

## **Potential Solar Radiation in a Vertical Shoot Positioned (VSP) Trellis at 38° N Latitude**

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### **The Importance of Sunlight on Grapes**

Systematic, quantitative understanding of sunlight in vineyards can provide a solid foundation for optimizing viticultural practices. The spatial and temporal variability of insolation (*incident solar radiation*) drives microclimatic variability among and within plant canopies (Geiger 1965). Trellis design, row direction, and canopy manipulations can all be managed to potentially produce daily and seasonal insolation regimes to optimize vineyard site-potential for quality and yield (Smart 1985, Kliewer and Smart 1989, Smart and Robinson 1991).

Insolation exposure is critical for grape quality. Insolation directly heats grape clusters and affects ripening rates -- sugar and acid content are functions of accumulated temperatures and temperature range (Mullins et al 1992). Additional heat is particularly important for ripening in cool climates. At the opposite extreme, various degrees of heat damage can occur on hot days and is most likely on grapes exposed to intense direct insolation during peak afternoon air temperatures.

This article addresses insolation exposure on grape clusters in a Vertical Shoot Positioned (VSP) trellis system using hemispherical photography. The resultant “insolation profiles” detail the hourly and monthly course

of potential direct insolation for an East-West row and 3 other simulated row directions. A production scale trial of South side fruit versus North side fruit demonstrates how these insolation differences translate into measurable wine qualities. This work was part of a larger project at Woodbridge Winery (in cooperation with Lodi area growers) to better understand the effects of trellis selection and row direction on vineyard microclimate and wine quality. Here we address the fundamental issues that lead to a common question in hot climate viticulture “Have you been burned by your VSP?”

### **“The Grape’s-Eye View” – Hemispherical Photography**

The insolation environments of plant canopies can be captured using hemispherical photography (Rich 1990). Digital image processing, using specialized software, precisely defines the geometry of open sky and projects sunpaths on 180° hemispherical photographs (commonly called fisheye photos as seen on the cover). Potential direct and diffuse insolation over an entire season can be estimated from a single photograph in the absence of major seasonal changes in canopy structure. The solar model used assumes that obstructions (leaves and shoots) absorb all insolation and that skies are clear (cloudiness is not an issue in Lodi).

Hemispherical photographs were taken near Lodi, CA on August 15 2001, in a clean VSP vineyard on flat terrain with 8’ vine spacing, 8’ row spacing, 34” cordon height, 6’ top wire height, and 10” canopy width. 10 photographs were taken on each side of the trellis, at fruiting wire height as close to grape clusters as possible. The camera was mounted on a self-leveling platform, and oriented to true north with a compass.

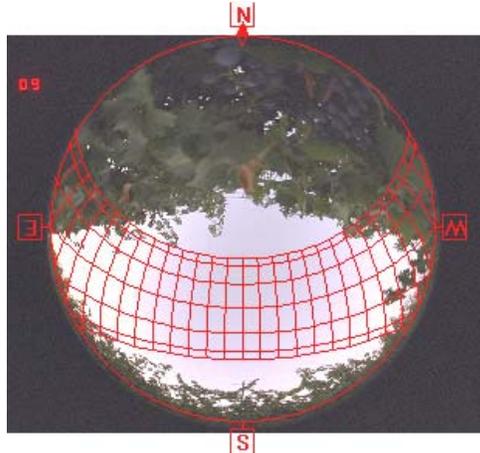


Photo 1.

Photo 1 is the VSP trellis facing south at the bottom of the photograph. Note that East (right) and West (left) are reversed because the image is looking straight upward. To the north is the vertical wall of dense foliage in the cordon, with only a few loose shoots extending out. Virtually no sky is visible north through the cordon, and almost half the sky is open to the south. The adjacent row near the horizon is clearly seen at the bottom of the image. The red grid maps the entire yearly sunpath for 38° N latitude. The southernmost sunpath is December 21, the middle is March 21 and September 21, and the northernmost is June 21. The sunpaths are divided into half-hourly segments and noon is directly south. Sunpaths are symmetrical around the summer and winter solstices – June and July (actually May 21 to June 21 and June 21 to July 21) have the same set of sunpaths, as do May/August, April/September, etc. May through September is the growing season analyzed in this article.

