A Research and Extension FINAL REPORT

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Effects of Sunlight Exposure on the Development and Management of Powdery Mildew

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Initial Experiments. We began our investigation in 2005, by inoculating 'Chancellor' vines with conidia of *Erysiphe necator* (the fungus that caused powdery mildew [PM]) and covering them with either one or two layers of neutral density shade cloth (black mesh fabric, allowing either 45% or 20% of natural light to pass through, respectively). We compared disease severity on shaded vines to that on uncovered vines receiving full sun exposure. In repeated experiments, foliar disease severity was two to three times greater on vines covered with one layer of the cloth than on those provided full sunlight- and was even greater on vines covered with two layers of the cloth (Figure. 1).

We also conducted experiments in a commercial 'Chardonnay' vineyard, to examine the effects of various levels of natural shading on PM development. In two consecutive years, we inoculated leaves on either the outer (exposed) or inner (shaded) portions of the canopies on vines in two locations – either immediately next to or 60 m away from a group of tall pine trees that cast these vines into their shadows until approximately noon each day. This design provided a total of four levels of natural shade. We found that increased levels of shade corresponded to progressive increases in PM severity, with approximately 8 to 40 times the levels of disease on the most heavily-shaded leaves (vine interior next to the trees) relative to those receiving the most direct sunlight, i.e., exterior leaves of vines away from the trees (Figure 2).

Although shading could potentially change air temperature or relative humidity within the vine canopy, we found *no measurable differences in either air temperature or relative humidity* in these shading experiments. However, UV radiation levels and leaf temperatures were dramatically different. Within the shaded treatments, UV levels were 2 to 8% of those in the sun, and leaf temperatures in the sun (measured with a non-contact infrared radiometer) were 1 to 13°C higher on exposed leaves than those in the shade. We hypothesized that both leaf surface temperature and UV radiation were responsible for the observed inhibitory effects of sunlight exposure on PM development.

Sunlight characteristics influencing powdery mildew development. UV radiation is a form of energy from the sun that can damage the cellular structure of virtually all forms of life. Although UV radiation has been shown to inhibit growth of many fungal plant pathogens, powdery mildew is uniquely vulnerable to such damage. Unlike almost all other fungi that cause plant diseases, the PM fungus lives primarily on the <u>outside</u> of infected tissues where it is directly exposed to whatever UV might be available. Furthermore, the white-colored PM fungus has no pigments to protect against this radiation.

The second component of sunlight hypothesized as inhibiting PM development, heat energy transferred to tissue surfaces intercepting the sunlight, can kill PM colonies depending on its intensity and duration. Powdery mildew grows best at temperatures near 26°C, but stops growing at temperatures above 32°C and will start to die at temperatures above 35°C. On a hypothetical 26°C 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 well into a range that is inhibitory or even lethal to the PM fungus.

Surface Temperature and UV: Field Experiments. In order to separate the two inhibiting components of sunlight for study in the vineyard, we erected supporting poles that allowed us to place a Plexiglas "roof" over 'Chancellor' and 'Chardonnay' vines in Geneva, NY and 'Chardonnay' vines in Prosser, WA. The Plexiglas structure blocks UV radiation, but permits the longer sunlight wavelengths that elevate surface temperatures to pass through. At the 'Chancellor' vineyard in Geneva, we also suspended shade cloths over separate vines to shield them not only from UV radiation but also from 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 (erecting Plexiglas above the vines) increased disease severity on fruit two- to fivefold, for both varieties and locations. The Chancellor shade cloth treatment, which also eliminated the increase in surface temperature further increased disease severity in one experiment. Thus, in our climate where leaf temperatures are also greatly influenced by other environmental variables such as vine water status (which affects stomatal opening and the degree of evaporative cooling provided by transpiration), the leaf warming effect of sunlight exposure appears to be less consistent than that of UV.

Laboratory Experiments. To more precisely examine the effects and possible interactions of UV and temperature, we inoculated 'Chardonnay' leaves with spores of the PM fungus and placed them into growth chambers maintained at 20°C, 25°C or 30°C (68, 77, and 86°F, respectively). For each temperature, we also exposed them to a 6-hour dose of UV radiation--equivalent in intensity to that measured mid-day in Geneva, NY during the summer--for each of 0, 1, 2, or 4 days.

Increased doses of UV radiation reduced PM spores' ability to germinate and grow. Furthermore, the inhibiting effect of increased doses of UV radiation was much greater at higher temperatures. In particular, higher temperatures lengthened the latent period or 'generation time' - defined as the number of days it takes one spore to infect, cause a lesion, and produce secondary 'offspring' spores.

