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Influence of leaf area density and trellis/training system on the light microclimate within grapevine canopies*

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Summary

The influence of leaf area density and canopy configuration on the light microclimate within 6 wine grape trellis/training systems commonly used in California (single curtain, double curtain, vertically shoot positioned, lyre, Smart-Henry and Smart-Dyson) was examined in two experimental vineyards (Oakville and Parlier). Mean canopy leaf area density varied considerably among the systems, ranging from approximately 2.8 m^2 m^{-3} for the Wye to 10.1 m^2 m^{-3} for the VSP. Non-positioned systems were characterized by a layer of relatively high leaf area density in their outer envelope and lower leaf area densities in their interior. In contrast, leaf area density in positioned systems increased from the top of the canopy moving downward to the fruit zone. Mean leaf area density within the fruit zone ranged from near 6 m^2 m^{-3} in the DC to over 12 m^2 m^{-3} in the VSP and LYR. The pattern of light attenuation within the canopy was generally similar among the systems, with PPF reaching its lowest level in or near the fruit zone. Fruit zone PPF was >10 % of ambient sunlight in low density canopies and <5 % in high density canopies. A gradual decline in fruit zone PPF was found as leaf area density increased in positioned systems. PPF decreased sharply in the fruit zone of non-positioned systems as leaf area density increased from 2 to 4 m^2 m^{-3}, then leveled as leaf area density exceeded 6 m^{2}m^{-3}. Fruit zone PPF decreased as the leaf area density of divided systems increased from 2 to 4 m^2 m^{-3}, then declined gradually as leaf area density approached 6m^2 m^{-3}. Fruit zone PPF in non-divided systems was initially lower, and declined more gradually as leaf area density increased, compared to divided systems. Compared to positioned systems, leaf layer number in the fruit zone rose more sharply in non-positioned systems as leaf area density increased. Leaf layer number was greater in non-divided systems compared to divided systems, but declined at similar rates in both systems as leaf area density increased. Shoot-positioned systems achieved well-exposed fruit zones at higher leaf area densities, but lower leaf layer numbers, compared to non-positioned canopies.

Key words: light quantity, *Vitis vinifera* L.

Introduction

Light regulation of grape berry growth and composition has received significant attention during the past three decades. A major component of this work was to characterize light quantity and quality within the canopy, and to examine potential interactions among light environment, canopy size and trellis/training systems (SMART 1988; DOKOOZLIAN and KLIEWER 1995 a, b). These studies and others reported correlations between canopy size and canopy light environment, despite the fact that a wide variety of canopy size descriptors were employed. These included total leaf area per vine and leaf area per meter cordon (DOKOOZLIAN and KLIEWER 1995 a, b), leaf area index (GRANTZ and WILLIAMS 1993) and leaf layer number in the fruiting zone (SMART 1998). While these indices are useful for comparing the canopy characteristics of vines grown under similar trellis and training systems, a major drawback is that they do not take into account canopy volume or the amount of space allocated for foliage distribution (SCHULTZ 1995). An accurate assessment of foliage density is critical, particularly when comparing trellis/training systems of various configurations and canopy sizes. For example, shoot-positioned systems generally have well defined canopy volumes and non-positioned systems do not, while vines trained to divided curtains have more space available for leaf area distribution compared to single curtain vines (DOKOOZLIAN *et al.* 1999).

Canopy leaf area density (m^2 leaf area per m^3 canopy volume) is a three-dimensional measurement that accounts for differences in canopy volume among systems varying in their architecture (SCHULTZ 1995). This measure integrates total leaf area or canopy size as well as the spatial distribution of leaf area within the given canopy volume or space. The expression also takes into account changes in canopy configuration as a result of shoot positioning and canopy division, and is useful for comparing a wide-range of trellising systems (SCHULTZ 1995; MABROUK *et al.* 1997; MABROUK and SINOQUET 1998). However, average canopy leaf area density (total leaf area distribution within the entire canopy volume) may not reflect localized variation in leaf area distribution typically found in grapevine canopies (SCHULTZ 1995; MABROUK *et al.* 1997). To overcome this problem, localized leaf area density must be determined by dividing the canopy into sections and measuring leaf area within each individual cell (SCHULTZ 1995; MABROUK *et al.* 1997).

Prior to the mid-1980s, nearly all California wine grapes were grown on a two or three wire single curtain, non-shoot positioned trellis (commonly referred to as the California sprawl). Little attention was paid to site-specific factors influencing vine vigor, such as climate, soil, rootstock x scion interactions and cultural practices, when selecting trellis/

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* Dedicated to the memory of Dr. NELSON SHAULIS (1914-2000), viticulture pioneer and father of modern grapevine canopy management.

training systems. Consequently, the trellis was often utilized improperly, resulting in excessive fruit zone shading under vigorous conditions and inefficient vineyard design in low-vigor situations (Dokoozlian and Kliewer 1995 a, b). More recently, a greater number of trellis/training systems has been utilized in order to better match trellis configuration to anticipated vine vigor (Dokoozlian *et al.* 1999). Several of the systems incorporate canopy division (either horizontal or vertical) and/or shoot positioning. These modifications are designed to improve production efficiency by reducing canopy density, as well as increasing solar interception by the canopy surface and sunlight penetration into the canopy interior (Smart 1973, 1995).