To interpret this photo, view the top three sunpaths that traverse the large south-facing opening. Note that Jun-Jul. sunpaths are open for 12 half-hour blocks (from 0900 h to 1500 h solar time not daylight savings time). But Sept. sunpaths are open for 18 half-hour blocks (from 0730 h to about 1730 h). These are the monthly average exposure periods for

the south side grapes. Note also that the sunpaths do not intercept the adjacent row during the growing season; the adjacent row provides NO shade for the grapes in this configuration.

### VSP in Lodi: East-West Rows

A majority of the vineyards in the Lodi appellation are planted in East-West rows and a significant portion use a VSP trellis. The combination of this photographic analysis and a production scale trial successfully linked specific insolation profiles with wine quality attributes. First, we will review the development of these insolation profiles and then detail the juice and wine composition analysis along with the tasting notes from the trial.

Hourly irradiance plots show time of day on the X-axis, and average irradiance on the Y-axis (see Figure 1). Each monthly average is represented by a different line style and the thick black line at the top is the unobstructed maximum for June/July, as a reference. Maximum potential irradiance at noon in June/July is about 1000 W/m<sup>2</sup> at 38° latitude (think of ten 100 watt light bulbs over a square meter). The South side grapes receive a single large peak of irradiance each day in all months. Peak values reach 800-900 W/m<sup>2</sup> for many hours, with longer exposure time in Sept. than in June/July (as described with Photo1).

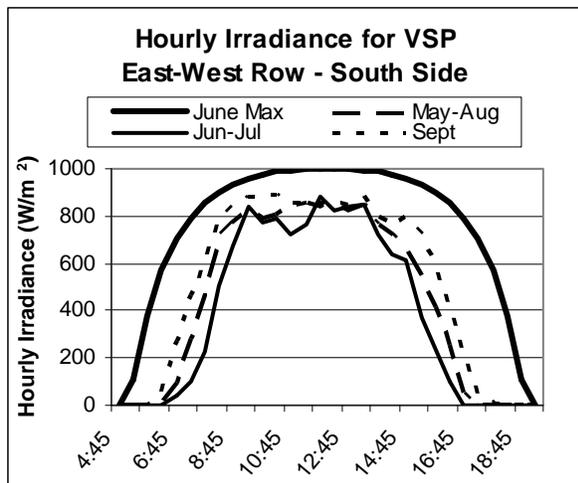


Figure 1.

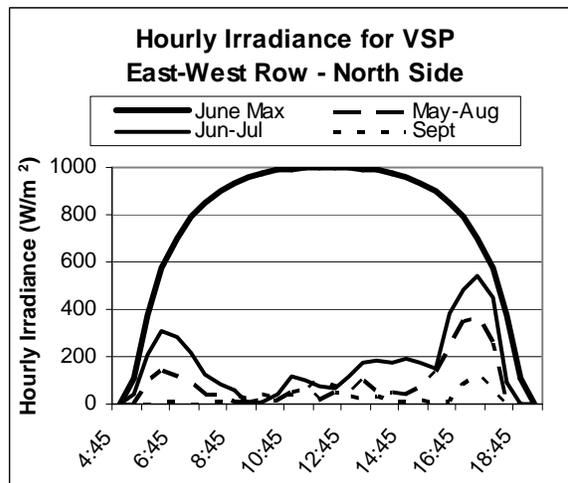


Figure 2.

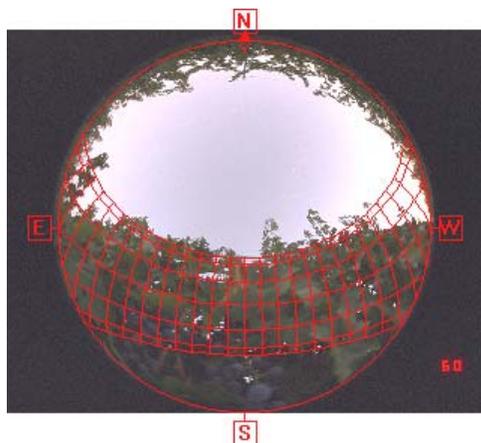


Photo 2.

On the North side, sunpaths are blocked by the canopy for most of the growing season, except for short periods at sunrise and sunset (Photo 2). The irradiance curve has two peaks in Jun/Jul (300-500 W/m<sup>2</sup>) at sunrise and sunset, with intermittent sunflecks (up to 200 W/m<sup>2</sup>) through the day (Figure 2). Note that direct irradiance at sunrise and sunset disappears in September; the grapes receive little or no direct light at the end of the ripening period. For the entire growing season, the North side grapes receive only 24% of the cumulative insolation as compared to the South side grapes. This large differential in insolation is the key factor in the wine quality measurements from the parallel field trial.

