



RESEARCH FOCUS

The Potential of Light Treatments to Suppress Certain Plant Pathogens and Pests

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Figure 1. Powdery mildews have been plant pathogens since the late Cretaceous Period, about 60 to 100 million years ago. Over that span of time, they evolved the means to sense, interpret, and use light to direct their development. We can use those evolutionary adaptations against them.

Since 1990, we have investigated how visible and ultraviolet (UV) light impacts plant pathogens such as powdery mildew. Early trials using UV showed promise, but rates necessary to suppress grapevine powdery mildew also unacceptably damaged foliage. A breakthrough occurred in 2010 when a colleague in Norway demonstrated that by applying UV at night, much lower doses could be used to suppress pathogens without host damage. We have since used nighttime UV on several crops, and developed mobile and static systems for greenhouses. More recently, we've tested mobile UV arrays sufficiently powerful to move at speeds practical for tractor-drawn equipment, as well as fully-autonomous robotic devices. Three seasons of weekly applications in strawberries provided season-long control of powdery mildew that were more effective than fungicides. Preliminary trials in Chardonnay grapes underway at Cornell AgriTech have shown effective suppression of powdery mildew, as well as activity against downy mildew and mites. Collaborative demonstration trials will be launched next spring at a commercial vineyard in NY, Washington State University, and the USDA ARS unit in Corvallis. This technology could provide growers with an effective alternative for some fungicide applications, slow the development of fungicide resistance in powdery mildews, increase efficacy of remaining fungicide applications, and provide additional suppression of downy mildew and certain arthropod pests.

KEY CONCEPTS

- Germicidal ultraviolet light, properly applied, can suppress powdery mildew on a variety of crops.
- Significant suppression has also been observed in laboratory and preliminary field studies of downy mildew and mites.
- Nighttime application is necessary to prevent reversal of the UV effect due to the blue light and UVA component of natural sunlight.
- Proper design of the light array is essential for proper dosing, and to reach the interior of the grapevine canopy.
- Lamp arrays are adaptable to a variety of carriages, including towable arrays and those moved by autonomous robotic devices.

Pathogens evolved in cycles of light and darkness.

Microbial pathogens have been attacking plants for a very long time (Fig. 1). They have about a 100-million-year head start on humans in exploiting plants, and they became pathogens over an evolutionary scale of time amidst endlessly repeated cycles of light and darkness. In that time, these one-celled microscopic organisms evolved the means to sense, interpret and use light to direct their development. One aspect of our present research is focused on how we can take one of those evolutionary traits and use it against a pathogen.

In 1990, our research group was approached by a retired engineer, Al Michaloski, who had experience in industrial photocopy processes. His retirement plan was to buy a vineyard and grow grapes. He also had an idea that the germicidal UVC lamps he used during his career could suppress the grapevine powdery mildew pathogen (*Erysiphe necator*). We cooperated with Al in laboratory and field trials that led to a US patent on the method in 1991. The treatments were effective, but UVC also damaged the vines, and the technology was never widely adopted.

Fast forward 20 years to 2010. Aruppillai Suthparan, a PhD student and colleague in Norway made a critical breakthrough that fundamentally changed how we could use UV light against plant pathogens. He found that if UV light was applied during the nighttime, we could use much lower doses than were required during daylight. That breakthrough largely resolved the issue of plant damage at the high UV doses required for daytime applications.

The mechanism underlying the success of nighttime UV applications is related to how pathogens respond to naturally-occurring ultraviolet light from the sun. Shorter-wave UVB and UVC both damage DNA in all living organisms. Exposure to UV causes thymine base pairs in the DNA to bind together, changing the genetic code to genetic gobbledygook. Pathogens sense visible light, but they also have evolved systems that can repair damage to their DNA caused by incoming UV. We now know that those biochemical and genetic repair systems are recharged by blue light and UV-A, and are reduced by red light and darkness. This repair mechanism effectively “unglues” the thymine base pairs as fast as they are bound by UV.