An earlier study examined the interaction between canopy size and light microclimate under the traditional California trellis/training system (Dokoozlian and Kliewer 1995 b). This work established optimum values for several canopy parameters and provided general guidelines for canopy evaluation. The purpose of the current study was to examine the effects of leaf area density on the light microclimate within the wine grape trellis/training systems currently employed in California. In addition, several indirect methods of canopy assessment were evaluated and correlated with fruit zone light microclimate. The ultimate goal of this work is to provide quantitative criteria for the selection of optimum trellis/training systems based on canopy size or leaf area density.

Material and Methods

Vineyard sites, trellis configurations and growing conditions: Experimental vineyards located at the University of California Kearney Agricultural Center (Parlier, CA) and the Department of Viticulture and Enology Experimental Vineyard (Oakville, CA) were used in the study. In Parlier, 6-year-old Chardonnay grapevines grafted to 5 C rootstock were grown in a fine-sandy loam soil, spaced 1.8 m (between vines) x 2.8 m (between rows) and oriented in east-west rows. In Oakville, 10-year-old Cabernet Sauvignon grapevines grafted to 3309 rootstock were grown in a clay loam soil, spaced 1.8 m (between vines) x 2.4 m (between rows) and oriented in north-south rows. Grapevines at both sites were cordon-trained, spur-pruned and irrigated at approximately 70 % of potential evapotranspiration. Standard commercial cultural practices, including pest and disease management, were followed for each cultivar and region. The configurations of the trellis/training systems used in this study are presented in Fig. 1. Trellis/training systems are abbreviated as follows: SC = single curtain, VSP = vertically shoot positioned, SD = Smart-Dyson, SH = Smart-Henry, LYR = lyre, DC = double curtain. At Parlier, each system was replicated 6 times using 6 vine plots. At Oakville 4 replicates of 8 vines were established in a single vine-row of each system. Canopy management practices (shoot positioning and hedging) were carried out according

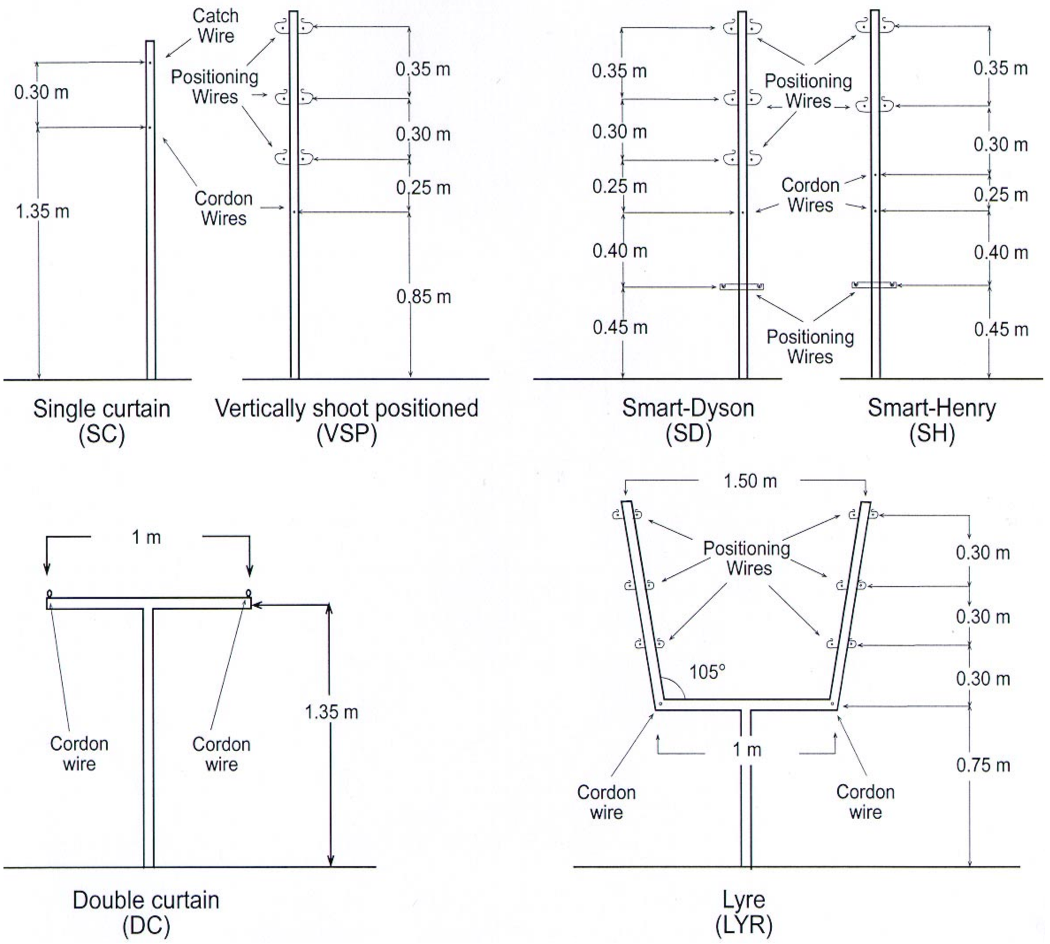

Fig. 1: Dimensions and wiring configurations for trellis/training systems used in the study. System abbreviations as follows; SC = single curtain, VSP = vertically shoot positioned, SD = Smart-Dyson, SH = Smart-Henry, DC = double curtain, LYR = lyre.

to normal commercial practice. Shoot positioning was performed per standard practice at both sites on the VSP, SD, SH and LYR. Shoot trimming was performed with hand shears just prior to berry softening at both sites in order to maintain canopy shape in the VSP, SD, SH and LYR. One week prior to berry softening at each site, a vine space near the center of each replicate was chosen on the basis of vegetative growth uniformity. A one-meter long section in the center of the vine space was demarcated and utilized for subsequent light and leaf area measurements.

