, i.e. leaf layer number (Smart 1988), allow a partial description of canopy structure in relation to light microclimate. However, they merely deal with mean values for the whole canopy without considering distributions. To be used in radiation and photosynthesis models, an accurate description of canopy structure based on the spatial and angular distribution of leaf area, is needed. To our knowledge, Schultz (1995) has been the first to study leaf area distribution inside the grapevine canopy. Studies referring to the leaf angle distribution of grapevine are also missing, except for Smart *et al.* (1982).

The aim of this paper was to describe the geometrical structure of two canopy systems exhibiting different vigor levels. The distribution of leaf area density (LAD, $m^2 \cdot m^{-3}$) and leaf angles (inclination and azimuth) were described considering main and lateral leaves separately. An attempt was made to evaluate the consequences of canopy system on grapevine geometrical structure. In a companion study canopy structure data were used as input parameters for a radiative transfer model to describe the radiation regime of the grapevine (Mabrouk *et al.* 1997).

Materials and methods

Field experiments: Fifteen-year-old Merlot vines (on SO 4 rootstock) of the experimental vineyard of the Ecole Nationale Supérieure Agronomique de Montpellier, France (43°36'N, 3°53'E) were used for the study. Row and vine spacing were 2.5 m and 1.2 m, respectively. The row orientation was east-south-east/west-north-west.

105 vines were chosen within the same row and divided into three groups according to their vigor and training system. In 1994 the vines, initially trained to a vertical trellising, were transformed to the following training systems:

- OLLV: Open Lyre training system according to Carbonneau (1980) with vines of low vigor.
- OLMV: Open Lyre training system with vines of moderate vigor.
- GDCMV: Geneva Double Curtain training system according to Shaulis (1966) with vines of moderate vigor.

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Note that technically the GDC training system could not be established with low vigor vines. In the Open Lyre system, each vine formed two separate, inclined foliage walls with shoots positioned vertically upwards between foliage wires.

In the Geneva Double Curtain system, each vine formed two hanging foliage curtains with shoots trained downward without foliage wires.

The vine vigor level was estimated by measuring the mean pruning weight as suggested by CHAMPAGNOL (1984). The difference in pruning weight between vines of low and moderate vigor was as high as 45.4 % accounting for a difference in total leaf area per vine of 29.4 %. Moderately vigorous vines were dormant pruned to 14 buds per vine (i.e. 46,000 buds·ha^{-1}), while low vigorous vines were pruned to only 12 buds per vine (i.e. 39,000 buds·ha^{-1}).

Canopy structure measurements: Measurements of the geometrical structure concerned the distribution of leaf area density (LAD, m^2·m^{-3}) and leaf angles. Because geometrical structure measurements were time consuming (8 h per vine on average), only one representative vine per treatment was chosen on the basis of mean pruning weight as an indicator of vigor and total leaf area as an indicator of vegetative expression. Measurements were performed mid-July 1995, when vines had completed vegetative growth. As described by SCHULTZ (1995) the method consisted of a 3D discretion of the volume occupied by the foliage elements by means of a metallic grid system. The canopy was divided into 0.10 m x 0.15 m x 0.30 m cells (for height, width and length in row direction, respectively).

In each cell, individual leaf areas were determined using the method of CARBONNEAU (1976) which bases on an allometric relationship between leaf area and the sum of the lengths of the two first lateral veins. Leaf inclination was determined as the angle between the normal leaf and the vertical axis, and leaf azimuth as the angle between the projection of the normal leaf onto the horizontal plane and a horizontal reference axis, here the row direction. Measurements were conducted using a custom-built compass-protractor (NORMAN and CAMPBELL 1989), positioned on the leaf petiole sinus. Leaf inclinations were pooled into 9 classes (10° each) and leaf azimuths were pooled into 11 classes (30° each). Finally, the leaf type, main or lateral, was noted.

Results and Discussion

Canopy characteristics: The Table summarises the vine canopy characteristics of the treatments. Values of mean pruning weight (MPW) and total leaf area (TLA) per vine were within the range of values usually found in field experiments with grapevine.