Specifically, **Figure 4** shows that the UV doses lengthened the latent period similarly at both 20°C and 25°C. At these temperatures, four daily 6-hour doses of UV radiation extended latent periods by about 2 days. However, at 30°C, the same UV exposure more than doubled the latent period, extending it from 7 to 15 days. These two sunlight components act together to produce an inhibitory effect that is greater than the sum of each acting alone.

Sunlight Manipulation in the Vineyard. If UV radiation and sun exposure reduce PM, how can we use this information to better manage the disease? We examined this question in a young 'Chardonnay' vineyard by varying the training system and using basal leaf removal to provide different levels of light exposure to the fruiting zone. We compared two training systems, Vertical Shoot Positioning (VSP) and Umbrella-Kniffen (UK). UK provided more shoots per linear foot of row than VSP and thus more potential for increased canopy shading in the fruit zone. Within each training system, we removed basal leaves in the fruiting zone at two dates: 2 weeks (fruit set) and 5 weeks post-bloom.

We inoculated clusters with powdery mildew spores at bloom (75% capfall) and rated PM severity in each treatment. We found that both factors 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 5 weeks after bloom had no effect.

The benefits of early leaf removal are likely explained by the relatively brief period of high susceptibility of fruit to powdery mildew infection near and shortly after bloom. Without applying pesticides--i.e., simply utilizing a VSP training system and basal leaf removal at fruit set--we were able to reduce fruit disease severity by 35% relative to UK-trained vines with no leaf removal.

Natural variation in the vineyard: association between powdery mildew and vine vigor. Dr. Justine Vanden Heuvel (Dept. Horticulture, Cornell University) and her graduate student Jim Meyers, have developed a technique to measure grapevine canopy density, called Enhanced Point Quadrat Analysis (EPQA). One of the variables that EPQA can help define is the proportion of available sunlight that reaches each grape cluster. We anticipated that natural variation in vine vigor within a block would lead to variation in canopy sunlight distribution, also influencing PM development on fruit.

We measured canopy variability and associated differences in PM severity on unsprayed fruit in numerous 'Chardonnay' vineyards in the Finger Lakes, Washington State, and South Australia, and present representative data from NY 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.

Spray deposition as a function of canopy density. Of course, commercial vineyards are not unsprayed, and it seemed likely that clusters provided good light exposure would have less PM not only due to the direct effects of sunlight on the pathogen, but also due to the favorable effects that open canopies should have spray penetration and deposition upon clusters. Utilizing EPQA measurements and with the assistance of Dr. Andrew Landers (spray application technology, Cornell University), we were able to quantify the effect that canopy density can have on spray coverage.

Vines in our 'Chardonnay' vineyard subjected to variable canopy manipulations were sprayed with a conventional Berthoud 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 less 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 major components of sunlight that appear to be inhibiting the fungus are UV radiation and increased surface temperatures.

Furthermore, at tissue temperatures above 30°C (which can occur on sunny days with much cooler air temperatures), UV radiation appears to have even more significance, as these two sunlight components interact synergistically to inhibit PM fungal growth.

Training systems and appropriately timed cultural practices that improve sunlight penetration into the fruit zone reduced PM disease severity. However, a concept associated with quality viticulture is "balance", and the information provided here needs to be balanced with other issues in a specific vineyard. Maximum sunlight exposure can lead to sun-burned berries and zero exposure can lead to diseased berries. Thus, it is important to balance the benefits of increased sunlight exposure for disease control with yield, quality, and other important components of a particular vineyard's management.

The great variability in PM severity noted from year to year in given NY vineyards can now be partially explained by the dramatic variations in solar radiation (cloud cover) that can occur among years. This information should allow growers and their advisers to better identify seasons or portions thereof during which PM pressure is atypically high or low, and adjust spray programs accordingly. Furthermore, these studies have dramatically emphasized the key role that cultural practices - such as leaf removal and canopy management - can play in concert with fungicides in developing an integrated program for successfully managing powdery mildew and other diseases.