The Cabernet Sauvignon trial was set up to detail the differences in juice and wine between these three treatments:

- 1) South fruit: consisted of whatever fruit was facing the South side, picked by hand.
- 2) North fruit: fruit facing north, this was all the fruit left on the vines after picking the South fruit, also picked by hand.
- 3) Composite fruit: fruit from both sides as it is used by the winery, picked mechanically (slightly higher yields).

The large scale trial consisted of 25 tons of fruit per treatment from a single vineyard (a 7x10 VSP trellis configuration). The nature of the trial was more observational without replications, which tend to conflict with the production scale. Thus the trial consisted of two contiguous blocks, with the North fruit and South fruit portions including twice the number of rows compared to the Composite fruit block.

At the time of picking, after a few days of severe heat, the fruit on the South side was dehydrated and raisined, whereas the clusters on the North showed more intact berries, with just occasional raisining. Picking date seems to be a necessary compromise between two

sides which develop very differently and all the treatments were picked within 48 hours of each other. Tables 1 and 2 show the key juice and wine attributes that varied across the treatments.

The South fruit (and the Composite) came in at 24.6 Brix, compared to 23.9 Brix for the North fruit. Besides the difference in Brix, we can emphasize the low alcohol of the North fruit (11.7 %) compared to the South fruit (13.1%). The color of the Composite fruit was by far more intense (A420+520=7.0) than those of the North or South fruit individually (A420+520 5.3 and 5.8, respectively).

A group of 25 growers and winery staff attended a meeting to review the trial results and taste the wines. The North fruit wine was described as thin and unripe (despite the high Brix), with a cherry nose and mouth. The South fruit wine had better color, a berry nose, and a raisin/prune note in both nose and mouth. The Composite fruit wine was quite similar to the South fruit, but with better color, more texture, and less astringency. In the blind ranking, the North fruit wine received NO first place votes. The group was split almost evenly on the ranking of the Composite and South fruit wines with a slight preference for the Composite wine.

Neither side fruit made the best wine on its own, but it was the combination of both that had the best quantitative results. A different row orientation that would minimize the disparity in insolation would be beneficial in homogenizing the fruit, and optimizing the picking decision. What are the risks and opportunities with other row directions for VSP?

**Table 1: Juice Analysis**

Treatment	Harvest Date	Yield (tons/a)	Brix	Titrateable Acidity (g/l)	pH	Malic Acid (g/l)	Malic Acid (%acidity)
North Fruit	9/28	7.0	23.9	4.7	3.59	1.28	27%
South Fruit	9/27	7.8	24.6	5.4	3.54	0.90	17%
Composite	9/27	8.7	24.7	6.7	3.39	1.00	15%

**Table 2: Wine Analysis**

Treatment	Alcohol (%v/v)	Tartaric Acid Added (g/l)	Titrateable Acidity (g/l)	pH	Volitile Acidity (g/l)	Abs. 280 Phenols	420/530 Hue	420+520 Intensity	Skin Contact (days)
North Fruit	11.7	0.6	5.2	3.60	0.42	44	0.67	5.3	30
South Fruit	12.7	0.4	5.5	3.64	0.37	48	0.73	5.8	31
Composite	13.1	0.3	5.3	3.71	0.59	50	0.80	7.0	31

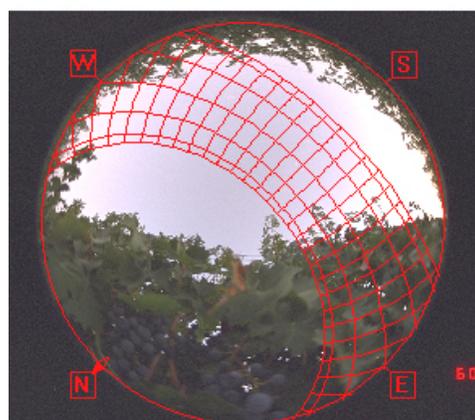


Photo 3.

**VSP Simulated in Other Row Directions**

Photo 3 shows the ease of simulating any row direction with the specialized software. This photo demonstrates the same VSP trellis in diagonal row orientation to the Northwest and Southeast (the grape exposure on the Southwest side is pictured here). We simulated 3 alternative row directions: North-South, diagonal NE-SW, and the other diagonal NW-SE.