Light attenuation: A 2 m fiberglass rod (20 mm diameter, marked at 0.2 m increments) was positioned vertically into the center of the vine row to serve as a guide for the measurements. Photosynthetic photon flux (PPF) was recorded at 0.20 m intervals along the vertical profile, beginning at the canopy exterior (ambient reading 2 m above ground), using a 0.8 m sunfleck ceptometer (Decagon Devices, Inc, Pullman, WA). The ceptometer was placed directly above the cordon parallel to the vine row at each measurement point, and three measurements were taken: one with the ceptometer oriented vertically upwards, and two with the ceptometer oriented perpendicularly to the canopy face into the vine row. Ambient readings were taken above and adjacent to the canopy surface. Measurements were taken within a two-week period of berry softening (8-10 weeks following anthesis) in July and August. Readings were collected every two hours from 7:00 to 19:00 Pacific Daylight Time (PDT) on clear days (mid-day PPF values ranged from approximately 1700 to 1900 μmol m^{-2} s^{-1}). All measurements for each date were combined and expressed as the percentage of total ambient PPF intercepted for the daylight period.

Vine defoliation, leaf area determinations and canopy volume calculations: To create a range of leaf area densities, shoots were removed twice within each plot following the initial (full canopy) PPF measurements. One-third of the vine shoots were removed in the first defoliation, followed by an additional one-third of the remaining shoots for the second. Actual reductions in total vine leaf area at both sites ranged from 28 to 40 % following the first defoliation and 60-73 % following the second. Leaf blades were removed manually from each shoot immediately after defoliation, placed in plastic bags and held in cold storage (2 °C, 90 % relative humidity) until area measurements were completed (within 48 h after shoot removal). Leaf area was determined with a LI-COR leaf area meter (LI 3100) (LI-COR, Lincoln, Nebraska). PPF measurements were taken as described above at full canopy (undefoliated) and immediately following the first and second defoliations. Following the last set of measurements, the vines were completely defoliated and total leaf area per meter canopy was determined. The number of shoots per vine was also recorded. Canopy volume was estimated using exterior canopy dimensions. All canopy cross sections were approximated to rectangles, except single curtain and double curtains, which were likened to truncated triangles (Smart *et al.* 1982). Shoot-positioned systems were assumed to have canopy volumes equivalent to the formula height x width x length. Non-positioned systems (single curtain and double curtain) were assumed to have canopy volumes equivalent to the formula ((0.5 x H x T) x (0.5 x H x B) x L); where T = width at top of canopy; H = vertical height; B = width at base of canopy; L = length. Canopy surface area was defined as the area bounded by the planes of the top and sides of the canopy (Smart *et al.* 1982). The exterior surface of the canopy was calculated from exterior canopy dimensions.

Leaf area density mapping: An additional randomly selected vine within each replicate was used for leaf area density mapping. Two wooden frames, 2.2 m high, 2.0 m wide and 1.0 m long, were placed on each side of the vine row. Twine was used to connect the frames through the canopy and divide the canopy into 40 individual cells (5 cells wide x 8 cells high), 0.1 m^3 in volume. Leaves within each cell were removed, placed in labeled paper bags and retained in cold storage (2 ºC, 90 % relative humidity) until area measurements could be completed (within 48 h after sampling). One vine within each replicate was mapped at each site (6 vines per treatment at Parlier and 4 vines per treatment at Oakville).

Point quadrat measurements: Point quadrat measurements were performed simultaneously to PPF measurements using the method described by Smart (1988). The sharpened tip of a 1 m rod (3 mm diameter) was positioned perpendicularly to the canopy surface at the height of the fruit zone. The rod was inserted into the canopy interior at an angle of 90º with respect to the canopy exterior, and the number of leaves, clusters and gaps intercepted by the tip of the rod recorded. Readings were taken through the entire width of the canopy, and shoots were ignored. Twenty insertions per replicate were made at 5 cm intervals. Leaf layer number represents the mean number of leaf contacts per insertion, while the percentage of canopy gaps refers to the percentage of insertions in which no leaf contacts were made. Interior clusters and leaves represent those organs located within the canopy, beneath one or more leaf layers.

Data summary and statistical analyses: Leaf area density distribution and light attenuation patterns within the canopy were similar with respect to trellis/training systems at both sites. Only the data collected from the Parlier site is presented for these parameters as a result. Few significant site x trellis interactions were found, therefore data for the two locations were combined to calculate canopy characteristics and correlation coefficients except where noted. Data were analyzed using LSD and GLM curve-fitting procedures in SAS (SAS Institute, Cary, N.C.).

