



RESEARCH FOCUS

Heat and UV Radiation from Sunlight Exposure Inhibit Powdery Mildew

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Plexiglas tents used to filter out ultraviolet (UV) radiation from sunlight in a Chardonnay vineyard at the New York State Agricultural Experiment Station in Geneva, NY.

Growers have long observed elevated levels of powdery mildew (PM) in shaded areas of vineyards, but the causes have been poorly understood. However, in a recently completed five-year study, we found that sun-exposed leaf and fruit microclimates are unfavorable for fungal growth—likely because increased ultraviolet (UV) radiation and surface temperatures resulting from that exposure affect survival and growth of PM colonies. This helps explain why PM is worse in wet and cloudy years, on vines close to bordering hedgerows, and in vigorous, shaded canopies. Our results indicate that growers can greatly enhance their disease management programs by using appropriate canopy management practices to optimize light interception.

KEY CONCEPTS

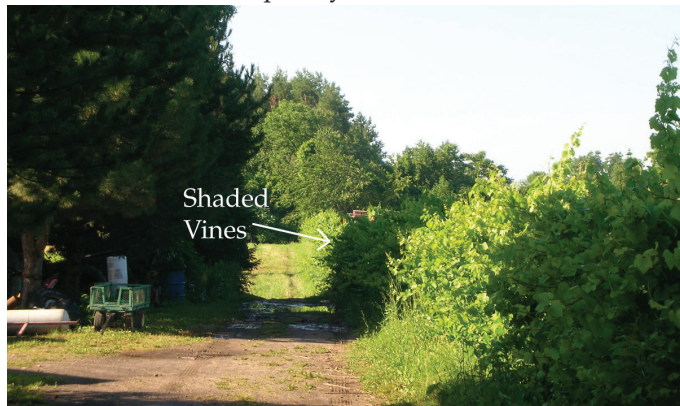
- Powdery Mildew (PM) severity is much greater on shaded leaves or fruit than on those with full exposure to sunlight.
- Ultraviolet radiation from sunlight damages powdery mildew colonies.
- Elevated leaf temperatures from direct sunlight hinder powdery mildew growth.
- UV radiation and temperature interact synergistically—warm temperatures amplify the damaging effects of UV radiation.
- Training systems that increase shoot density increase the risk of PM development.
- Other canopy management practices, such as leaf removal, can also improve disease control if applied at the appropriate time.
- Leaf removal also reduces PM development through improved spray coverage.
- Cluster exposure needs to be optimized for individual vineyards and fit within a balanced vineyard management system.



Controlling powdery mildew, caused by the fungus *Erysiphe necator*, is an essential component of any vineyard management program. All commercial grape varieties, to some degree, are susceptible to this disease. Disappointingly, the varieties that are the most susceptible are also the most valuable, i.e., *Vitis vinifera* cultivars such as ‘Pinot Noir’, ‘Riesling’, and ‘Chardonnay’. The disease is active across a wide range of weather conditions and can be particularly challenging because—unlike other grape pathogens—rainfall is not required for new infections to develop and spread the disease during the growing season. The near-universal importance of PM has led grape pathologists at Cornell to focus on understanding this disease over the past quarter century. These efforts have improved disease management by providing a better understanding of the pathogen’s biology and how to “short circuit” disease development through chemical and cultural means. This article reports on the dramatic effect that optimizing sunlight exposure can have on reducing PM development.

Sunlight and powdery mildew: initial observations.

Numerous anecdotal observations link shading to powdery mildew severity, but two observations led us to believe it might be even more significant than generally recognized. First, during the prolonged rainy and cloudy weather of the 2003 growing season, unprecedented levels of PM were noted in a number of New York vineyards. The weather-PM link was also confirmed by analysis of twenty years of historical weather and PM severity records from an unsprayed block of vines at the New York Agricultural Experiment Station (NYSAES) in Geneva. Second, in a local ‘Chardonnay’ vineyard where a small portion of the easternmost row was bounded by 50-foot tall pine trees, a spray program controlled PM adequately on most vines, yet PM completely destroyed the fruit on vines immediately next to the trees. The diseased vines were completely shaded until the sun crested



Shaded Chardonnay vines near Dresden, NY

over the tree tops just before noon each day. Intriguingly, shading from both cloudy weather and neighboring trees were linked to increased PM severity, but to establish causation we needed to directly manipulate sun exposure in the vineyard.