A N-S row has E- and W-side fruit and produces a balanced insolation profile for the grapes (Figure 3). In Jun-Jul, morning irradiance peaks at 800-950 W/m<sup>2</sup> on the E-side by 1030 h, followed by a rapid drop in late morning. The afternoon peak on the W-side rises rapidly and maintains high irradiance (800-950 W/m<sup>2</sup>) from 1300 to

1500-1700 h. Monthly differences, not shown in the graph for clarity, are primarily near sunrise and sunset.

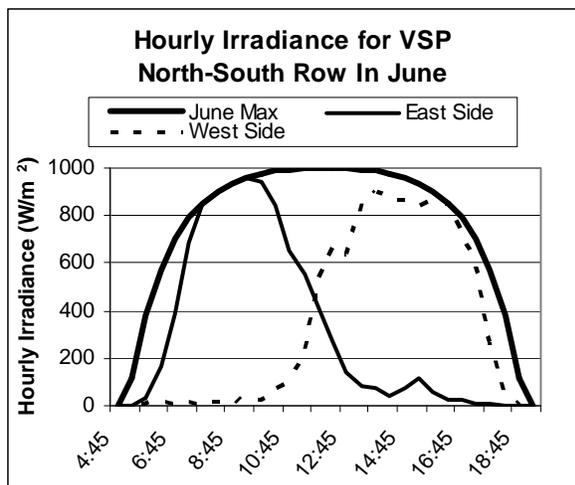


Figure 3.

A diagonal NE-SW row has SE-and NW-sides (Figure 4). The SE-side receives more irradiance than NW-sides. There is an unobstructed morning irradiance peak (800-900 W/m<sup>2</sup> for several hours) on the SE-side, and a shorter, lower afternoon peak (600-900 W/m<sup>2</sup>) on the NW-side.

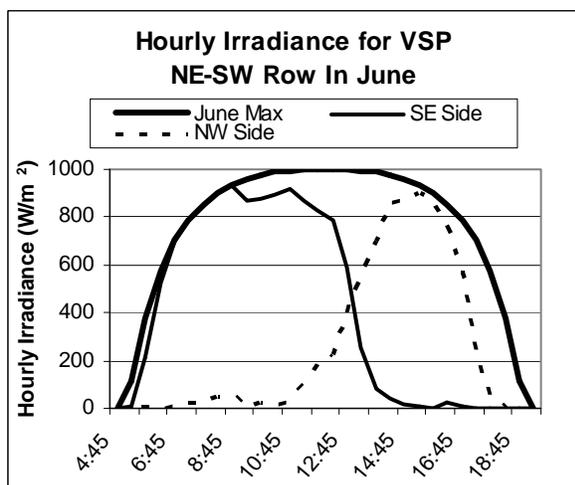


Figure 4.

The other diagonal row NW-SE row has NE and SW sides (Figure 5). The NE side receives a morning irradiance peak, with

shade by 1100 h. The SW side rapidly transitions from shade to full irradiance at 1100 h, leading to an especially long period of intense afternoon irradiance.

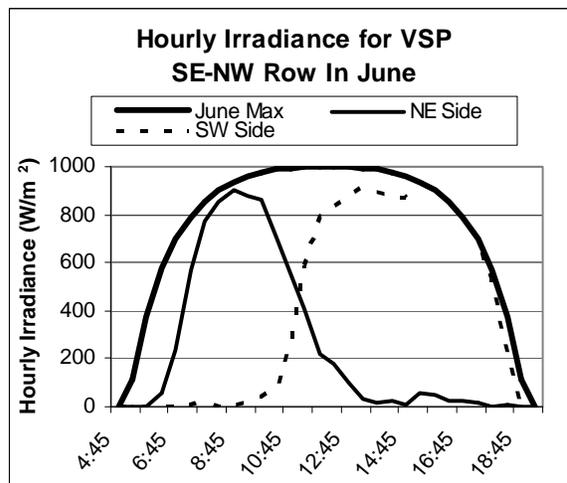


Figure 5.