Light relationships are important in a few IPM programs where specific effects of light upon pathogen growth and development are used in disease forecasting models. For example, the apple scab pathogen (*Venturia inaequalis*) releases its overwintering spores primarily during daytime, but not nighttime rains. The grape powdery mildew pathogen produces its spores shortly after sun-

rise, and the grape downy mildew pathogen (*Plasmopara viticola*) only produces its spores when temperature and humidity conditions are optimal during night hours.

We are now at a point in our research where we are using the very relationships that have evolved between pathogens and light to directly affect the ability of the pathogen to cause disease. Powdery mildews proved to be the ideal pathogens for our preliminary research.

Why start with powdery mildews?

We chose to start with powdery mildews, instead of other grape pests, because they attack a variety of crops in a number of countries around the world. It doesn't matter whether you grow a crop in an open field, a glasshouse, or a high tunnel — there's a good chance that it will be attacked by a powdery mildew (Fig. 2). In fact, if you grow the crop in either a high tunnel or glasshouse, powdery mildews will likely be your number-one IPM problem. Again, that's largely due to the relationships that have evolved in relation to exposure to the natural solar spectrum, and day/night cycles (Fig. 3).

Glass and plastic filter out UV light.

Any time a light filter (glass or plastic) is placed between a plant pathogen and the sun, or natural day/night cycles are disrupted by electric lighting, there is a potential to alter pathogen reproduction and spread. Nearly all commonly-used plastics not only alter the spectral distribution of natural light, they increasingly do so as they age. Nothing in the evolutionary biology of powdery mildews equips them to deal with spectral changes caused by the imposition of plastic or glass between them and the sun. Likewise, their evolutionary biology was shaped by the rising and setting of the sun, not by electric lighting that has a temporal and spectral distribution that is totally unfamiliar. Natural UV is screened out by most glass and plastics, and horticultural lighting provides lots of blue



Figure 2. Powdery mildews are often the number-one disease in glasshouses and high tunnels. Alteration of the natural light environment by plastic, glass, and electric lighting are a major reason why. The links between pathogen biology and light can also be exploited to suppress disease.

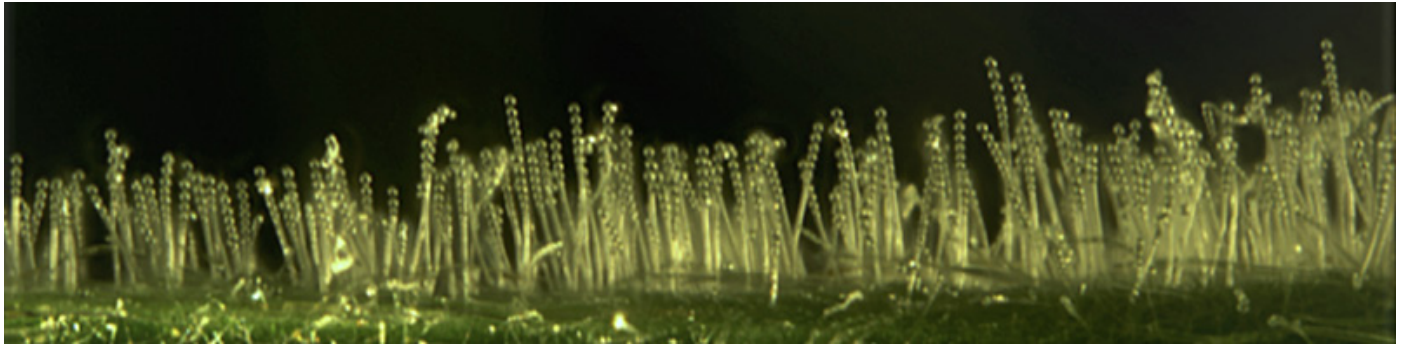


Figure 3. Although completely devoid of protective pigmentation, and growing in a totally exposed niche upon the epidermis of plants, powdery mildews are remarkably resistant to the UV- component of natural sunlight.

light for plant growth. Both of these alterations can shift powdery mildews into reproductive overdrive, and that's a major reason why they are such a threat in controlled-environment agriculture.

