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Canopy structure and radiation regime in grapevine.
II. Modeling radiation interception and distribution inside the canopy

by

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Summary: A 3D version of the radiation model of Sinoquet and Bonhomme (1992) was used to simulate the light microclimate of grapevine. It was tested against measurements of radiation interception and distribution within two canopy systems (Open Lyre and Geneva Double Curtain) exhibiting different vigor levels. The agreement between the model and the measurements was generally good. Discrepancies may have arisen from incorrect assumptions concerning leaf azimuth distribution and leaf dispersion as well as a lack of accuracy in the description of the distribution of leaf area density inside the canopy. The model also permitted to assess light partitioning between main and lateral shoot leaves which can influence global canopy photosynthesis and berry ripening. As an example of application, the model was used to evaluate the consequences of lateral leaf removing on the interception efficiency of the canopy and the light environment of the fruit zone. The possible use of a geometrical approach to simulate the radiation interception at the canopy scale was also discussed.

Key words: grapevine canopy, light environment, light partitioning, radiation transfer models.

Abbreviations: OLLV - Open Lyre training system with low vigor vines; OLMV - Open Lyre training system with moderate vigor vines; GDCMV - Geneva Double Curtain training system with moderate vigor vines; PAR - Photosynthetically active radiation (400-700 nm).

Introduction

Much attention has been paid to the light environment within grapevine canopies and the physiological responses to light microclimate (Dokoozlian and Kliewer 1995 b). Increased leaf and fruit exposure to sunlight generally improves vine yield, berry composition and wine quality (Shaulis *et al.* 1966; Carbonneau 1980; Kliewer 1982; Smart 1985; Reynolds and Wardle 1989; Carbonneau 1995). Investigating the light environment of grapevine canopies is difficult since they are characterized by large spatial and temporal variations (Smart *et al.* 1985; Schultz 1995). In studies concerned with the influence of canopy management and training systems on the grapevine radiation environment the comparison between the effects of several treatments is laborious. Therefore, temporal variation of the light regime is frequently neglected and measurements are made mostly near solar noon (e.g. Morsi *et al.* 1992). Spatial variation is often restricted to vertical profiles of light attenuation at the center of the vine row (e.g. Dokoozlian and Kliewer 1995 a), while variation in the horizontal plane is generally disregarded. Thus, descriptions of radiation environment of grapevine are rarely comprehensive. Consequently, simulation models appear to be an interesting tool to overcome these difficulties.

To our knowledge, only three models deal with the radiation regime in grapevine canopies; two of them, presented by Smart (1973) and Riou *et al.* (1989), are geometrical. They assume the grapevine canopy to be composed of a set of simple-shaped subcanopies (i.e. foliage rows of rectangular cross-section) and canopy structure is simply described in terms of row dimensions, porosity and spacing. These models give an estimation of the vineyard radiation balance, but they do not allow any description of radiation distribution inside the canopy, all the more because no information about leaf area is involved.

The model of Sinoquet and Bonhomme (1992) is based on the turbid medium analogy and the gap frequency concept. The volume between the soil surface and the top of the canopy is divided in horizontal layers and vertical slices parallel to the row direction. They define vegetation cells looking like long cylinders of rectangular section and characterized by a leaf area density and a leaf angle distribution. In addition to the radiation balance at the canopy scale, this model estimates the spatial distribution of the transmitted radiation to the soil.

Nevertheless, none of the above cited models accounts for the three dimensional radiation distribution within the canopy required for an accurate simulation of canopy photosynthesis.

Some other light models applied to orchard and forest systems (Cohen and Fuchs 1987; Myneni 1991; Cohen *et al.* 1995), also based on the turbid medium analogy, allow an estimation of radiation distribution inside the canopy. They

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generally include simplifying assumptions with regard to canopy structure such as random leaf dispersion inside the canopy, random leaf azimuth distribution, small leaf size, etc.

In this paper, a 3D version of the radiation model of Sinoquet and Bonhomme (1992) was used to investigate the radiation interception and distribution within the grapevine canopy. The model was tested against measurements of radiation interception at the canopy scale and light distribution within the canopy of two grapevine canopy systems. The model was then used to study light partitioning between main and lateral leaves as well as to evaluate the possible use of a geometrical approach to simulate radiation interception by the canopy.