Shade and powdery mildew. In 2005, we inoculated ‘Chancellor’ leaves with PM spores and covered the vines with either one or two layers of neutral density shade cloth, black mesh fabric that allowed 45% and 20% of natural light to pass through, respectively. In repeated experiments, foliar disease severity increased with shading: it was two to three times greater on vines covered with one layer of the cloth than those in full sunlight and was even greater on vines covered with two layers of the cloth (Figure 1).

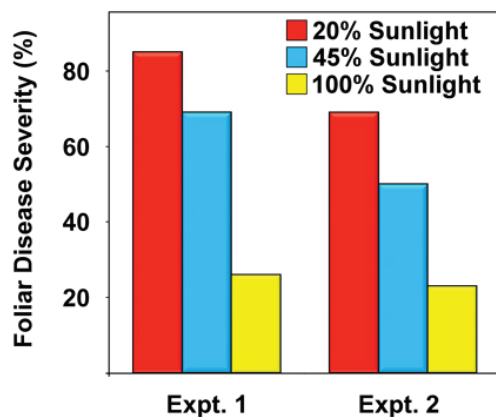


Figure 1: Effect of artificial shading on the severity of powdery mildew (PM) on foliage of ‘Chancellor’ grapevines in two different experiments. Leaves were inoculated with spores of the PM fungus, vines were covered with either one or two layers of neutral density shade cloth (allowing approximately 45% or 20% of natural light to pass through, respectively), and symptoms were rated after two weeks.

We also conducted experiments in the pine-shaded ‘Chardonnay’ vineyard to examine the effects of natural shading on PM development. We inoculated leaves on the outer (exposed) and inner (shaded) portions of the canopies on vines in two locations: adjacent to and 200 feet from the trees that provided morning shade, for a total of four different levels of natural shade. We found that increased natural shading, like our artificial shade cloth treatments, corresponded to increases in PM severity, with approximately 8- to 40-fold increases in disease on interior leaves of vines next to the trees, relative to exterior leaves of vines away from the trees (Figure 2).

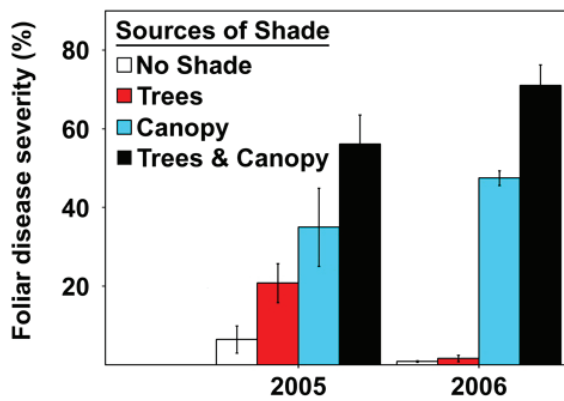


Figure 2: Percent disease severity on ‘Chardonnay’ leaves receiving (i) full solar radiation, on the outer canopy edge of vines away from trees (No Shade); (ii) morning shade from an adjacent grouping of pine trees but otherwise exposed to the sun, on the outer edge of the vine canopy (Trees); (iii) shade provided by the vine itself, i.e., located within the center of the canopy of vines away from the trees (Canopy); or both tree and the internal canopy shading (Tree & Canopy). For each season, final foliar disease severities were collected 17 days after inoculation.