### Ripening, Heat Damage, and Sunburn

The ultimate effect of insolation on wine quality is a complex subject, and this work addresses the first stages of converting sunlight into wine – some basic interactions between the VSP trellis structure, row direction, and insolation. Figure 6 shows the cumulative insolation potential over the growing season for the 4 row directions analyzed. The highest insolation, at greater than 3500 MJ/m<sup>2</sup>, is on the South side and the lowest is on the North side, creating the highest contrast between sides. E- and W-sides have approximately equal insolation, while the diagonal rows produce a moderate skew towards the southerly facing sides.

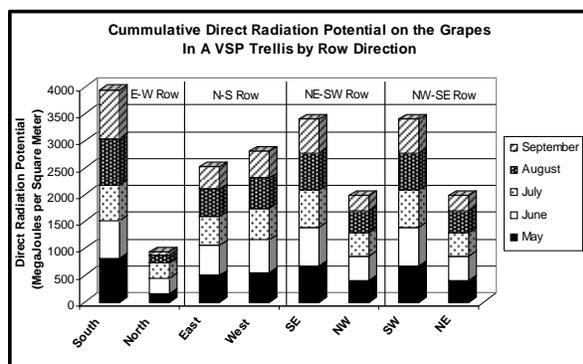


Figure 6.

### Heating of berries and clusters

Direct insolation heats berries and clusters, and berry temperatures fluctuate rapidly with irradiance levels (Smart and Sinclair 1976). When in direct sun, each berry has a “hotspot” directly facing the sun that receives full normal irradiance. Hotspots move with the sun around each berry and cluster, so no one part of the cluster receives the cumulative insolation value. Hotspot temperatures are a linear function of irradiance, and maximum skin temperatures on green grape berries can be on the order of 12°C above ambient air. Darker berries absorb more insolation and can heat even more. Mid-day temperatures of fully exposed post-veraison Cabernet Sauvignon berries can exceed ambient air by 7°C (Dokoozlian 2001). Under high air temperatures (>40°C), this excess can reach 12-15°C. Center temperatures of berries are also a linear function of irradiance, and are lower than hotspot temperatures. In tight clusters, heat is rapidly conducted between berries, and the whole cluster may be heated above ambient air, but less than an individual berry. Heating potential is largely a linear function of irradiance when all other factors, especially wind, are held equal.

### Grape Ripening

Direct insolation on grape clusters has a multifaceted effect on the ripening process and wine quality (Crippen and Morrison 1986a 1986b, Dokoozlian and Kliewer 1995a,

1995b, Bergqvist et al.2001). In addition to the temperature effects discussed above, secondary compounds that are responsible for aroma and flavor development in the skin are affected by direct insolation (Smart 1987, Gladstones 1992). Generally accepted field observations show that well exposed bunches of red grapes develop the best color and flavor (Gladstones 1992). Selection of trellis type and row direction has a profound effect on direct insolation which in turn affects grape ripening and wine quality. This hemispherical photography analysis takes the first step in quantifying the differences in direct insolation. One of the main challenges to vineyard management is to achieve evenness of ripening. Table 3 describes the evenness of direct insolation from side to side of a trellis using the ratio of cumulative insolation over the growing period. A clean VSP trellis in an east-west row has a ratio of direct insolation from south to north of 4:1. This creates a significant potential for differing levels of sugar and other key compounds during harvest, as demonstrated by the wine trial data. North-south rows have the most even distribution of direct insolation from side to side but this row direction creates other potential problems such as sunburn discussed below.

### Heat Damage (Sunburn)

Intense beam radiation combined with high air temperatures damages grapes to varying degrees (commonly referred to as “sunburn”), which destroy crops outright or reduces quality. In California, where air temperatures can exceed 40°C (105°F); high irradiance can heat hotspots into the high 40’s and low 50’s (>115°F). Peak daily air temperatures are typically in mid afternoon, when potential irradiance is 800-950 W/m<sup>2</sup>. Table 3 summarizes the balance of insolation and sunburn risk by row direction. Not surprisingly NW-SE rows and N-S rows of VSP trellises have the highest sunburn risk

(SW side and W side respectively, see Photo 3 and Figures 3-4). The S side of an E-W row also has a high risk of sunburn in hot climates. The NW side of a NE-SW row also appears to have moderate sunburn potential by this measure, but peak irradiance is short (see Figure 5).

**Table 3: VSP Trellis at 38° Latitude**

Row Direction	Balance of Insolation (ratio)	Sunburn Risk
East-West	Maximum uneven (4:1)	High (south side)
North-South	Even (1:1)	Very High (west side)
Northeast-Southwest	Somewhat uneven (2:1)	Moderate (NW side)
Northwest-Southeast	Somewhat uneven (2:1)	Extremely High (SW side)

## Conclusions

This project succeeded in clarifying some of the risks and opportunities by row direction for VSP trellis systems in hot climate viticulture.