Material and methods

Field experiments and canopy structure measurements: Details of field experiments and canopy structure measurements are given in a previous paper (Mabrouk *et al.* 1997).

Radiation measurements: The interception efficiency (ε_i) as defined by Varlet-Grancher *et al.* (1989) is

$$\varepsilon_i = 1 - (R_t/R_i) \qquad (1)$$

where R_t is the transmitted radiation to the soil surface and R_i the incident radiation above the canopy. Measurements of ε_i on each canopy system were conduced two weeks after measurements of canopy structure characteristics, assuming no significant changes in canopy structure affecting ε_i during this period.

The device used was a Picqhélios (Aeric Sarl, F31130 Balma, France). It consists of a 2.5 m vertical metallic rod joining two single quantum sensors located on the top to two line quantum sensors of 0.35 m length located at the base. The upper single sensors measure incident radiation in the PAR (Photosynthetically Active Radiation, 400-700 nm) and NIR (Near Infra Red, 700-1100 nm) wavebands. The line sensors are made up of alternate PAR and NIR single sensors. When the metallic rod is vertical, the upper sensors are located above the canopy and the lower ones at the ground. The device automatically computes ε_i from measurements of incident radiation recorded by the upper sensors and transmitted radiation recorded by the line sensors.

To account for horizontal variation of transmitted radiation, a 2.5 m wide soil band under the measured row was used. The Picqhélios was moved every 0.35 m along a cross-row transect from row center to next row center. Repetitions were made at 5 different locations along the row. Canopy system ε_i was defined as the spatial average of ε_i measured at each measuring point.

Measurements were performed for all the canopy systems on August 15, 1995, at 9 and 11 a.m. and 1 and 3 p.m.

The PAR distribution along a vertical transect at the center and the outer sides of both foliage walls was measured for each canopy system. The PAR measurements were performed near noon on July 7, 9 and 11, 1995 on the plants used the day before for canopy structure determination.

PAR was measured by a sunfleck ceptometer quantum sensor model sf-80 (Decagon Devices, Inc., Pullman, WA, USA). The line sensor of 0.8 m length was hand-held and positioned horizontally. It was used in the row direction and moved vertically every 0.15 m from the basis to the top of the canopy. Measurements were achieved at the center and the two vertical sides of each foliage wall. A vertically positioned woody rod of 2.4 m length, marked at 0.15 m increments, was used as a guide. All light measurements were made under clear sky conditions.

Leaf and soil optical properties: Leaf reflectance and leaf transmittance in the PAR waveband were determined by the field method described by Schultz (1996) using a single PAR quantum sensor model PAR/CBE (Solems Sarl, F91124 Palaiseau, France) and a tripod to fix the leaf. The sampling method considered main and lateral leaves separately. In each group, 12 leaves were selected according to leaf age: 4 senescent, 4 adult and 4 young leaves for main leaves; 6 adult and 6 young leaves for lateral leaves. Soil reflectance was estimated using an inverted PAR quantum sensor model LE (Solems Sarl, F91124 Palaiseau, France) positioned 0.2 m above ground. Leaf and soil optical properties were measured at noon.

Model description: The light transfer model derived from Sinoquet and Bonhomme (1992) deals with the radiative balance of spatially heterogeneous canopies and simulates light partitioning between several plant components within the canopy. For this purpose, the model is based on the turbid medium analogy. The vegetation volume is abstracted as an array of three-dimensional (3D) cells which may contain foliage of either one, several or no plant component. Leaf area within a 3D cell is assumed to be uniformly distributed. Leaf area density and leaf inclination distribution for each individual 3D cell are derived from the canopy geometry measurements (Mabrouk *et al.* 1997) distinguishing between main and lateral leaves. Thus, foliage differences between cells account for the 3D changes in the canopy structure.