Shading has several potential microclimate effects, including lowering canopy air or leaf temperature, increasing relative humidity, and decreasing UV exposure, but we found no measurable differences in temperature or relative humidity in the air around the different leaves in these shading experiments. However, UV radiation levels and leaf temperatures were dramatically different with shading. Within the shaded treatments, UV levels were a mere fraction of those in the sun, and leaf temperatures were 10° F to 30°F lower than their sun-exposed counterparts. We hypothesized that increased leaf surface temperature and UV radiation were responsible for the inhibition of PM development in sunlight.

Sunlight and fungal development. What could cause PM to be vulnerable to the effects of sunlight exposure? For one thing, direct sunlight heats up exposed leaf surfaces—or anything else for that matter—as we all know from the difference between standing in the sun versus the shade. Because PM grows on the leaf surface, it is also exposed to this heat which, with sufficient intensity and duration, can kill PM colonies. Powdery mildew thrives at temperatures near 80°F, stops growing at temperatures above 90°F, and will start to die at temperatures above 95°F. On an 80°F summer day, shaded leaves and clusters will remain near the air temperature, which is optimal for PM growth. However, leaves exposed to sunlight can often have temperatures elevated to well above 90°F, at which point PM development will stall or cease.

Sunlight also contains UV radiation, which can damage the cellular structure of virtually all forms of life. UV radiation inhibits the growth of many fungal plant pathogens, but powdery mildew is uniquely vulnerable to such damage. The PM fungus lives primarily on the outside of infected tissues (most other pathogens live almost entirely within infected tissues, protected from UV radiation). In addition, the PM fungus lacks UV-protective pigments, which gives it a powdery, white appearance. Thus, because of its external growth habit, PM is potentially vulnerable to damage from both UV and high leaf/fruit temperatures resulting from sun exposure.

Decoupling the effects of UV and leaf temperature. In order to investigate the effects of UV and leaf temperature, we erected a Plexiglas “roof” over ‘Chancellor’ (Geneva, New York) and ‘Chardonnay’ (Geneva, New York, and Prosser, Washington) grapevines. The Plexiglas selectively blocks UV radiation but not the longer wavelengths of sunlight that elevate leaf and berry surface temperatures. In the ‘Chancellor’ vineyard, we also draped shade cloths over separate vines to decrease both UV radiation and the heating effect of direct sunlight. Clusters were inoculated with PM spores at 75% capfall. As shown in **Figure 3**, we found that reducing UV radiation through these Plexiglas structures increased disease severity on fruit two- to five-fold, for both varieties and

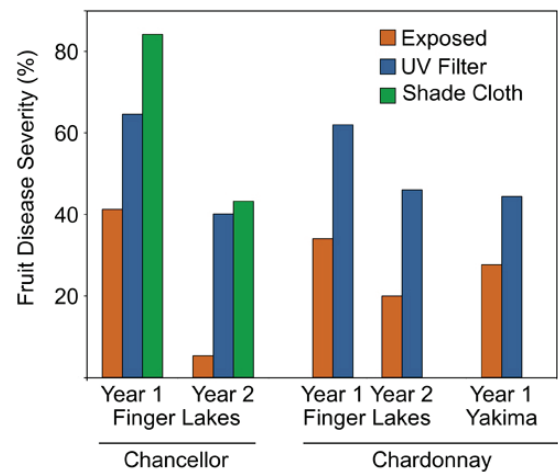


Figure 3: Percent disease severity on cv. ‘Chancellor’ and cv. ‘Chardonnay’ vines receiving: full solar radiation (Exposed), sunlight from which 95% of the UV radiation had been filtered with Plexiglas (UV Filter), or sunlight reduced to 20% of ambient via neutral density shade cloths draped over vines (Shade Cloth). Clusters were inoculated with spores of the powdery mildew fungus at 75% capfall. Vineyards were located in Geneva, New York (Finger Lakes), or the Irrigated Agriculture Research and Extension Center of Washington State University in Prosser, Washington (Yakima).

locations. The ‘Chancellor’ shade cloth treatment, which eliminated the increase in surface temperature in addition to UV radiation, further increased disease severity in one experiment. The warming effect of sunlight exposure is more indirect and was less consistent than that of UV, because leaf surface temperatures are also affected by parameters such as vine water status (leaves heat up more when vines are water stressed), wind, and variable ambient temperatures.