Results and Discussion

Due to their well-defined architecture, positioned systems generally had lower canopy surface areas and volumes compared to non-positioned systems (Tab. 1). Canopy division (horizontal or vertical) increased both surface area and volume in positioned and non-positioned systems. Non-positioned systems also had lower surface area:volume ratios compared to positioned systems, indicating that they have more interior area for leaf area distribution (Smart 1985). DC vines had the greatest surface area and canopy volume, while VSP vines had the lowest surface area and canopy volume. Although total leaf area per vine prior to defoliation

Table 1

General characteristics of grapevine training/trellising systems used in the study (Parlier and Oakville sites combined)

Training/trellis system	Canopy divided	Shoot positioned	Canopy surface area (m^2 m^{-1})	Total canopy volume (m^3 m^{-1})	Surface area: Volume (m^2 m^{-3})	Total leaf area per vine (m^2)	Mean leaf area density (m^2 m^{-3})
Single curtain (SL)	No	No	4.5	1.6	2.8	12.6	4.4
Vertically shoot positioned (VSP)	No	Yes	3.0	0.6	5.0	11.4	10.1
Smart Dyson (SD)	vertically separated	Yes	4.0	0.8	5.0	11.4	7.9
Smart-Henry (SH)	vertically divided	Yes	3.7	0.7	5.3	11.5	9.1
Lyre (LYR)	horizontally divided	Yes	5.8	1.3	4.4	11.7	5.7
Double curtain (DC)	horizontally divided	No	6.8	2.3	2.9	11.6	2.8
LSD (0.05)			0.9	0.4	0.8	n.s.	0.7

was similar among the systems (~11-12 m^2), mean (total canopy) leaf area density varied significantly. Horizontally divided and non-positioned canopies had lower mean leaf area densities than vertically divided and positioned canopies, with values ranging from 2.8 m^2 m^{-3} for DC vines to 10.1 m^2 m^{-3} for VSP vines. MABROUK *et al.* (1997) reported mean leaf area densities near 5.0 m^2 m^{-3} for DC and LYR canopies, while SHULTZ (1995) reported values of 3.7 m^2 m^{-3} and 2.0 m^2 m^{-3} for vines trained to the VSP and SC, respectively. As pointed out by SCHULTZ (1995), the leaf area density of grapevines is significantly greater compared to other perennial crop canopies. The leaf area density of deciduous fruit tree species typically ranges between 0.5 and 2.5 m^2 m^{-3} (JACKSON 1980).

Localized leaf area density within the canopy varied considerably among the trellis systems (Fig. 2). Localized leaf area density within a single 0.1 m^{-3} cell ranged from 0.9 m^2 m^{-3} (near the vineyard floor of the SC) to 14.7 m^2 m^{-3} (near the fruiting zone of the SH). The pattern of leaf area distribution was distinct between positioned systems and non-positioned systems, with localized leaf area density being generally lower in non-positioned systems. This pattern can be explained by the fact that shoot positioning concentrated foliage within a defined canopy volume. Non-positioned systems were characterized by a layer of relatively high leaf area density in the outer canopy envelope, followed by reduced leaf area density in their interior. By contrast, leaf area density in positioned systems increased from the top of the canopy downward to the fruiting zone. Canopy division had more variable effects on leaf area distribution, based on whether or not shoot positioning was employed. Horizontal canopy division without shoot positioning, as practiced in the DC, significantly increased canopy volume and the area available for leaf area distribution. This reduced leaf area density within the canopy interior compared to the SC. Canopy division in the LYR (horizontal) and SD and SH (vertical), coupled with shoot positioning, produced localized density profiles similar to the VSP.

Localized leaf area density in all systems was greatest in or immediately above the fruiting zone, where the highest concentration of primary and lateral shoots occurs, and least in the regions beneath the fruiting zone and in the lower portions of the canopy. Mean leaf area density in the fruiting zone ranged from near 6 m^2 m^{-3} in the DC to over 12 m^2 m^{-3} in the VSP and LYR. The large spatial variation in leaf area density within the canopy observed here is similar to previous reports on grapevines (SCHULTZ 1995; MABROUK *et al.* 1997), and points out why mean or total canopy leaf area density cannot be used to predict leaf area density in the fruiting zone or other specific regions of the canopy. For example, mean leaf area densities for the VSP and DC systems were 2.8 m^2 m^{-3} and 10.1 m^2 m^{-3}, respectively. In comparison, leaf area density within the fruiting region of the DC was approximately 5.9 m^2 m^{-3}, while the VSP was 12.9 m^2 m^{-3}.

The general pattern of light attenuation within the canopy interior was similar among the systems, with the greatest attenuation observed when the ceptometer sensors were positioned upward (Fig. 3). In this position, PPF decreased 90 % or more moving from ambient (above the canopy) to the fruiting zone, reached its lowest level in or near the fruiting zone, then increased moving below the fruiting zone to the soil surface. Overall light attenuation was much less when the sensor was oriented either north or south (east-west rows), toward the avenue between vine rows. The patterns and amount of light attenuation within the canopy seen here are similar to that reported in previous studies (DOKOOZLIAN and KLIEWER 1995 a; SCHULTZ 1995). However, note that PPF (upward oriented sensors) in the interior of positioned canopies, such as the VSP, SD and LYR, is greater and more consistent compared to the SC or DC. PPF in the fruiting zone ranged from <1 % of ambient for the SC to almost 10 % for the VSP. These differences can be explained by the leaf area distribution data presented in Fig. 2. Due to the lack of shoot positioning in the SC and DC systems, shoots became pendant above the cordon and filled the regions adjacent to their fruit zones with leaf area. As a result, light must travel through several concentrated layers of foliage to reach the canopy interior. Since shoot growth is generally vertical (up or down) in positioned systems, light travels through fewer leaf layers to reach the interior of these