Light interception is inferred from a sample of beams entering the vines at the top of the canopy. The fate of a beam of direction Ω within the vegetation canopy is computed i) by identifying the 3D cells visited by the beam; ii) by deriving the foliage thickness crossed by the beam within the visited cells; iii) by applying the Lambert-Beer law to calculate the beam extinction (P0) within any visited cell, and the probability Pj of beam interception by component j:

$$P0 = \exp\left[- \Sigma\, Gi \cdot ui \cdot (dz / \sin h) \right] \qquad (2)$$

$$Pj = [\, 1 - P0 \,] \cdot [\, Gj \cdot uj \,] / [\, \Sigma\, Gi \cdot ui \,] \quad i, j = 1 \ldots n \qquad (3)$$

n is the number of components of the cell and Gi, the G-function of component i (Ross 1981), is the ratio of projected leaf area perpendicular to the direction Ω, to leaf area. The G-function is computed by assuming a uniform distribution of the leaf azimuths, i.e. using formulas proposed by Ross (1981). It depends on both the leaf inclination distribution of component i and the direction Ω. The variable ui is the leaf area density of component i ($m^2 \cdot m^{-3}$). The angle h is the sun elevation, and dz is the vertical thickness (m) crossed by the beam within the 3D cell. Equations (2) and (3) assume no preferential leaf overlapping between plant components in a 3D cell, i.e. leaf dispersion is random (Sinoquet and Bonhomme 1991). Fractions P0 and Pj apply to the beam flux I coming into the 3D cell. The radiation flux leaving the 3D cell is thus I·P0, which is used as the incoming flux to the next 3D cell visited by the beam.

Applying this process to a sample of beams allows to derive radiation exchange coefficients between light sources and receivers. For the direct sunlight, the only sun direction Ω is taken into account. For the diffuse incident radiation, the sky is abstracted as pinpoint light sources coming from a set of solid angles which cast the whole sky. For radiation scattered by the soil surface and the phytoelements, a rough phase function assuming isotropic scattering is used to estimate the directional distribution of the scattered radiation (Sinoquet and Bonhomme 1992).

The radiative balance, i.e. reflected and transmitted fluxes and light absorbed by each vegetation component, are then computed by integrating the contribution of both incident and multiple-scattered radiation. This is made by using an adaptation of the radiosity method (Ozisik 1981), which allows to express the radiation flux intercepted by any plant component as a linear combination of the source fluxes (i.e. incident and scattered fluxes) weighted by exchange coefficients. This leads to a system of linear equations, the solutions of which are the radiation fluxes intercepted by each plant component within each 3D cell (Sinoquet and Bonhomme 1992). These intercepted fluxes allow to derive the spatial distribution of the light microclimate as well as the terms of the radiative balance at the canopy scale.

Results and Discussion

Leaf and soil optical properties: The optical properties of main and lateral leaves are presented in Tab. 1. Leaf reflectance and leaf transmittance in the PAR waveband decreased with increasing leaf age for both leaf types, although leaf transmittance decreased more rapidly with leaf age than leaf reflectance. Schultz (1996) reported similar changes in leaf optical properties with leaf age for Riesling. He related these changes of leaf reflectance and leaf absorbance to changes of the leaf chlorophyll content, the epidermal structure and the internal leaf anatomy.

Lateral leaves reflected and transmitted light more than main leaves. This was mainly due to differences in leaf age since lateral leaves are generally younger. Mean leaf reflectance and mean leaf transmittance of Merlot were near 13 and 9 %, respectively. These values are higher than those reported by Smart (1987) for Gewürztraminer (7 and 6 %, respectively).

Soil reflectance in the PAR waveband was estimated to be 16 %, using the inverted quantum sensor method.

Interception efficiencies ε_i: Calculated ε_i of each canopy system was determined using mean transmitted radiation computed by the model and compared to measured ε_i. Fig. 1 shows the daily course of calculated and measured ε_i of all canopy systems.

The values and evolution trends of calculated ε_i were in good agreement with measured ε_i. The determination coefficient and the slope of the linear regression analysis calculated using the combined data of all treatments were 0.887 and 0.957, respectively. Average and standard deviation of residuals were -0.018 and 0.034, respectively. This indicates that the model slightly underestimates the values of ε_i. The model correctly simulated the differences in light interception between the two levels of vigor (i.e. OLLV and OLMV), but it did not account for much of the differences between the two training systems (i.e. OLMV and GDCMV). Indeed most discrepancies between the modeled