Although fungicides and disease-resistant varieties are important means of control, there is need for control measures that are not entirely dependent on either fungicides or resistant varieties. In particular organic production systems are threatened. Very few practical organic options for controlling powdery mildews, and the worldwide trend towards growing crops in glasshouses and tunnel production systems favors severe powdery mildew epidemics.

Types of UV lamps for pathogen suppression.

Lamps producing ultraviolet light have been commonly available for over 75 years. Those that are powerful enough to be practically used against powdery mildews produce either UVC (100 to 280 nm) or UVB (280 to 315 nm). Both UVC and UVB affect DNA in the same way. UVB poses less potential to harm plants, and may therefore be preferred for static and permanent installations in greenhouses. However, with precise dosing, UVC can be used safely on even UV-sensitive crops.

Low pressure discharge lamps are the most common available technology. Low pressure discharge UVC lamps are generally clear quartz-glass tubes containing a small amount of mercury vapor. Passing an electric arc through this vapor results in the efficient production of a narrow waveband centered on 254 nm, which is excellent for germicidal applications.



Figure 4. UVB lamps suspended in the superstructure of a greenhouse can suppress powdery mildew on a broad variety of crops with as little as 6 minutes of nighttime exposure twice per week.

UVB low pressure discharge lamps are similar, but incorporate a fluorophore powder coating on the inside of the tube. When this is struck by the internally-produced UVC, the fluorophore absorbs the UVC and emits the longer-wavelength UVB. This process is also relatively inefficient—nearly 95% of the usable germicidal energy is lost in the conversion from UVC to UVB. So, low-pressure discharge UVC lamps can produce much more usable power than comparably sized UVB lamps. While UV LEDs are available, they are far too expensive and underpowered at present to be useful for treating crops. LEDs that produce light in the red range can however be teamed with low pressure discharge lamps to enhance the germicidal effect of UVB or UVC (Fig. 4).

At Cornell AgriTech we've outfitted two greenhouses with UV lamps and red LED lights to provide research and demonstration units for evaluation of this technology on several crops (Fig. 4). All of the greenhouse systems are automated, and operate at night for only a few minutes at a time. We are using stationary lamps, but the lamps could conceivably be retrofitted to an existing boom used for greenhouse spraying, or otherwise linked to a mobile system. Our collaborators in Norway have been very innovative in developing mobile lamp arrays, including mobile booms, tracked units, and even completely autonomous robots to move the lamp arrays within plant production structures.

Field applications: the need for speed.

Arrays of stationary lamps suspended above plants in a greenhouse are comparatively simple to design. But for very large areas, a mobile unit is much more practical—just based on the number of lamps required. To take the UV technology from the greenhouse to larger field plantings, we faced a number of challenges. It was impractical to erect a superstructure over a 50-acre open field to support and power UV lamps. We needed a smaller and much more powerful mobile array to treat the entire field, preferably in a single evening. The mobile booms we used in our greenhouse studies moved at approximately 20 inches per minute (0.019 mph). We needed something that could move 100 times faster: at least 2 mph, a common speed for tractor operations.

Our first trials on an open-field crop were conducted in a commercial strawberry operation in Florida (Wish Farm) in 2017 (Fig. 5). The lamp array was designed around the dimensions of the raised strawberry bed. It was a densely-packed hemi-cylindrical grouping of twenty 30W UVC lamps backed by polished aluminum reflectors, designed by our colleagues at the Lighting Research Center at Rensselaer Polytechnic Institute.