UV, temperature, and spore development. Clearly, UV and temperature affected disease severity, but the mechanism was still elusive. To begin answering this question, we took the experiments out of the vineyard and into the controlled environment of growth chambers. We inoculated ‘Chardonnay’ leaves with spores of the PM fungus and placed them into growth chambers maintained at 68°F, 77°F or 86°F. For each temperature, we also exposed the inoculated leaves to a six-hour dose of UV radiation for zero, one, two, or four days.

We found that increased doses of UV radiation reduced PM spores’ ability to germinate and grow. Furthermore, the inhibiting effect of UV radiation was much greater at the highest temperature, as illustrated by differences among treatments in the latent period—the number of days it takes one or more spores to infect, form a lesion, and produce the next generation of “offspring” spores. **Figure 4** illustrates the effect of UV doses on the latent period. At both 68°F and 77°F, four daily, six-hour doses of UV radiation extended latent periods by about two

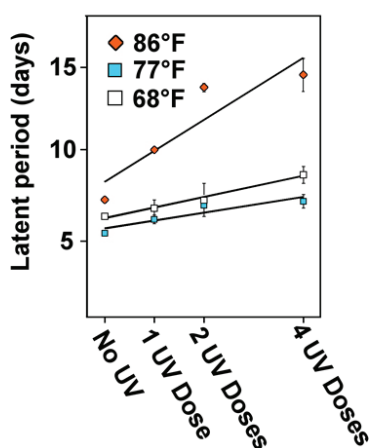


Figure 4: Interactive effects of temperature and UV dosage on the latent period (“generation time”) of powdery mildew. Inoculated leaves were maintained at either 68°F, 77°F, or 86°F and received six-hour doses of UV (3.0 W/m² UV-B radiation, a representative amount for midday in mid-summer) for either zero, one, two, or four days.

days. However, at 86°F, the same UV exposure significantly extended the latent period, from 7 to 15 days. Thus, UV radiation essentially hits PM harder at warmer temperatures, and these two factors together produce an inhibitory effect greater either acting alone.

Sunlight manipulation in the vineyard. If UV radiation and sun exposure reduce PM, can canopy management be used to better manage the disease? We examined this question in a young ‘Chardonnay’ vineyard by varying the training system and timing of basal leaf removal to provide different light exposure regimes in the fruiting zone. We compared two training systems: Vertical Shoot Positioning (VSP) and Umbrella Kniffen (UK). UK has more shoots per linear foot of row than VSP and thus greater potential for canopy shading in the fruit zone. Within each training system, we removed basal leaves in the fruiting zone at two dates: two weeks post-bloom (fruit set) and five weeks post-bloom. We inoculated clusters with powdery mildew spores at bloom (75% capfall) and rated PM severity in each treatment during late summer.

We found that both training system and leaf removal affected PM severity (**Figure 5**). First, powdery mildew severity was lower in the VSP than in the UK training system, regardless of leaf pulling treatment. Second, leaf removal at fruit set significantly reduced the amount of disease in both training systems, but leaf removal five weeks after bloom had no effect. The benefits of early leaf removal are likely explained by the fact that fruit

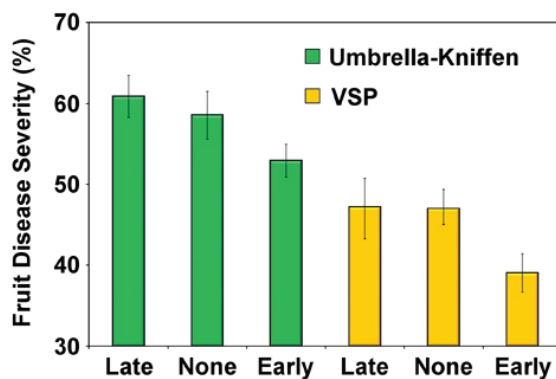


Figure 5: Powdery mildew severity on ‘Chardonnay’ clusters within two training systems, Umbrella-Kniffen and Vertical Shoot Positioning (VSP). Within each system, basal leaves were removed around fruit either two weeks post-bloom (Early), five weeks post-bloom (Late), or not at all (None). Clusters were inoculated with powdery mildew spores at 75% capfall to ensure high disease pressure, and were assessed on a 0-100 scale to determine the percentage of fruit tissue visibly diseased.