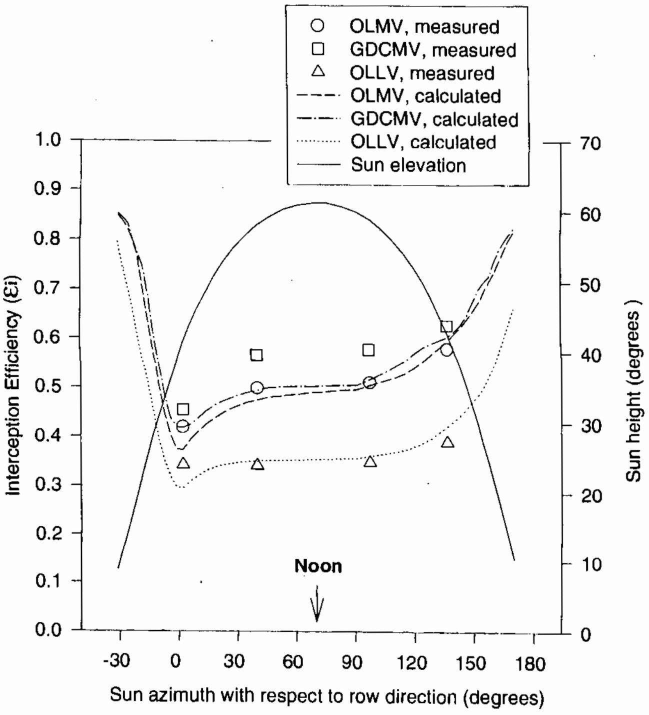

Fig. 1: Daily course of the interception efficiency ε_i.

Table 1

Optical properties of leaves in the PAR waveband determined by the method of Schultz (1996)

Leaf type	Main				Lateral		
Leaf age	young	adult	old	mean	young	adult	mean
Reflectance (%)	13.5	12.1	11.1	12.2	13.9	12.7	13.3
Transmittance (%)	13.8	6.4	4.1	8.1	13.6	8.0	10.8

and measured ε_i were found for GDCMV with a mean underestimation of 0.05.

All canopy systems exhibited the same evolution tendency of ε_i which can be summarized as follows: ε_i was high early in the morning due to low sun elevation and radiation interception by the vertical sides of foliage. Then, ε_i showed a rapid decline to reach a minimum value when sun rays were parallel to the row direction (i.e. direct sunlight was only intercepted by the top of the canopy). Within a range of sun azimuth around solar noon, values of ε_i stayed almost constant. This is because i) changes in sun elevation around midday are small and ii) the effect of changes in sun azimuth on light interception by row canopies are small when the sun rays are not parallel to the row direction (ANDRIEU and SINOQUET 1993). The decrease in sun elevation in the afternoon resulted in a regular increase of ε_i until sunset.

The resulting daily calculated ε_i values were 0.40, 0.54 and 0.56 for OLLV, OLMV and GDCMV respectively. As a result of the comparison between measured and simulated values of ε_i, the difference between the two training systems (i.e. OLMV and GDCMV) was probably underestimated. The differences among the two vigor levels may be related to canopy dimensions (i.e. height and width of foliage walls), since the OLLV canopy was characterized by reduced dimensions as a consequence of lower vigor (MABROUK *et al.* 1997). In recent work on the energy balance of a vineyard HEILMAN *et al.* (1996) showed that changing canopy dimensions by means of trellising had a major effect on canopy ε_i.

PAR distribution: The spatial distribution of transmitted PAR (expressed as a fraction of incident radiation) is presented in Figs. 2-4. The patterns of PAR attenuation at a given location were similar for OLLV and OLMV but differed slightly for GDCMV especially at the center of the foliage walls.