Construction and testing of prototypes built around the raised bed and plant dimensions allowed us to determine the lamp placement and density needed to achieve a desired intensity and uniformity, given the complex canopy architecture of the growing plants. The densely-packed lamp and reflector array provides a large number of reflectance angles. So, although the lamp-to-plant distances varied, the dose obtained throughout the 3-dimensional tunnel was quite uniform. The multiple reflectance angles also provided improved exposure to the undersurfaces of many of the leaves, in particular due to the lateral lamps and reflectors near the bottom edge of the tunnel. Treatments were applied beginning 30 minutes after sunset, once per week, at the rates between 85 and 190 J/m².

It worked!

Weekly applications of UVC provided suppression of foliar powdery mildew across the duration of the experiment. In fact, it was substantially better than that provided by the best fungicide treatment in the trial (Fig. 6), a tank mix of two materials sold under the trade names Quintec and Torino. We also confirmed that the UV treatments did not reduce plant size, or reduce the yield of harvested berries. Equally good results were obtained in 2018 and 2019 trials.

Additional trials adapted modified designs of the original tractor-drawn array to an autonomous robotic device (Fig. 7), called Thorvald, manufactured by SAGA Robotics, a Norwegian company collaborating with our research group. The use of a robotic carriage provides additional flexibility in nighttime applications. UV applications must not only be made during night hours: they must also be completed no later than 4 hrs before sunrise. Four hours of darkness are required for the UV exposure to be lethal to the pathogen. Thus, if sunrise occurs within 4 hrs of treatment, the efficacy of the treatment will be reduced.

At temperate latitudes, the duration of night near the summer solstice can be less than 8 hrs, leaving only 4 hrs during which the UV treatments could be applied with optimal effect. In situations where employing nighttime labor to make applications split over sev-

eral relatively short night intervals would be problematic, an autonomous robotic device offers a practical alternative.



Figure 5. Tractor-drawn UVC array used in our first large-scale field trials on strawberries. Side-by-side arrays allowed two rows to be treated in each pass.

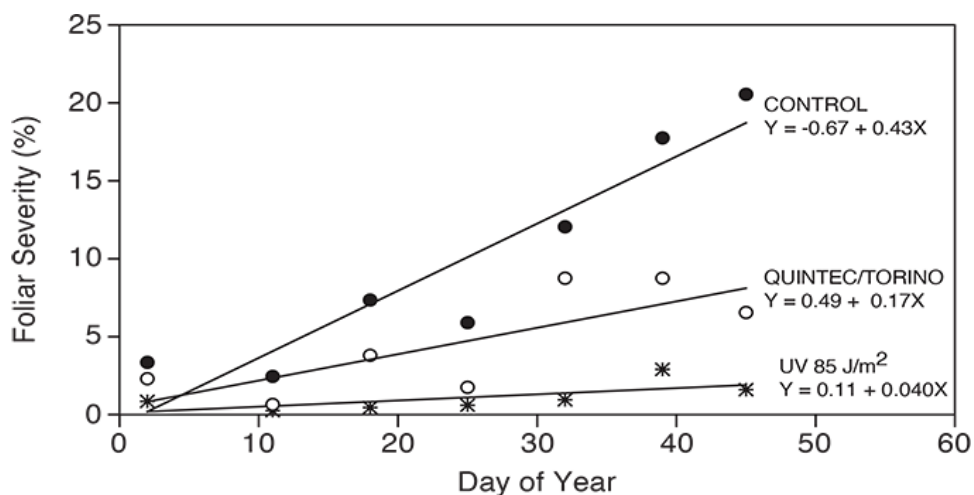


Figure 6. Weekly nighttime applications of UV light at 85 J/m² provided season-long suppression of strawberry powdery mildew that was better than that provided by the best available fungicides.



Figure 7. Thorvald, an autonomous robotic device developed in collaboration with SAGA Robotics in Norway, can carry and power the same UV array used in tractor drawn devices.

Finally, we were ready to resume work on grapevine!

After successful greenhouse trials on rose, strawberry, basil, rosemary, cucumber, and tomato, and three seasons of successful field trails on strawberry, in 2019 we came full circle, and were ready to resume UV treatments on grapevine that we started in 1991.