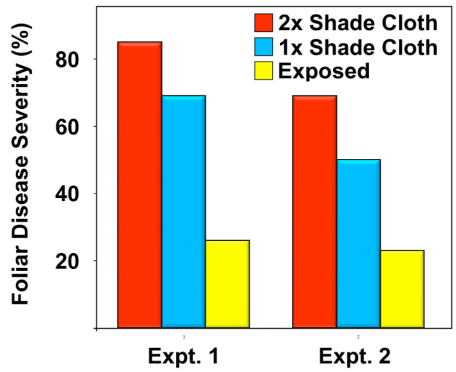

Figure 1. Effect of artificial shading on the severity of powdery mildew (PM) on foliage of 'Chancellor' grapevines in two repeats of the same experiment. Leaves were inoculated with spores of the PM fungus, vines were covered with either one or two layers of neutral density shade cloth (allowing approximately 45% or 20% of natural light to pass through, respectively), and symptoms were rated 2 weeks later.

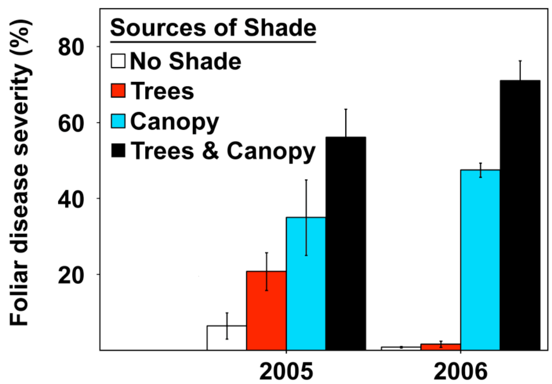

Figure 2. Percent disease severity on 'Chardonnay' leaves receiving (i) full solar radiation, on the outer canopy edge of vines away from any trees (No Shade); (ii) morning shade from an adjacent grouping of pine trees, but otherwise exposed to the sun on the outer edge of the vine canopy (Trees); (iii) 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 internal canopy shading (Tree & Canopy). For each season, final foliar disease severities were collected 17 days after inoculation. Leaf disease severity was assessed visually on a 0-100% scale.

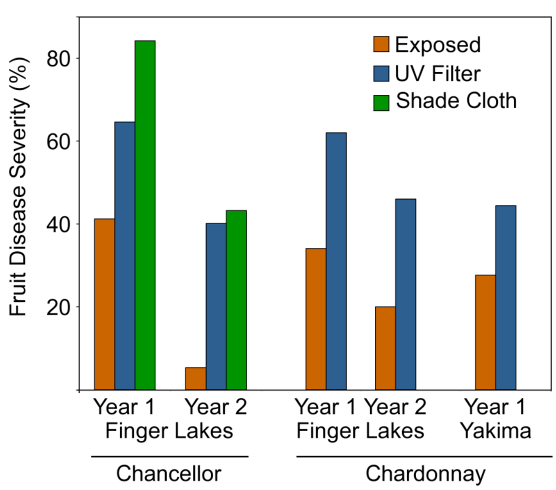

Figure 3. Percent disease severity on cv. 'Chancellor' and cv. 'Chardonnay' vines receiving: (i) full solar radiation (Exposed); (ii) sunlight from which 95% of the UV radiation had been filtered (UV Filter); or (iii) sunlight reduced to 20% of ambient intensity via neutral density shade cloths suspended over vines (Shade Cloth). Clusters were inoculated with spores of the PM fungus at 75% capfall. Vineyards were located in Geneva, NY (Finger Lakes) or the Irrigated Agriculture Research and Extension Center of Washington State University in Prosser, WA (Yakima).

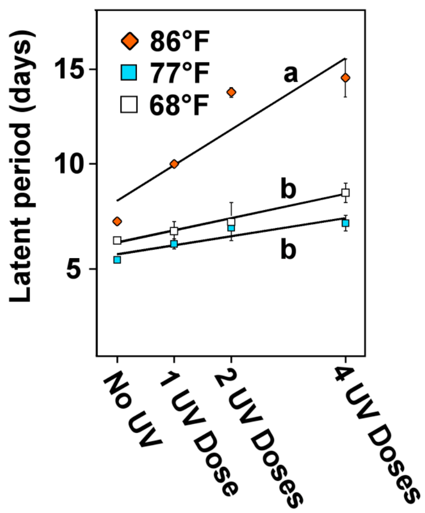

Figure 4. Interactive effects of temperature and UV dosage on that latent period ("generation time") of powdery mildew. Inoculated leaves were maintained at either 20, 25, or 30°C (68, 77, or 86°F, respectively) and received 6-hour doses of UV (3.0 W/m² UV-B radiation, a representative intensity for midday in mid-summer in Geneva, NY) for each of either 0, 1, 2, or 4 days.