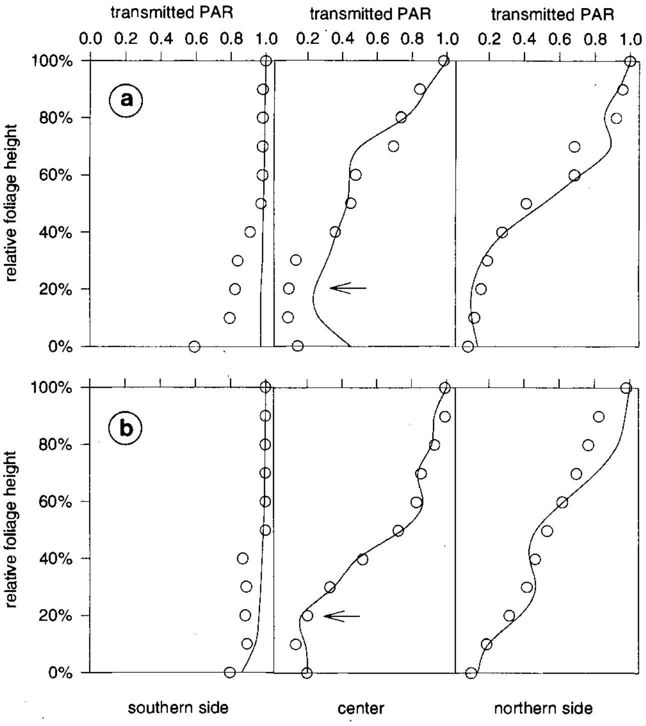

Fig. 2: Transmitted PAR distribution in the OLLV canopy system. **a**: southern foliage wall; **b**: northern foliage wall. Arrows indicate the center of the fruit zone.

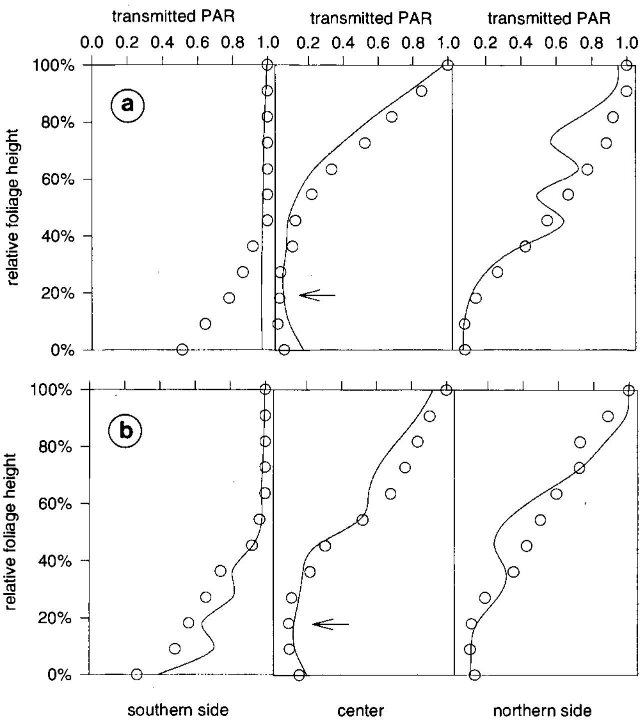

Fig. 3: Transmitted PAR distribution in the OLMV canopy system. For details see Fig. 2.

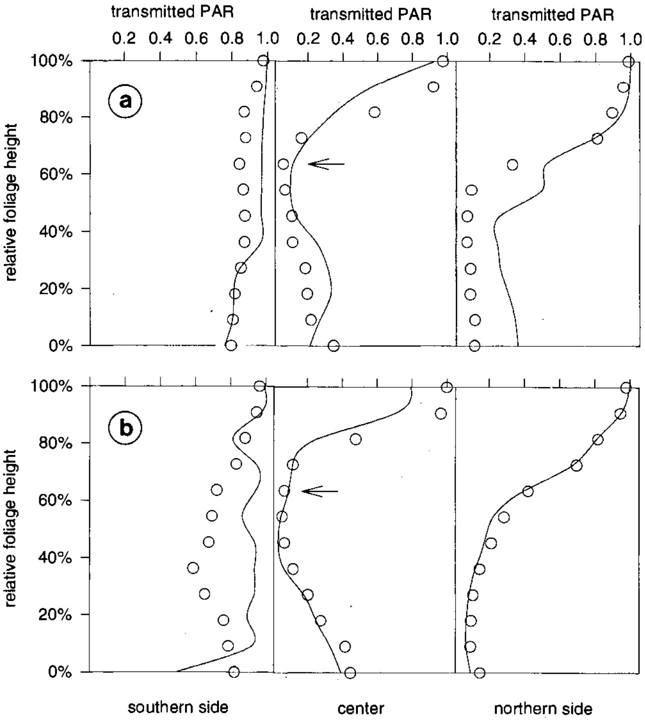

Fig. 4: Transmitted PAR distribution in the GDCMV canopy system. For details see Fig. 2.

Due to the row direction, the southern sides of both foliage walls were sunlit at solar noon while their northern sides were partially shaded. The decrease of transmitted PAR at the base of the southern side of the northern foliage walls was presumably due to the shadow cast by the southern foliage walls on the former. The more important shading in the case of OLMV can be related to its foliage walls spacing and dimensions.