Compared to moderate vigor vines, low vigor vines had a lower canopy height and width, a lower proportion of lateral leaves, less leaves per vine and smaller leaves. Similar results have been reported previously by DOKOOZLIAN *et al.* (1995), KLIEWER *et al.* (1989), SMART (1982, 1988) and CARBONNEAU *et al.* (1978).

Compared to the results of SMART (1985) mean leaf inclinations (MLI), i.e. the average leaf inclination weighted by leaf area, were higher than those of Concord (ca. 45°) but lower than those of Cabernet-Sauvignon (60-75°) and Gewürztraminer (ca. 75°). There was no significant difference (at the 1 % level) between the MLI of OLMV (53.30°) and GDCMV (54.34°) as revealed by the analysis of variance for unbalanced data. MLI of OLLV (57.78°) was, however, significantly higher.

The average LAD for the entire canopy was lowest for the GDCMV system. This is presumably due to the large number of free hanging shoots in this non-trellised system, leading to an increased canopy volume and thus a lower average LAD. Average LAD of the OLLV system was 11 % lower than the LAD of the OLMV system as a result of lower vigor and number of shoots. The average LAD values found in this study for divided canopies, ranging from 2.02 to 3.71 m^2·m^{-3} were markedly higher than those of non-divided Riesling canopies presented by SCHULTZ (1995). The higher planting density (2.0 m x 0.9 m) in the Riesling trial, reducing the vegetative expression of the vines, could partly explain these differences.

The concept of SFEp (CARBONNEAU 1980, 1989) combining canopy density, canopy surface area and vineyard geometrical characteristics (distance between rows, etc.) accounts for the canopy photosynthetic potentiality in relation to light microclimate. The comparison between the canopy systems based on the SFEp showed that OLMV and GDCMV have similar potentialities, while OLLV has a lower one (Table).

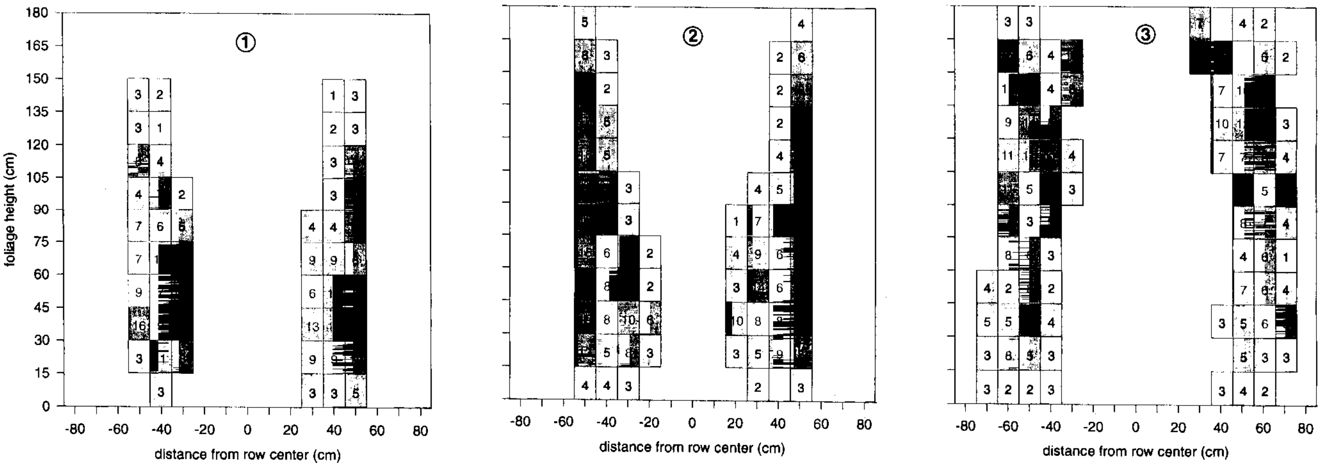
LAD distributions: Plots of leaf area density distributions within the canopy in a cross-row section are