are highly susceptible to PM infection until only two to four weeks after bloom. Without the use of pesticides, the VSP training system and basal leaf removal at fruit set reduced fruit disease severity by 35% relative to UK-trained vines without leaf removal.

Powdery mildew and canopy density. In addition to training systems, vigor in the vineyard plays a key role in canopy self-shading. Based on our previous studies of natural and artificial shading, we anticipated that natural variation in vine size within a block would lead to variation in canopy sunlight distribution, also influencing PM development on fruit. To test this, we enlisted a technique to measure grapevine canopy density developed by Cornell assistant professor of horticulture Justine Vanden Heuvel and her student, Ph.D. candidate Jim Meyers. Called Enhanced Point Quadrat Analysis (EPQA), it is a modified version of the classic Point Quadrat Analysis developed by viticulturist Richard Smart. EPQA can help to define the proportion of available sunlight that reaches each grape cluster. We measured canopy variability and PM severity on unsprayed fruit in numerous ‘Chardonnay’ vineyards in the New York Finger Lakes, Washington State, and South Australia, and present representative data from New York in **Figure 6**. For all locations and in all seasons, there was a strong inverse relationship between the percentage of available sunlight reaching the fruit and the severity of PM on those fruit.

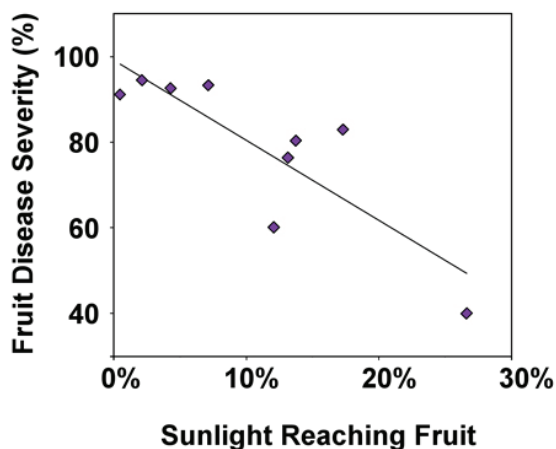


Figure 6: Powdery mildew disease severity on ‘Chardonnay’ clusters as it relates to the percentage of sunlight reaching fruit. Each vine was assessed via Enhanced Point Quadrat Analysis (EPQA) in order to establish the fruit exposure levels to sunlight. Fruit were inoculated with a suspension of powdery mildew spores at 75% capfall to ensure high disease pressure, and were assessed on a 0-100 scale based on the percentage of fruit tissue visibly diseased.

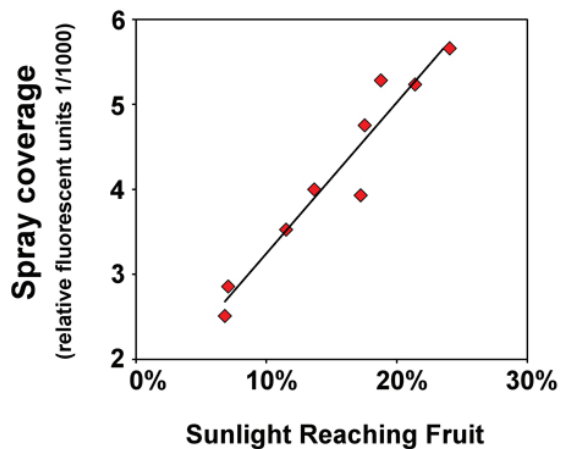


Figure 7: Effect of canopy density on deposition of sprays to clusters of ‘Chardonnay’ vines treated in mid-July with a fluorescent dye in a conventional airblast sprayer. Fruit were collected in the vineyard and assessed in the lab for the quantity of an applied fluorescent dye per cluster. Each vine was assessed via Enhanced Point Quadrat Analysis (EPQA) to establish fruit exposure levels to sunlight.