The distribution of transmitted PAR along the vertical transect at the center of the foliage wall was lowest at about 20 and 60 % of the foliage height for the Open Lyre systems and the GDC system, respectively.

For either canopy system, the fruit zone was located in the most shaded zone of the canopy. The values of transmitted PAR at the center of the fruit zone were 14, 5 and 7 % of incident PAR for OLLV, OLMV and GDCMV, respectively. These values were within the range of variation of light available to the grapevine fruit zone (SMART 1988; MORSI *et al.* 1992; DOKOOZLIAN and KLIEWER 1995 a). Transmitted PAR at the fruit zone center was markedly higher for OLLV than for OLMV and GDCMV, probably due to differences in vine vigor affecting leaf area density.

A comparison between measured and simulated values indicates that the light model adequately describes the main tendencies of the transmitted PAR distribution .

Mean residuals (i.e. measured values minus simulated values) were -0.025, 0.006 and -0.031 for OLLV, OLMV and GDCMV, respectively. The standard deviation of the residuals were 0.071, 0.113 and 0.140, respectively, and r^2 values were 0.95, 0.90 and 0.84, respectively. Hence, estimation bias appeared to be low while dispersion was large. This may result from the fact that predicting transmitted radiation at different locations inside the canopy is very sensitive to the variability and errors of input parameters, i.e. the description of the geometrical structure (SINOQUET and BONHOMME 1992). This may be the case in grapevine canopies because shoots (even when trellised) are moveable and leaf location may have changed between the time of structure measurements and light measurements. Obviously the worst agreement between light measurements and the model outputs was found for the GDC system, where shoots are trained downward without foliage wires.

Another source of discrepancy between the measurements and the model outputs is that the spatial location of measured and simulated data were not exactly the same. Measurements of transmitted PAR were recorded at locations relative to the vegetation walls (i.e. wall center or wall boundary), while transmitted PAR was computed by the model at the base of the vegetation cells delineated by the coordinate system used for canopy structure determination. Although linear extrapolation was used for the estimation of transmitted PAR distribution at the boundary of the foliage walls, this may result in a lack of spatial correspondence between measured and simulated radiation data. Moreover, the boundary of foliage walls did not necessarily match the boundary of a vegetation cell. This leads to large gradients of leaf area density and light transmission in the vegetation cells corresponding to the canopy boundaries. Indeed, the maximum discrepancies between measured and simulated transmitted PAR occurred at the foliage wall sides (Figs. 2-4).

Finally, differences between measured and simulated data may also be due to hypotheses used in the model, e.g. uniform distribution of leaf azimuths and random location of leaf area in the vegetation cells. This might be improved by replacing the basic Lambert-Beer law of light interception by binomial laws where the size and leaf orientation of each leaf could be explicitly taken into account. In that case, the only remaining hypothesis would be the random distribution of leaves in the vegetation cells. This latter assumption could only be overcome by using light interception models based on a complete description of the canopy structure, i.e. location, orientation, size and shape of every phytoelement of the canopy (e.g. CHEN *et al.* 1994).

Light partitioning between main and lateral shoot leaves: Among others, KOBLET (1987) reported that retaining a higher proportion of young lateral leaves after early shoot topping increased grape quality because lateral leaves appeared to have a higher photosynthetic efficiency. In contrast, according to SCHNEIDER (1985) a continuous removal of lateral shoots representing an important part of the total leaf area, did not affect yield and sugar content, due to the fact that lateral leaf area suppression was balanced by a better exposure of the remaining foliage. Therefore, the investigation of light partitioning between main and lateral leaves appeared to be relevant if interested in canopy photosynthesis and grape quality.