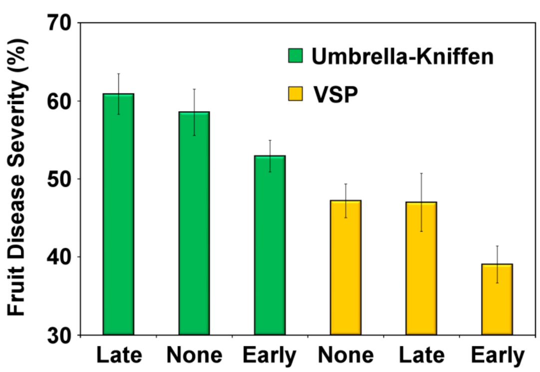

Figure 5. Powdery mildew severity for 'Chardonnay' clusters on vines subjected to two training systems, Umbrella-Kniffen and Vertical Shoot Positioning (VSP). Within each system, basal leaves were removed around fruit either 2 weeks post-bloom (Early), 5 weeks post-bloom (Late), or not at all (None). Clusters were inoculated with powdery mildew spores at 75% capfall to ensure high disease pressure, and were assessed on a 0-100scale to determine the percentage of fruit tissue visibly diseased.

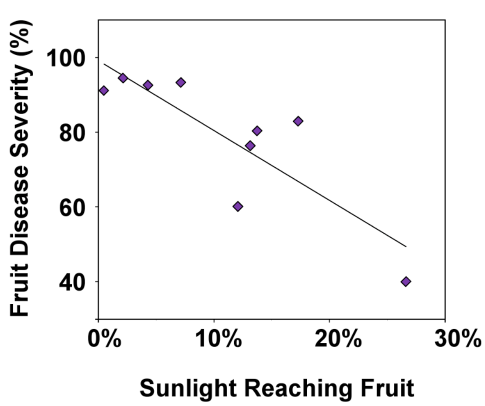

Figure 6. Powdery mildew severity on 'Chardonnay' clusters as a function of the percentage of available sunlight reaching fruit. Each vine was assessed via Enhanced Point Quadrat Analysis (EPQA) in order to establish the fruit exposure levels to sunlight. Fruit were inoculated with a suspension of PM 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.

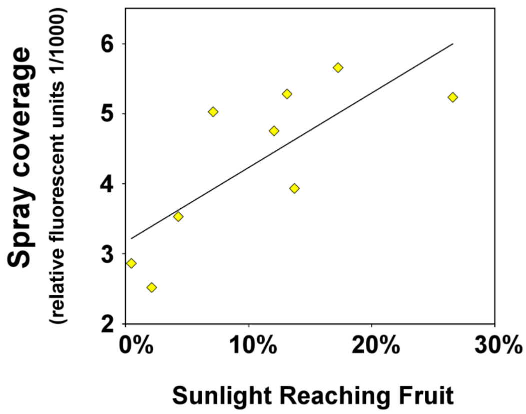

Figure 7. Effect of canopy density upon deposition on clusters of sprays applied to 'Chardonnay' vines in mid-July with a conventional airblast unit. Fruit were collected in the vineyard and assessed in the lab for the quantity of an applied fluorescent dye per cluster. Each vine was assessed via Enhanced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

APPENDIX

1. IMPACT STATEMENT: Powdery mildew is the most ubiquitous disease of grapes in eastern viticultural regions, and control programs are not always successful, even when multiple fungicide applications are made. The results from this research have, for the first time, quantified the tremendous importance on sunlight exposure on disease development, and have demonstrated the utility of incorporating simple cultural techniques that maximize sun exposure into integrated disease management programs. The results will provide guidance in determining the necessary intensity of fungicide programs at different times of the season, by identifying particularly high- or low-pressure situations and the attendant requirement for fungicides at that time.