Table

Description of leaf area for OLLV, OLMV and GDCMV canopy systems

Treatment	MPW (g/shoot)	TLA/vine (m^2)	H (m)	WG (m)	SFEp	LLA/TLA	LN/vine	MLS (cm^2)	MLI (°)	LAD (m^2·m^{-3})
OLLV	32.15	4.35	1.4	0.3	0.85	0.29	462	94.28	57.78	4.73
OLMV	60.40	6.50	1.6	0.4	1.03	0.34	574	113.33	53.30	5.31
GDCMV	41.50	5.81	1.6	0.5	0.99	0.39	596	97.63	54.34	4.66

MPW: mean pruning weight, TLA: total leaf area, H: canopy height, WG: canopy width in the fruit zone, SFEp: potential exposed leaf area, LLA/TLA: ratio of lateral leaf area to total leaf area, LN: leaf number, MLS: mean leaf size, MLI: mean leaf inclination angle, LAD: average leaf area density. OLLV, OLMV, GDCMV: see Materials and methods.



Figs. 1-3: Leaf area density (LAD, $m^2 \cdot m^{-3}$) distribution within the OLLV (1, left), OLMV (2, middle), and GDCMV (3, right) canopy systems. The grey level of each cell occupied by the foliage elements was set to be proportional to the LAD value. OLLV, OLMV, GDCMV: see Materials and methods.

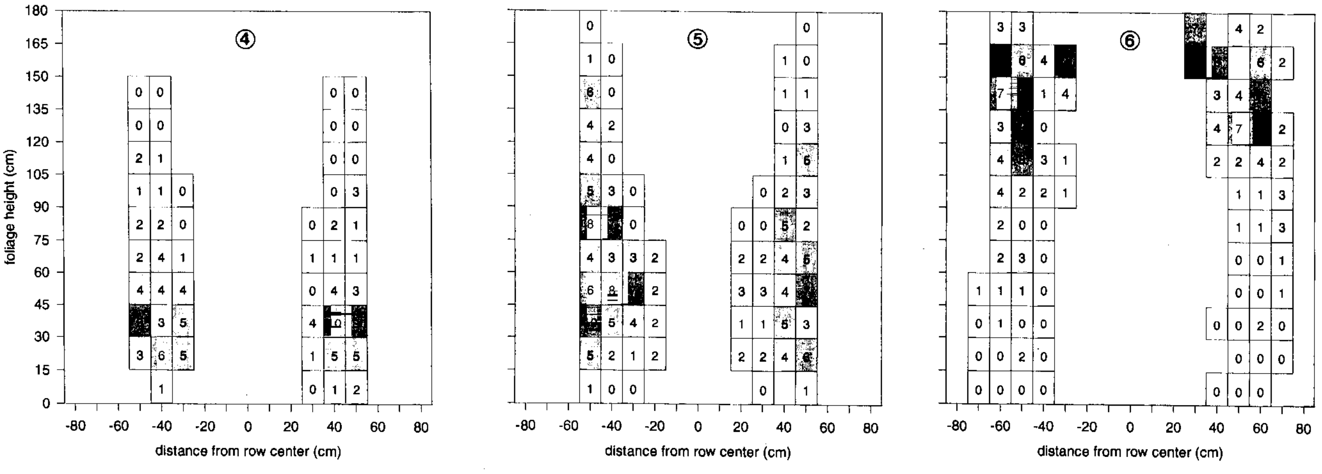
shown in Figs. 1-3.There is evidence for non-uniform LAD distribution for all canopy systems with both, vertical and horizontal variations. The vertical variation is characterized by a zone of highest density within the basal third of the canopy for the Open Lyre systems and the upper third of the canopy for the Geneva Double Curtain system. Unfortunately, these zones of highest density corresponded to the fruit zones in all systems. The same feature has been mentioned by Schultz (1995) for two non-divided canopy systems, an espalier and a cordon system. The horizontal variation of LAD was more difficult to characterize. However, in the Open Lyre systems, the highest densities were found near the canopy sides facing the inter-row which is in agreement with the results of Sinoquet *et al.* (1992) for an espalier system (Figs. 1 and 2). On the contrary, in the GDCML system highest densities were located at the center of the canopy (Fig.3).