- For the East-West row, significant differences in insolation (North side to South side) produce measurable differences in juice and wine composition.
- Although North side fruit alone produced significantly lower wine quality, the combination in the Composite wine produced good results.
- South side fruit did show some signs of sunburn that produces a raisin/prune flavor in the wine.
- Other row directions for VSP have different opportunities and risks:
  - North-South rows provide balanced insolation but have significant sunburn risk on the West side

- NW-SE rows have the longest afternoon exposure and therefore, the highest sunburn risk on the SW side
- NE-SW rows are likely to be the best compromise in balance of insolation and sunburn risk reduction for a VSP trellis design in hot climates.

Vineyard canopy analysis with hemispherical photography is a powerful scientific tool that can influence critical vineyard-level decisions focused on improving wine quality. This methodology has been used to evaluate a wide variety of trellis types, to compare insolation profiles between Napa and Oregon, to select row directions for VSP plantings, to design an asymmetrical trellis that reduces sunburn risk, and to quantify the effects of canopy management techniques including leaf and shoot removal. Trellis and row direction decisions are long-term capital investments, and hemispherical photography can better evaluate opportunities and liabilities of those decisions in existing and proposed vineyard designs.

## Literature Cited

- Bergqvist, J., N. Dokoozlian, et al. 2001. Sunlight exposure and temperature effects on berry growth and composition of Cabernet Sauvignon and Grenache in the central San Joaquin Valley of California. *American Journal of Enology and Viticulture* **52**: 1-7.
- D.D. Crippen, Jr. and J.C. Morrison 1986a. The effects of sun exposure on the phenolic content of Cabernet Sauvignon berries during development. *American Journal of Enology and Viticulture* **37**: 243-247.

- D.D. Crippen, Jr. and J.C. Morrison 1986b. The effects of sun exposure on compositional development of Cabernet Sauvignon berries. *American Journal of Enology and Viticulture* **37**: 235-242.
- Dokoozlian, N.K. and W.M. Kliewer 1995a. The light environment within grapevine canopies. I. Description and seasonal changes during fruit development. *American Journal of Enology and Viticulture* **46**: 209-218.
- Dokoozlian, N.K. and W.M. Kliewer 1995b. The light environment within grapevine canopies. II. Influence of leaf area density on fruit zone light environment and some canopy assessment procedures. *American Journal of Enology and Viticulture* **46**: 219-226.
- Geiger, R. 1965. *The Climate Near the Ground*. Harvard University Press, Cambridge, MA.
- Gladstones, J. 1992. *Viticulture and Environment*. Adelaide, Wine Titles.
- Kliewer, W.M. 1982. Vineyard canopy management - A review. *Grape and Wine Centennial Symposium Proceedings*.
- Kliewer, W.M. and R.E. Smart 1989. Canopy manipulation for optimizing vine microclimate, crop yield, and composition of grapes. *Manipulation of fruiting*. C. J. Wright. London, Butterworth.
- Mullins, M.G., A. Bouquet, et al. 1992. *Biology of the Grapevine*. Cambridge, UK, Cambridge University Press.
- Rich, P.M. 1990. Characterizing plant canopies with hemispherical photographs. *Remote Sensing Reviews* **5**:13-29.
- Smart, R.E. and T.R. Sinclair 1976. Solar heating of grape berries and other spherical fruits. *Agricultural Meteorology* **17**: 241-259.
- Smart, R.E. 1985. Principles of grapevine canopy microclimate manipulation with implications for yield and quality. *American Journal of Enology and Viticulture* **36**: 230-239.
- Smart, R.E. 1987. Influence of light on composition and quality of grapes. *Acta Horticulturae* **206**: 37-47.
- Smart, R.E. and M. Robinson. 1991. *Sunlight into wine: A handbook for winegrape canopy management*. Winetitles, Adelaide, Australia.
- Weiss, S.B. 2000. Effect of row direction on sun exposure of grapes in a vertical shoot position trellis system. Menlo Park, CA.
- Weiss, S.B. 2000. Vertical and temporal patterns of insolation in an old-growth forest. *Canadian Journal of Forest Research* **30**: 1953-1964.



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