We constructed another UV array and tractor-drawn carriage, and applied UV Treatments weekly at 100 or 200 J/m² to Chardonnay vines that received no other fungicide treatments (Fig. 10). We compared the incidence and severity of powdery mildew on leaves and fruit of UV treated vines, vines treated with an effective conventional fungicide, and completely untreated vines. 2019 was a moderately severe year for powdery mildew, and one of the worst years for downy mildew in recent memory. Laboratory experiments had indicated that the UV doses used would stop 80 to nearly 100% of the conidia of *E. necator* from germinating (Fig. 8).

Both the 100 J/m² and 200 J/m² UVC treatments significantly but equivalently reduced the severity of powdery mildew on berries (severity of 5%) compared to the untreated vines (severity = 15%), albeit not to the degree provided by the standard fungicide treatments (severity= 1%). What surprised us was that both the 100 J/m² and

200 J/m² UV treatments also suppressed foliar downy mildew (*Plasmopara viticola*), and did so better than the fungicide standard (Fig. 9). Laboratory studies indicated that the suppression of the downy mildew pathogen was due to a pre-inoculation increase in host resistance. This was distinct from the impact of UV on powdery mildew, which was primarily a direct effect of UV on the pathogen itself.

Suppression of arthropod pests by UV treatments.

In addition to suppressing plant pathogenic fungi, UV treatments can also suppress populations of phytophagous mites. A number of studies have noted that UVB and UVC treatments can kill eggs of spider mites and European red mites. In addition to these effects, our preliminary trials indicate that the UV treatments can also alter behavior of adult mites, reduce egg laying, and reduce fecundity of the generation of surviving mites that emerge from UV treated eggs.

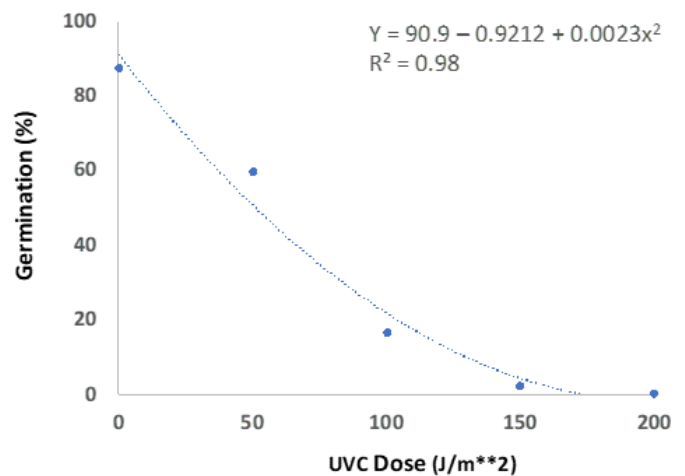


Figure 8. Suppression of germination of conidia of *E. necator* due to increasing doses of UVC applied to sporulating mildew colonies 24 hrs before assessment.

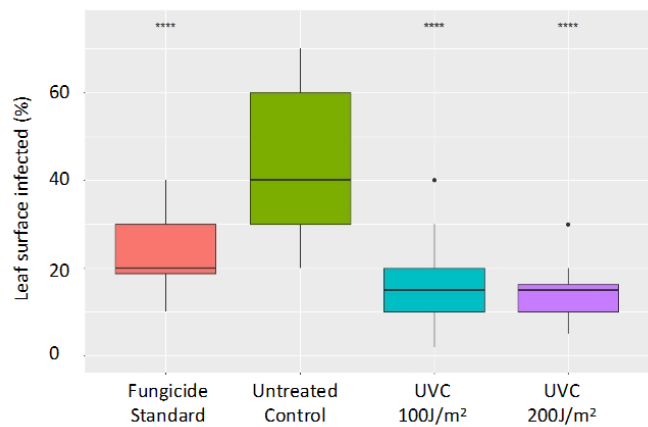


Figure 9. Foliar severity of grapevine downy mildew on Chardonnay vines treated with UVC at 100 or 200 J/m² compared to a standard fungicide treatment and untreated control.