The values of LAD encountered are very high. Locally they could reach 25 $m^2 \cdot m^{-3}$ in the GDCMV system, which is much higher than 8 $m^2 \cdot m^{-3}$ or 15 $m^2 \cdot m^{-3}$ reported by Schultz (1995) and Sinoquet *et al.* (1992), respectively. The highest LAD values for grapevine canopies in this study were also substantially higher than those reported for other horticultural crops like citrus and apple trees (Cohen *et al.* 1995). Yet, these values depend on leaf size and cell size of the grid used for spatial discretion.

From an assessment of foliage density based on the average LAD for the entire canopy, we concluded that GDCMV had a less dense canopy than OLLV and OLMV (Table).

However, both GDCMV and OLMV exhibited zones of very high LAD. On the contrary, the OLLV system was characterized by a less heterogeneous LAD distribution without very dense zones. Therefore, the canopies of GDCMV and OLMV could be considered to have similar densities, while OLLV had a lower density and thus a sparser canopy. Hence, average LAD was not a satisfactory indicator of canopy density and analysis of LAD distribution within the canopy was necessary for an accurate estimation of the variability of foliage density.

Leaves of main and lateral shoots differ in their physiological age which is closely related to leaf photosynthe-



Figs. 4–6: Leaf area density (LAD, $m^2 \cdot m^{-3}$) distribution of lateral leaves within the OLLV (4, left), OLMV (5, middle), and GDCMV (6, right) canopy systems. For details see Figs. 1–3.

sis (Schultz 1993). Until harvest young leaves have higher photosynthetic rates and their position within the canopy, with regard to light microclimate, may influence whole canopy photosynthesis (Schultz 1995). Therefore the positions of lateral leaves inside the canopy were determined. The LAD distribution of lateral leaves in a cross-row section are presented in Figs. 4-6. Highest densities, and thus the majority of lateral leaves, in the Open Lyre systems were located at the base of the canopy, presumably as a result of not hedging the shoots. In the GDCMV system, however, lateral leaves occurred mainly on the top of the canopy because of the downward bending of the shoots. The consequences of lateral leaf positioning inside the canopy on light interception are considered in a companion paper (Mabrouk *et al.* 1997).

Leaf angle distributions: Leaf inclination distributions of all canopy systems showed similar global trends (Fig. 7). They resembled the plagiophile distribution described by De Wit (1965), but with more leaves inclined vertically from 80° to 90°. Statistical comparison of inclination distributions using a chi-square test showed no difference at the 1% significance level between OLMV and GDCMV while OLLV had significantly more vertical leaves.

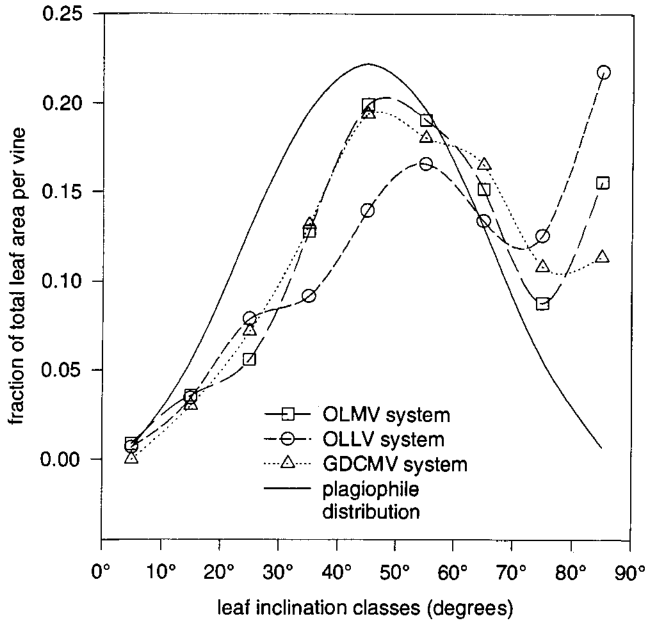


Fig. 7: Leaf inclination distribution of OLLV, OLMV, and GDCMV canopy systems. OLLV, OLMV, GDCMV: see Materials and methods.