Canopy and spray penetration. Most of our experiments have been based on unsprayed vineyards, but of course, commercial vineyards are not unsprayed. It seemed likely that open canopies would have less PM not only due to the direct effects of sunlight on the pathogen, but also due to improved spray penetration and deposition upon clusters. Utilizing EPQA measurements and with assistance from Dr. Andrew Landers (Pesticide Application Technology Program, NYSAES, Cornell University), we were able to quantify the effect that canopy density has on spray coverage.

Vines in our ‘Chardonnay’ vineyard subjected to variable canopy manipulations were sprayed with a conventional air blast unit, and deposition on clusters from each vine was assessed in the lab with the aid of a fluorescent dye. Not surprisingly, we found a direct relationship between the quantity of spray deposited on each cluster and the EPQA sunlight exposure level (Figure 7), with well-exposed clusters receiving approximately twice the deposition as those with poor exposure.

Management Implications. In all vineyards, in all seasons, for all experiments, and at all locations, increasing sunlight exposure on leaves or fruit reduced the severity of powdery mildew on those tissues—independent of spray coverage. Sunlight appears to directly inhibit the development of this surface-growing, unpigmented fungus. Two aspects of sunlight exposure that appear to suppress the fungus are increased UV radiation exposure

and higher leaf surface temperatures. Furthermore, at leaf temperatures above 85°F (which can occur on exposed tissues on sunny days when air temperatures are only in the 70s), UV radiation appears to have even more significance, as these two sunlight components act synergistically to inhibit PM fungal growth.

Training systems and appropriately timed cultural practices that improve sunlight penetration into the fruit zone reduce PM disease severity. However, a concept associated with quality viticulture is balance—and the information provided here must be balanced with other issues in a specific vineyard. Maximum sunlight exposure can lead to sunburned berries, and zero exposure can lead to diseased berries. Thus, it is important to balance the disease control benefits of increasing sunlight exposure with yield, quality, and other components of vineyard management.

This information was applicable to both the cool climate region of New York and the warm climates such as those found in Washington State and South Australia. The great variability in PM severity noted from year to year in NY vineyards can now be partially explained by the dramatic variation in solar radiation, rainfall, and cloud cover across years. Circumstantial evidence suggests that even in some hotter climates with consistently sunny weather, unusually wet and cloudy weather during critical periods can instigate severe outbreaks of PM. Once again, environmental conditions during the bloom and early post-bloom period were shown to be crucial in setting the stage for cluster disease development over the rest of the growing season. Cloudy weather around bloom not only can reduce fruit set and next year's bud fruitfulness, but also can determine how much of a foot-hold powdery mildew establishes on this season's crop. These studies have verified the importance of cultural practices—such as leaf removal and canopy management—as key components along with fungicides in successfully managing powdery mildew.



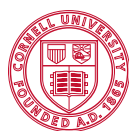
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References

Meyers, J., and Vanden Heuvel, J. 2008. Enhancing the Precision of Spatial Acuity of Point Quadrat Analyses via Calibrated Exposure Mapping. *American Journal of Enology and Viticulture*. 59: 425-431.

Acknowledgments

This project was funded by the Viticulture Consortium East, the New York Wine and Grape Foundation, the American Society for Enology and Viticulture, the American Wine Society, and the Lacroute Endowment. We thank Dr. Gary Grove of Washington State University for assisting us with our Washington State trials. We would also like to thank Drs. Trevor Wicks and Michael McCarthy, and Mr. Peter Magarey of the South Australia Research and Development Institute for providing trial sites and advice in South Australia.



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