Light partitioning between the two types of grapevine leaves can be related to their relative importance in terms of leaf area, leaf angle, leaf dispersion and relative position inside the canopy with regard to the solar track. Tab. 2 shows the contribution of lateral leaves to the total leaf area and

Table 2

Light partitioning between main and lateral leaves in actual and virtual canopies composed of main leaves only

Canopy system	LLA/TLA	RaL/RaT	εaa	εav	TFa	TFv
OLLV	0.29	0.19	0.42	0.40	0.14	0.30
OLMV	0.34	0.16	0.55	0.52	0.05	0.14
GDCMV	0.39	0.48	0.57	0.51	0.07	0.28

LLA/TLA: ratio of lateral leaf area to total leaf area; RaL/RaT: ratio of absorbed PAR by lateral leaves to total absorbed PAR; εaa: absorption efficiency of the actual canopy; εav: absorption efficiency of the virtual canopy; TFa: fraction of PAR transmitted to the center of the fruit zone for the actual canopy; TFv: fraction of PAR transmitted to the center of the fruit zone for the virtual canopy.

to the fraction of absorbed PAR simulated by the model. For Open Lyre systems, the fraction of absorbed radiation by lateral leaves was lower than their contribution to the leaf area index. This was the opposite in the case of the GDC system. Since lateral and main leaves had similar leaf angle distributions, the difference between the Open Lyre and the GDC training systems can be related to the location of lateral leaves inside the canopy (Mabrouk *et al.* 1997). Unlike the Open Lyre training system, lateral leaves in the GDC training system were located in the upper third of the canopy, which was of advantage in terms of light capture capacity, especially for high sun elevations.

The proportion of total radiation absorbed by lateral leaves ranged between 15 and 50 %, depending on the treatments. Thus the contribution of lateral leaves to radiation absorption could be substantial. To further investigate the role of lateral leaves in radiation absorption, a simulation study was conducted with a virtual canopy composed of main leaves only (i.e. lateral leaves were discarded). This analysis, however, assumed no change of structural parameters of main leaves as a result of removing lateral leaves. Removing lateral leaf area resulted in a decrease of total leaf area by 30-40 % depending on the treatments, but did not modify the canopy dimensions (Tab. 2). The absorption efficiency of each canopy system (ratio of absorbed radiation to incident radiation) was not significantly affected by removing lateral leaves. It is suggested that canopy dimensions are more determinant than leaf area for the light absorption properties of the canopy at these high levels of leaf area density (LAD: 4.73, 5.31 and 4.66 for OLLV, OLMV and GDCMV, respectively). A similar result has been reported by Heilman *et al.* (1996).

On the other hand, removing lateral leaves significantly improved cluster exposure; transmitted PAR to the fruit zone doubled for OLLV, tripled for OLMV and quadrupled for GDCMV. Thus, for all treatments, removing lateral leaves did not penalize the absorption efficiency of the canopy but considerably enhanced the fruit zone exposure.

Simulation of interception efficiency with a geometrical model: If the interception efficiency of the canopy systems is assumed to be largely determined by canopy dimensions geometrical models should adequately simulate the radiation interception at the canopy scale. To test this hypothesis, the model was used as a geometrical model by replacing the vegetation cells by opaque cells and by multiplying the leaf area density in each vegetation cell by 1000 to get a simulated canopy with the actual shape and dimensions but with a porosity equal to zero.

The interception efficiency ε_{iC} was then estimated from the interception efficiency ε_{iG} calculated by the geometrical model which was corrected according to Jackson (1983):

$$\varepsilon_{iC} = \varepsilon_{iG} \cdot [\,1\text{-}\exp[\,(\text{-}c/\sin h)\cdot(\mathrm{LAI}/\varepsilon_{iG})\,]\,] \qquad (4)$$

where h is the sun elevation, LAI is the leaf area index and c is a constant. In this equation, the factor correcting ε_{iG} accounts for canopy porosity. The correction factor is parametrized according to the Lambert-Beer law where LAI is related to the area shaded by the opaque canopy, i.e. ε_{iG} . The term (c/sin h) is similar to an extinction coefficient, it globally includes the effect of leaf angle, leaf optical properties and leaf dispersion. In this study, fitted values of c were 0.29, 0.30 and 0.33 for OLLV, OLMV and GDCMV, respectively.

Fig. 5 shows the comparison between ε_{iC} inferred from the geometrical approach and the above equation, and ε calculated with the complete model. For all treatments, r^2 coefficients were greater than 0.98, and slopes of the linear regression analysis ranged between 0.988 and 1.002. Mean residuals were 0.0004, -0.006 and -0.005 for OLLV, OLMV and GDCMV, respectively, and standard deviations of residuals were 0.018, 0.026 and 0.026, respectively.