Since OLLV, OLMV and GDCMV had similar leaf inclination distributions and similar leaf inclination means, it can be expected that this parameter does not lead to large differences in radiation interception between the canopy systems.

Leaf azimuths were measured with regard to the row direction. Thus a leaf with an azimuth of 70° was facing South. Leaves of the OLMV and GDCMV systems showed a clear tendency to clump towards two preferential azimuths of 90° and 270° (Fig. 8). The resulting azimuth distributions were bimodal with most leaf area oriented perpendicular to the row direction. The OLLV system exhibited a different leaf azimuth distribution with no apparent azimuthal preference. For all canopy systems, leaf azimuth distributions differed from a uniform distribution.

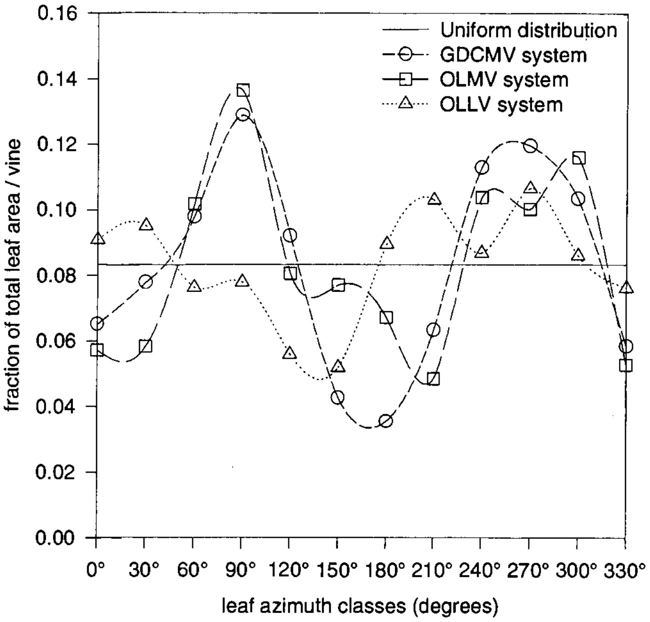


Fig. 8: Leaf azimuth distribution of OLLV, OLMV, and GDCMV canopy systems.OLLV, OLMV, GDCMV: see Materials and methods.

Most leaf area of the dense OLMV and GDCMV canopies faced the inter-row region. This suggested a tendency of leaves to orient towards the largest gaps. A similar behavior has been reported for Concord grapevine by Smart (1982) and Clearwater *et al.* (1995) for juvenile leaves of *Pseudopanax crassifolius* growing in a partially shaded forest environment. When foliage density was lower, like in the OLLV system, gaps in the canopy were larger and leaf azimuths tend to be more randomly distributed. These trends of leaf orientation were observed for both, main and lateral leaves (data not shown).

As a consequence of a preferred leaf orientation perpendicular to the row direction, the gap frequency of grapevine foliage walls, during most of the day and especially towards noon, decreased. This results in a more shaded canopy interior. Moreover, solar radiation and especially its direct component, is principally intercepted by the exterior leaves constituting the foliage wall sides. According to Smart (1974) these exterior leaves account for most of photosynthesis in grapevine. The concept of SFEp (Carbonneau 1980, 1989) using the ratio of exterior to interior leaves has been derived from such considerations and thus should be a good indicator of canopy photosynthesis.

Conclusion

The three-dimensional spatial discretion method used in this study allowed a satisfactory description of grapevine foliage structure for two canopy systems differing in vigor. Spatial and angular leaf area distributions of OLLV, OLMV and GDCMV were described as well as the position of lateral leaves inside the canopy. Vine vigor level appeared to have a small influence on angular distribution of leaf area. Low vine vigor was associated with more vertical leaves distributed nearly randomly. Moderate vine vigor, resulting in denser canopies, induced a preferential leaf orientation perpendicular to the row direction. The training system affected the distribution of leaf area density and the position of lateral leaves. Downward shoot training resulted in a concentration of leaf area and lateral leaves in the upper third of the canopy. When shoots were trained upwards, this was inverse.

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