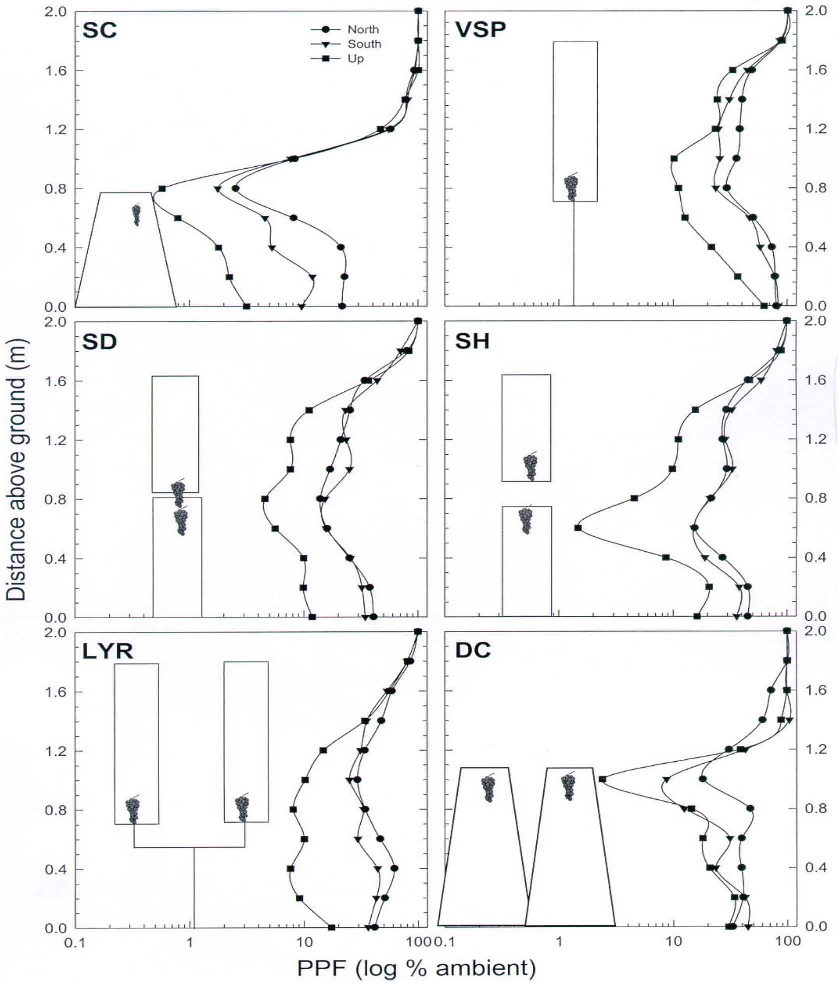

Fig. 2: Localized leaf area density in 6 different trellis/training systems at Parlier, CA. Each cell represents a volume of 0.09 m^3. Values in cells represent leaf area density (m^{-2} m^{-3}). Increasing level of gray scale indicate increasing leaf area density. Each cell represents the mean of 6 replicate measurements. See Fig. 1 for system abbreviations.

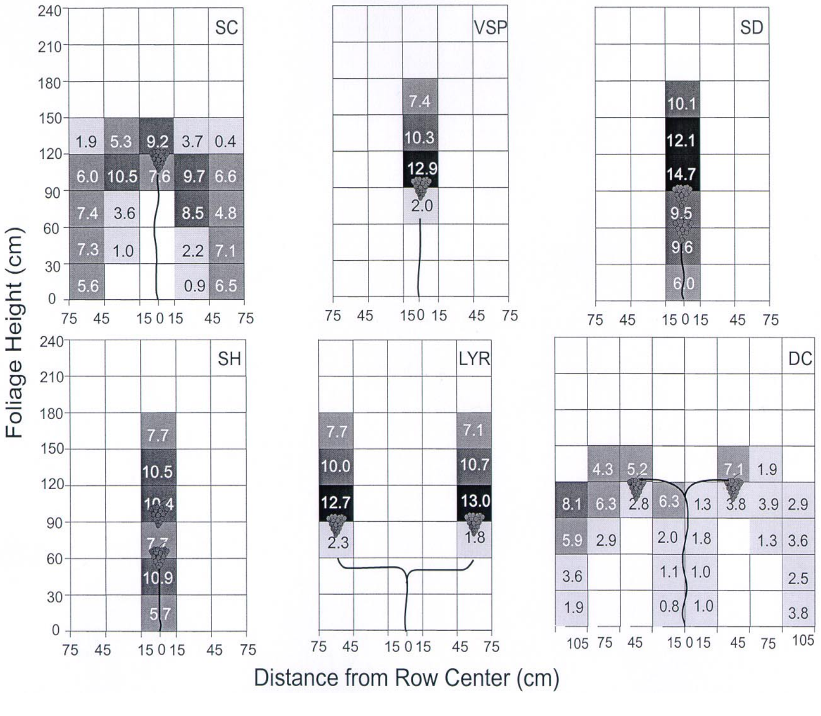

Fig. 3: Relationship among canopy depth, leaf area density (m^2 m^{-3}), and PPF attenuation (log % ambient) in 6 different trellis training system at Parlier, CA. Boxes and clusters indicate canopy shape and location of fruiting zone, respectively. See Tab. 1 for canopy characteristics of each system and Fig. 1 for system abbreviations.

canopies. The strong attenuation observed in the SH reflected the combined effects of the two distinct cluster and foliage-bearing regions present in this system. As reported previously for the SC, PPF in all systems reached its lowest level in or near the fruit zone (Dokoozlian and Kliewer 1995 a). In addition to the high concentration of foliage in the fruit zone, Schultz (1995) estimated that canes, clusters and permanent structures (canes, cordons, etc.) occupy approximately 6.2 % of total surface area. These organs likely contribute to the strong light attenuation observed in this region.