The next steps.

We are presently assisting growers at several US locations in fabricating their own units for UV trials. On grapes, we have provided cooperators at Bully Hill Vineyards in Hammondsport NY, Washington State University's research and extension center in Prosser, and the USDA Horticultural Crops Research Center in Corvallis, OR with designs and materials for UVC lamp arrays adapted for their vineyard pruning and training systems. In the 2020 growing season, we'll also begin the first UV autonomous robotic trials on grapes at Cornell AgriTech using a specially adapted version of the Thorvald robotic platform.

Proceed with caution.

The design of a lamp array to match a particular crop canopy and target pest biology is a critical aspect that determines the success of the treatments. Our cooperative projects with growers across the US have always involved our array designs and electronics. The growers designed and fabricated the various carriages for the arrays. But, the UV array itself is NOT a do-it-yourself project, nor is calibration. The photobiological and epidemiological calculations that enter into calculations of a proper UV dose for specific applications are complex.

The key to safe use of UV in agricultural operations.

In addition to the engineering and biological considerations, UVB and UVC can be injurious to you unless devices are properly designed and the lamps are properly shielded from direct view. No person should ever have an unshielded view of germicidal UV lamps, as there is a significant risk of eye and skin damage from exposure UVB and UVC. The arrays shown in this article incorporate clear PVC curtains at each end of the array to block any such exposure. As would be the case with any IPM technology, UV does not pose undue risks to operators or the environment if used properly. Proper training and use protocols are the key to safe and effective applications.



Figure 10. A tractor-drawn UVC lamp array used to treat grapevines at Cornell AgriTech. This same unit is also used to treat low-trellised hops.

For additional information

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David M. Gadoury is a senior research associate in Cornell's Plant Pathology and Plant-Microbe Biology Section at Cornell AgriTech, where his program focuses on pathogen ecology, pathogen biology, and disease management. He leads the Light and Plant Health Group.



Group photo: Members of the research/extension team and advisory committee for our USDA-OREI project. Left to right: Laura Pedersen, Pedersen Farms, Geneva, NY; Eric Sideman, NOFA; Arupplillai Suthaparan, NMBU, Norway; Arne Stensvand, NIBIO Norway; Mariana Figueiro, RPI-LRC; Mark Rea, RPI-LRC; David Gadoury, Cornell University; Ole Myhre, Myhre AS, Norway; Rebecca Sideman, University of New Hampshire; and Robert Seem, Cornell University. Below (left to right), other members of the research and extension project team: Dr. Natalia Peres and PhD student Rodrigo Onofre, UFL Gulf Coast Research and Education Center; Dr. Lance Cadle-Davidson, USDA-ARS-GGRU, and Dr. Jan Nyrop, Department of Entomology, Cornell University and Director at Cornell AgriTech.

Our collaborative working group.

Our project website is LightAndPlantHealth.org, and our work is funded by competitive grants from the USDA Organic Research and Extension Initiative, and the USDA Specialty Crops Research Initiative. Additional support has been provided by the National Research Council of Norway, the New York Farm Viability Institute, the USDA Sustainable Agriculture Research and Extension Program, and Bully Hill Vineyards. We work as a diverse international group to promote this research area and its applications, and to act as a resource to train others. In addition to [Cornell AgriTech](http://CornellAgriTech), the group includes [Rensselaer Polytechnic Institute's Lighting Research Center \(RPI/LRC\)](http://RensselaerPolytechnicInstitute), [Norway's Institute of Bioeconomy Research \(NIBIO\)](http://NorwayInstituteofBioeconomyResearch), the [Norwegian University of Life Sciences \(NMBU\)](http://NorwegianUniversityofLifeSciences), and the [University of Florida Gulf Coast Research and Education Center \(UFL/GCREC\)](http://UniversityofFloridaGulfCoastResearchandEducationCenter). The work spans disciplines from plant growth and photobiology to physics and lighting technology.



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