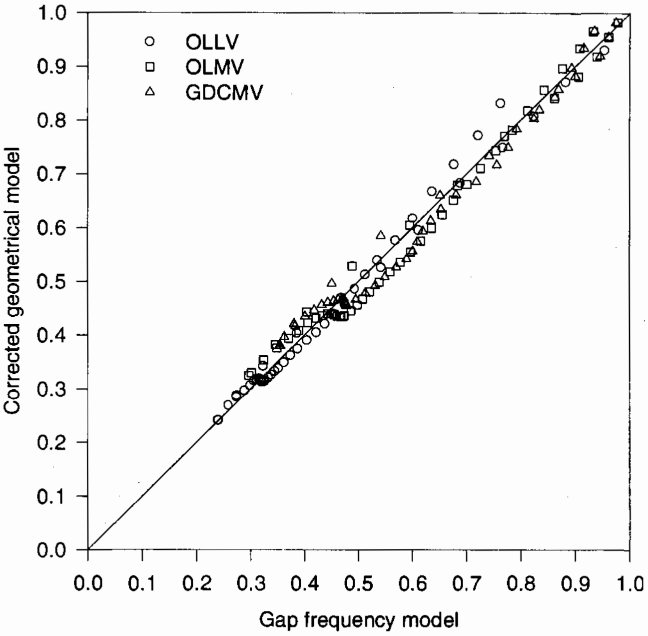

Fig. 5: Comparison between the interception efficiency calculated by the complete model and the geometrical approach.

Thus, it appears that the daily course of interception efficiency simulated with the geometrical approach was in excellent agreement with that modelled using the complete model. Using geometrical models is interesting because they do not require the determination of accurate structure parameters such as the spatial distribution of leaf area density, leaf angles and leaf optical properties. However, the formalism used in this study (Equation 1) requires a calibration parameter c in order to estimate the interception efficiency ε_{iC} from the geometrical model. Fortunately values of c for the three treatments were not so different, but it should be verified to what extent a value of c equal to 0.3 is a constant property of vineyard canopies. From a methodical point of view, the geometrical approach derived from the light model allows to represent any canopy shape and dimensions: unlike geometrical models (e.g. Smart 1973; Riou *et al.* 1989), the equations used in the model do not intimately depend on a given shape of the canopy. On the other hand, as any geometrical model this approach does not enable insight into the radiation distribution inside the canopy.

Conclusions

The radiation model used in this study enabled us to simulate correctly the daily evolution of the interception efficiency of two grapevine canopy systems exhibiting different vigor levels. It has also permitted a satisfactory description of the radiation distribution within these complex canopies.

Moreover, light partitioning between main and lateral leaves could be assessed for all treatments. Some discrepancies between the model and the measurements occurred when simulating the interception efficiency of the GDCMV canopy system and the distribution of transmitted radiation on the outer sides of either canopy system. On the one hand, this can be related to a lack of accuracy in the description of the canopy structure when using the grid-cell system, especially the distribution of leaf area density. On the other hand, the present model uses some assumptions about the canopy structure that are not valid in actual canopies, e.g. the uniform distribution of leaf azimuth. Evidence for a preferential leaf orientation was presented in a previous paper (Mabrouk *et al.* 1997). To improve the simulation of the grapevine light microclimate, it appears necessary to obtain an accurate determination of the absolute and relative position of foliage elements as well as their orientation. Three-dimensional digitising systems are very useful tools for this purpose (Thanisawanyangkura *et al.* 1997). The radiation model has also to be enhanced by considering actual leaf angle distributions and leaf dispersion parameters.

Another useful improvement of the model could be the calculation of the sunlit leaf area, which could be directly related to the SFEp (Carbonneau 1980, 1989, 1995) which has been used to evaluate grapevine canopy systems with regard to grape and wine quality.

A simulation study showed that the geometrical approach can be used for the simulation of the canopy interception efficiency. This approach only requires the determination of a calibration factor, the canopy dimensions and LAI without considering more elaborated structure parameters.

The radiation model, based on the turbid medium analogy, used in this study may have several applications: (1) It allows an accurate description of the grapevine radiation regime and its spatial and temporal variations. Such a description is very useful for the simulation of canopy photosynthesis and vine growth. (2) The model can be used to assess the consequences of canopy management practices on the light microclimate (e.g. lateral leaf removal). (3) It can help to evaluate existing canopy systems and designing new ones with regard to improved foliage and cluster exposure.

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