Distinct relationships between leaf area density and PPF in the fruit zone were observed for positioned and non-positioned systems (Fig. 4 A). A gradual decline in PPF was found as leaf area density increased in positioned systems. In comparison, PPF decreased sharply in non-positioned systems as leaf area density increased from 2 to 4 m^2 m^{-3}, then leveled and remained relatively constant as leaf area density exceeded 6 m^2 m^{-3}. When leaf area density was between approximately 3 and 7 m^2 m^{-3}, PPF was greater in positioned systems. However, when leaf area density exceeded 7 m^2 m^{-3}, PPF in the fruiting zone of positioned and non-positioned canopies was similar. Distinct patterns of light attenuation were also observed for divided and non-divided systems (Fig. 4 B). PPF in the fruit zone decreased sharply for divided systems as leaf area density increased from 2-4 m^2 m^{-3}, then leveled and declined gradually as leaf area density approached 6 m^2 m^{-3}. PPF in non-divided systems was initially lower, and declined more gradually, compared to divided systems. The rate of PPF decline in both systems was similar once leaf area density exceeded 6 m^2 m^{-3}.

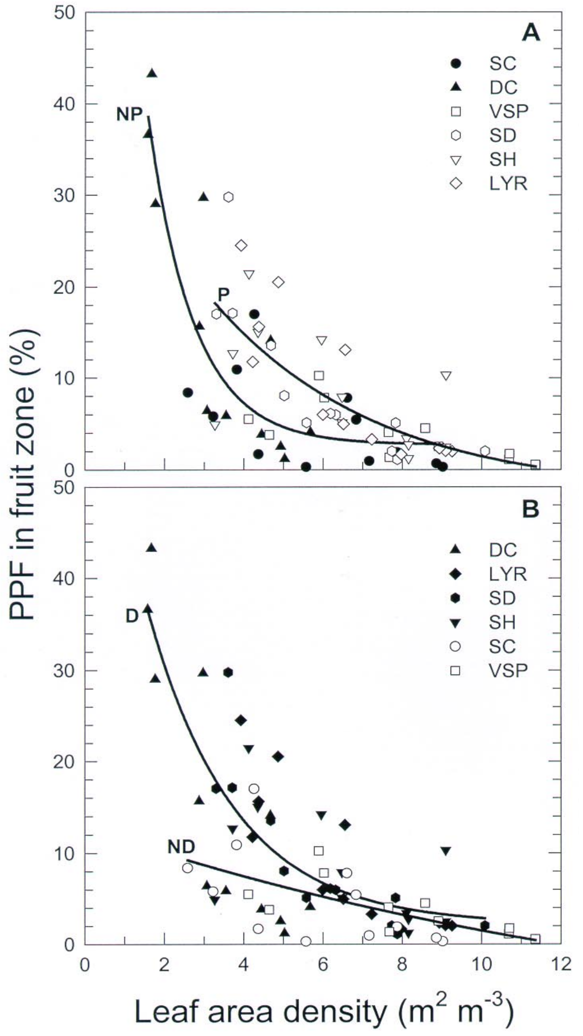

Fig. 4. Relationship between PPF and leaf area density in the fruiting zone for positioned (P) and non-positioned (NP) (Fig. 4 A) and divided (D) and non-divided (ND) (Fig. 4 B) trellis/training systems. Parlier and Oakville sites combined. See Fig. 1 for system abbreviations. Lines fitted to the following equations: positioned systems (P), $y = -2.595 + 46.051e^{-0.243x}$, ($r^2 = 0.551$); non-positioned systems (NP), $y = 2.724 + 139.263e^{-0.858x}$, ($r^2 = 0.743$); divided systems (D), $y = 2.109 + 70.860e^{-0.4555x}$, ($r^2 = 0.651$); non-divided systems (ND), $y = -11.729 + 24.630e^{-0.4555x}$, ($r^2 = 0.321$).

Point quadrat measurements provided few significant correlations with leaf area density when data from all trellis systems were combined (Tab. 2, column with combined analysis). Similar results were also obtained when the data from divided and non-divided systems were analyzed separately (data not presented). However, correlations improved when positioned (P) and non-positioned (NP) systems were separated. Among the parameters measured, the most useful was leaf layer number. It provided significant correlations with all other point quadrat parameters, as well as leaf area density and PPF in the fruit zone, for both positioned and non-positioned canopies. As leaf area density increased, leaf layer number rose more sharply in non-positioned systems compared to positioned systems (Fig. 5 A). At the same leaf area density, leaf layer number was also greater for non-positioned systems compared to positioned systems. These observations result from the differences in shoot orientation and leaf area distribution between positioned and non-positioned systems discussed earlier (see Fig. 2). Leaf layer number was greater in non-divided systems compared to divided systems, while leaf layer number increased at similar rates as leaf area density increased in both types of systems (Fig . 5 B). This is a direct result of the increases in canopy volume and surface area associated with canopy division (Tab. 1).