2. PUBLICATIONS AND PRESENTATIONS in which results from this project were presented (since 1 July 2006, when funding began):

    Presentations:

    1. Powdery Mildew: Biology and Control. Great Lakes EXPO, Grand Rapids, MI. 12/6/06
    2. New Research on Powdery Mildew in New York. Washington Wine Grape Growers Assoc. and Washington State Univ., Prosser, WA. 1/9/07
    3. New research on powdery mildew. Long Island Ag. Forum. Riverhead, NY. 1/24/07
    4. Grape Disease Control Programs. North Carolina Grape Growers, Greensboro, NC. 2/3/07.
    5. Powdery Mildew Management. Viticulture 2007, Rochester, NY. 2/9/07.
    6. Powdery Mildew Management. Virginia Grape Growers Assoc, Charlottesville, VA. 2/10/07
    7. Powdery Mildew. Ontario Fruit and Vegetable Conference, St. Catherines, Ont. 2/21/07
    8. Advanced Powdery Mildew Management. Hudson Valley Grape School, Hudson, NY. 3/2/07
    9. Powdery mildew control. Kentucky Wine Grape Growers. Lexington, KY. 1/8/08.
    10. Managing grape diseases. North Carolina Grape Growers. Greensboro, NC. 2/2/08.
    11. An eastern perspective on powdery mildew and bunch rots. Washington Wine Grape Growers Association. Kenwick, WA. 2/8/08.
    12. Biology and control of powdery mildew. Oregon Winge Grape Growers. Corvallis, OR. 3/5/08
    13. Update on disease management issues for 2008. Finger Lakes Grape Growers Convention. 3/15/08.

14. Update on disease management issues for 2008. Lake Erie Grape Growers Convention. 3/27/08.
15. Powdery mildew and wood canker management. Long Island grape growers. 3/29/08.
16. Powdery and downy mildew control. Missouri grape growers. 6/5/08.
17. Grape disease control programs. New grower school, Columbia, MO. 6/08/08.
18. New developments in disease control. Long Island Agriculture Forum. 1/09/09.
19. Grape disease management programs. Mid-America Cold Climate Grape Conf. Bloomington, MN. 2/13/09.
20. New developments in disease control. Finger Lakes Grape Conference. 3/7/09.
21. Update on disease control. Lake Erie Grape Conference. 3/18/09.
22. Disease control programs for wine grapes. Lake Erie Grape Conference. 3/19/09.
23. Disease control programs for 2010. National Grape Cooperative meeting. North East, PA. 1/24/10.
24. Disease control programs for 2010. National Grape Cooperative meeting. Portland, NY. 1/24/10.
25. Disease control programs for 2010. National Grape Cooperative meeting. Forrestville, NY. 1/25/10.
26. Honk if you hate mildew. Viticulture 2010, Rochester, NY. 2/7/10.
27. Disease control programs for 2010. National Grape Cooperative meeting. Branchport, NY. 3/26/10.
28. Grape disease management. Long Island Pest Management Workshop. 3/29/10.

<u>Publications:</u>

1. Powdery Mildew: Biology and Control. Proc. Great Lakes EXPO 2006.
2. New Developments in Grape Disease Control. Wine East: April, 2007.
3. Grape disease Control, 2007. Annual 20-page newsletter article distributed to growers in NY and multiple eastern states. April, 2007.
4. Austin, C. N., Lakso, A. N., Seem, R. C., Riegel, D. G., Gadoury, D. M., and Wilcox, W. F. 2007. Increased powdery mildew in shaded vineyard regions: Association with reduced leaf temperature and UV radiation. Phytopathology 97:S5 (Abstr.).
5. Grape Disease Control: What's new?. Wine East: April, 2008.
6. Grape Disease Control, 2008. Annual 20-page newsletter article distributed to growers in NY and multiple eastern states. April, 2008.
7. Austin, C. N., Lakso, A. N., Seem, R. C., Riegel, D. G., Gadoury, D. M., and Wilcox, W. F. 2008. Impact of sunlight and its components on severity of grapevine powdery mildew. Phytopathology 98:S15 (Abstr.).
8. Grape Disease Control Update. Wines and Vines: April, 2009.

9. Grape Disease Control, 2009. Annual 20+-page newsletter article distributed to growers in NY and multiple eastern states. April, 2009.
10. Austin, C. and Wilcox. W. Heat and radiation from sunlight exposure inhibit powdery mildew. Appellation Cornell Research Focus 2010-2.
11. Austin, C.N. and Wilcox, W. F. 2010. Effects of Fruit Zone Leaf Removal, Training System, and Variable Irrigation on Powdery Mildew Development on Vitis vinifera L. Chardonnay. Jour. Am. Soc. Enol. Vitic. (submitted).
12. Austin, C.N. and Wilcox, W. F. 2010. Inhibition of grapevine powdery mildew by sunlight. Phytopathology 100: (submitted).
13. Austin, C.N., Grove, G. G., and Wilcox, W. F. 2010. Effects of canopy density on powdery mildew development and management. Jour. Am. Soc. Enol. Vitic. (submitted).