In terms of the leaf area density and light microclimate interactions observed in this study, grapevine trellis/training systems can be characterized as shoot positioned or non-positioned and divided or non-divided. Both manipulations are commonly employed in current wine grape trellis/training systems to improve canopy sunlight exposure and fruit zone microclimate (Dokoozlian 1999). Shoot positioning prevents shoots from becoming pendant, decreasing the number of leaf layers surrounding the fruiting zone and allowing the distance required between the rows to be reduced. In positioned systems shoots are confined between foliage support wires, restricting canopy volume and limiting the area available for foliage distribution. In this study, shoot positioning reduced leaf layer number and increased PPF in the fruit zone when leaf area density was 3 to 7 m^2 m^{-3}. When leaf area density exceeded this range, positioned canopies became heavily shaded and fruit zone PPF dropped below that of non-positioned systems (Fig. 4). Canopy division improved canopy microclimate by increasing the total canopy volume available for foliage distribution. At the same leaf area density, divided canopies had fewer leaf layers in their fruit zone compared to non-divided canopies. How-

Table 2

Correlation coefficients among leaf area density and point quadrat indices. Parlier and Oakville sites combined

Variable	Leaf area density (m^2 m^{-3})			Leaf layer number			Foliage gaps (%)			Interior clusters (%)			Interior leaves (%)			PPF in the fruit zone (% ambient)		
	C	P	NP	C	P	NP	C	P	NP	C	P	NP	C	P	NP	C	P	NP
Leaf area density (m^2 m^{-3})	1.00	1.00	1.00															
Leaf layer number	n.s.	0.93	0.76	1.00	1.00	1.00												
Foliage gaps (%)	-0.55	-0.85	n.s.	-0.70	-0.88	-0.71	1.00	1.00	1.00									
Interior clusters (%)	n.s.	0.89	n.s.	0.88	0.93	0.88	-0.80	-0.82	-0.81	1.00	1.00	1.00						
Interior leaves (%)	n.s.	0.75	n.s.	0.93	0.91	0.91	-0.71	-0.77	-0.80	0.85	0.86	0.84	1.00	1.00	1.00			
PPF in the fruit zone (% ambient)	n.s.	-0.82	-0.62	-0.71	-0.93	-0.79	n.s.	0.72	n.s.	n.s.	-0.54	n.s.	n.s.	-0.63	n.s.	1.00	1.00	1.00

C column represents positioned (vertically shoot positioned, Smart-Dyson, Smart-Henry and Lyre) and non-positioned systems (single curtain and double curtain) combined. For C column: n=30; significance of correlation coefficient at p = 5 %: 0.357; at p = 1 %: 0.465. P column represents positioned systems (vertically shoot positioned, Smart-Dyson, Smart-Henry and Lyre) alone.
For P column n = 18; significance of correlation coefficient at p = 5 %: 0.468; at p = 1 %: 0.590. NP column represents non-positioned systems (single curtain and double curtain) alone.
For NP column n = 12; significance of correlation coefficient at p = 5 %: 0.576; at p = 1 %: 0.708.

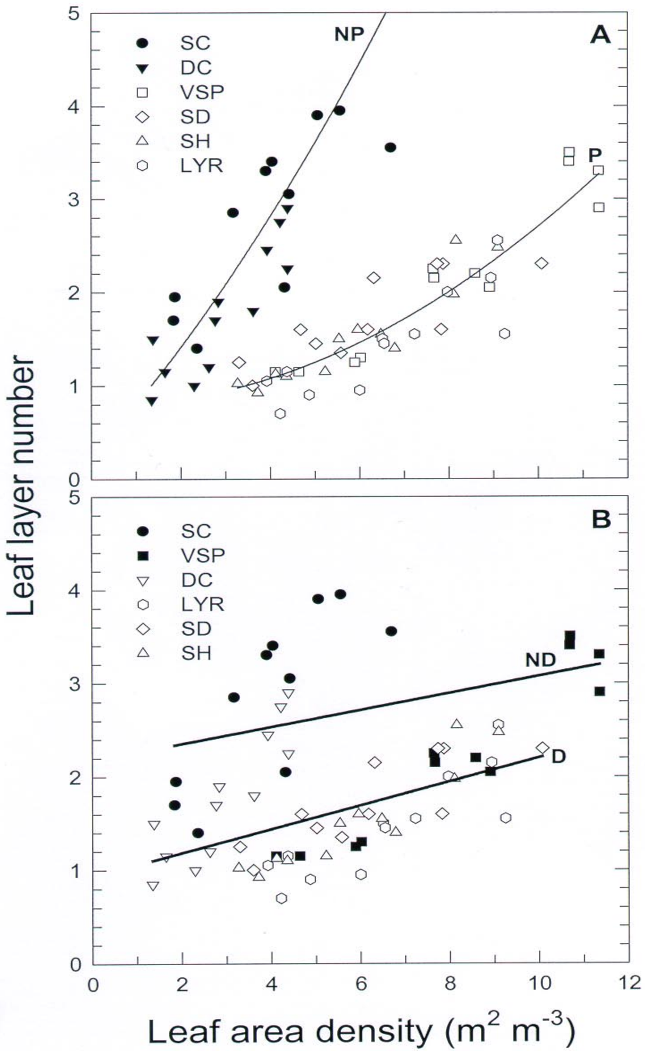

Fig. 5: Relationship between leaf layer number and leaf area density for positioned (P) and non-positined (NP) (Fig. 5 A) and divided (D) and non-divided (ND) (Fig. 5 B) trellis/training systems. Parlier and Oakville sites combined. See Fig. 1 for system abbreviations. Lines fitted to the following equations: positioned systems (P), $y = 0.785 - 0.006x + 0.019x^2$ ($r^2 = 0.814$); non-positioned systems (NP), $y = 0.254 + 0.515x + 0.031x^2$ ($r^2 = 0.528$); divided systems (D), $y = 0.926 + 0.128x$ ($r^2 = 0.239$); non-divided systems (ND), $y = 2.172 + 0.090x$ ($r^2 = 0.007$).

ever, compared to non-divided systems, canopy division increased PPF in the fruit zone only when leaf area density was <6 $m^2 m^{-3}$ (Fig. 4).

High and low-density canopies from the various trellis configurations in this study may be characterized by the parameters in Tab. 3. The criteria were based on the assumption that canopies receiving 10 % or more of ambient PPF in their fruit zones during the course of the day were well exposed (low leaf area density), while those receiving less than 5 % were poorly exposed (high leaf area density) (DOKOOZLIAN and KLIEWER 1995 b). Although the range of leaf area densities separating poorly exposed and well-exposed vines in each category was relatively narrow, several notable trends appeared. First, all positioned systems had similar criteria for low and high-density canopies (<5 $m^2 m^{-3}$ and >7 $m^2 m^{-3}$, respectively, for low and high density canopies) whether they were divided or not. The criteria for low and high-density non-positioned canopies were also similar (<3 $m^2 m^{-3}$ and 6-7 $m^2 m^{-3}$, respectively, for low and high density canopies) regardless of canopy division. Second, less than one leaf layer separated low and high-density canopies in shoot-positioned systems (<1.0 and >1.5, respectively, for low and high density canopies), while the range was 2 leaf layers (2 and 4 leaf layers, respectively, for low and high density canopies) in non-positioned systems. This reflects the relative sensitivity of positioned (restricted canopy volume) and non-positioned systems to additional leaf area. Similar trends for canopy gaps and cluster exposure were also obtained. The values in Tab. 3 for non-positioned canopies are similar to those suggested previously for the SC system in California (DOKOOZLIAN and KLIEWER 1995 a). These workers reported that leaf area density ranged from ≤3 $m^2 m^{-3}$ for low-density canopies to ≥8 $m^2 m^{-3}$ for high-density canopies. Studies conducted in New Zealand on VSP trellised vines (SMART 1988; SMART and SMITH 1988) suggested that leaf area density was ≤4 $m^2 m^{-3}$ for low-density vines and ≥7 $m^2 m^{-3}$, for high-density vines, similar to the range reported here. In the same study, PPF in the fruit zone ranged from >40 % to <10 % of ambient sunlight for low and high density vines, respectively, while leaf layer number was <1 for low density vines and >1.5 for high-density vines. These values are also similar to those reported here.

Table 3

Some parameters for high and low density wine grape trellis/training systems in California

Parameter	Trellis System							
	Positioned, non-divided (VSP)		Positioned, divided (SD, SH, LYR)		Non-positioned, divided (DC)		Non-positioned, non-divided (SC)	
	Low Density	High density	Low Density	High density	Low Density	High density	Low Density	High density
Mean leaf area density ($m^2 m^{-3}$)	<5	>7	<5	>7	<3	>7	<3	>6
Leaf layer number in the fruit zone	<1	>1.5	<1	>1.5	<2	>4	<2.5	>4
Canopy gaps (%)	>50	<20	>50	<20	>40	<20	>40	<20
Interior clusters (%)	>40	<10	>40	<10	>40	<10	>40	<10
Sunlight in the fruit zone (% ambient)	≥10	<5	≥10	<5	≥10	<5	≥10	<5

Shoot positioning and canopy division have different effects on canopy architecture and the relationship between leaf area density and fruit zone light microclimate. Shoot-positioned systems achieved well-exposed fruit zones at higher leaf area densities, but lower leaf layer numbers, compared to non-positioned canopies. This is a direct effect of vertical shoot positioning, which restricts canopy volume and produces a single column of leaf area. In non-positioned systems canopy volume and shoot orientation are comparatively unrestricted, and leaf area typically concentrates in the region adjacent to the fruit zone. These systems achieve high exposure at lower leaf area densities, but higher leaf layer numbers, compared to positioned systems. Canopy division reduces leaf area density and improves sunlight exposure into the canopy interior by simply increasing canopy volume or the amount of space available for foliage distribution. Based on our results, trellis systems with canopy surface area:volume ratios >4 (VSP, SD, SH and LYR) are best used for low to moderate sized canopies. This ensures that a high percentage of total vine leaf area is exposed to sunlight and interior shading is kept to a minimum. In contrast, systems with canopy surface area:volume ratios <4 (SC, DC) are best suited for moderate to large canopies. This allows less restricted shoot growth and canopy distribution over a larger volume of space, reducing leaf area density and potential shading within the canopy interior.

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