Disease Management Guidelines for Organic Grape Production in the Lake Erie Region

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Introduction

Increasing consumer demand for organically grown food and more environmentally sustainable production practices, as well as increasing concern over the management of fungicide resistance, are creating new pest management challenges and potentially profitable marketing opportunities for grape growers in Pennsylvania and New York. However, organic fruit production is among the slowest growing sectors of the organic industry, largely due to the enormous risks associated with high pest pressure in humid climates (Tamm et al. 2004). Greater development of research based pest management strategies for organic fruit production can minimize the risks and help close the gap between demand and supply.

The transition to organic represents a major, long term commitment for growers. In addition to more careful planning and detailed record keeping, the grower in transition must produce a crop without any prohibited substances for 3 years *before* the first 'certified' crop can be sold for a premium. Pesticides available to organic producers are often less effective than conventional materials, increasing the organic growers risk of economic crop loss and requiring the integration of more cultural approaches (at added expense) into pest management programs. Although there is a bewildering multitude of commercially available pesticides for organic crop management, thorough testing of these products by universities is very limited and the efficacy of many of them is largely unknown with respect to grape diseases. The pest management guidelines available to conventional grape growers have evolved through years of research and experience, and are essential to the sustainability of the industry. On the other hand, organic growers may have to rely on limited information sources rather than research-based information and previous grower experience in organic grape production to make management decisions.

Components of organic management of grape diseases in the Lake Erie belt

Conventional grape production in the East relies on a battery of highly effective synthetic pesticides for disease control, and their timely application has enabled many grape growers to produce a profitable crop with minimal attention to non-chemical methods. The organic approach to disease management must focus on maximum integration of non-chemical strategies with the goal of constantly maintaining disease pressure as low as possible. Rather than the core of a disease control program, pesticides are but one component in a holistic disease management system. To illustrate, in 2006, an organic formulation of copper hydroxide was evaluated for control of grape black rot under two contrasting levels of disease pressure within the same vineyard. Copper fungicides are only modestly effective against black rot and weather conditions in 2006 were very conducive to disease development. In plots where black rot infected mummies were added to the trellis to augment inoculum pressure, losses on unsprayed vines were nearly 80 % and five applications of copper hydroxide only suppressed black rot by 31 %, representing a loss of more than half the crop. However, in subplots where much of last year's infected tissue was removed from the trellis, losses on unsprayed vines were around 15 %, and the same copper program provided a very successful 97 % control of black rot (less than 1 % crop loss). The more integrated approach requires greater attention to things like proper site and varietal selection, cultural methods, scouting, and better, more timely pesticide coverage, but greatly improves an organic producers chances of success.

Site/Vineyard Selection

Proper site selection is an essential component of the integrated approach to organic production and is critical to the profitability of the operation. A vineyard on a good site will always yield a larger, better quality crop with fewer inputs and expense than one on a poor site. Every grower has vineyard blocks that require less input to control diseases than other blocks. Differences in the topography of the site, the layout of the vineyard (row and vine spacing, row orientation), the variety grown, management of adjacent land, etc, all can contribute to make disease control relatively easy or nearly impossible under organic management. A common tendency is to think that the profitability of a poor site can be improved by transition of that site to organic with the prospect of price premiums. But, if a vineyard is unprofitable under conventional management, it will likely be unprofitable under organic management where pest control and nutrition are an even bigger challenge. As a first step in making the transition to organic, growers should endeavor to devote their *best* blocks to organic transition, not blocks that are difficult to manage.

Disease control, particularly with respect to black rot and Phomopsis will be a greater challenge under organic management. Choose a vineyard site where these diseases have presented minimal problems in the past. Black rot and Phomopsis are more difficult to control where air movement is inhibited, humidity is higher (and hence wetting periods are longer), and there are sources of inoculum immediately adjacent to the vineyard. Vines growing on elevated or gently sloped, open areas with good drainage and aeration will remain wet for shorter periods of time after rain than vines growing in valleys or other low areas, near water and wood-lots. Avoid sites adjacent to woods, streams, and abandoned or poorly maintained vineyards.

Vine and vine row spacing is important. Generally, the wider the vine row spacing, the better the airflow through the vineyard, the greater the exposure of vines and row middles to solar radiation, and the shorter the leaf wetness periods after rainfall.

Weed control history can be a factor when choosing a site for organic transition. Weed control is a bigger challenge under organic management than under conventional management. Choosing a site where weeds have been well controlled over the years under conventional management, may minimize (at least initially) the challenge of weed control during organic transition. Weed control can affect disease control. Increasing density and height of weed growth in row middles and under vines can increase humidity and leaf wetness duration after rainfall, relating unfavorably to disease control. Choosing a site where good weed control is easier to achieve can make good disease control easier to achieve.

Scouting

Organic growers must make regular scouting part of their disease control program. The key to successful disease control in organic systems is to maintain disease pressure at the lowest level possible. Once disease spirals out of control, it is much harder to regain control under organic than under conventional management (if it can be regained), and the ramifications for disease control in the future may be far more serious and long lasting. Good scouting may help a grower to anticipate and act on disease control problems while they are still manageable. There are really no action thresholds for grape disease control as there are for insect control and it is generally necessary to apply disease control preventively, especially in organic systems, than to wait until disease symptoms become manifest. However, scouting for diseases can provide information on current inoculum levels and disease pressure in different parts of the vineyard and how effective present control measures have been. Recording the results adds more value to the scouting experience and builds a detailed record of disease history that can be used to fine tune control efforts in the future. To be effective and efficient, a grower needs to know what to look for, what plant parts to examine, and where and when disease is most likely to appear first. For example, we often find black rot developing among vines along wooded edges before it appears in more open, better aerated areas of the vineyard. Concentrate scouting efforts where disease is most likely to show up first. Also, leaf and fruit symptoms take time to develop depending on vine phenology and weather. When grape berries are infected with black rot during the first 3 weeks after bloom (when they are most susceptible), fruit rot symptoms can appear in as little as 10-12 days after the infection period under warm conditions. This period may take an extra day or two under cooler conditions and may be extended to 2-3 weeks or more if the infection period occurred 4 weeks or more after bloom. Also, black rot berry infections that occur early in the post bloom period, may become capable of supplying additional inoculum before remaining healthy berries become resistant, adding to the risk of economic loss. Infections occurring 3 weeks or more after bloom are less likely to supply inoculum before fruit are resistant, especially in Concord grape. This is one reason why thorough early control of fruit infections can reduce the need for further control efforts later. By scouting, a grower develops a knowledge of the biology and life cycle of the pathogen that can help him/her determine when disease management efforts have succeeded or failed and how long they need to continue.

Varietal selection

The scientific advances of the agricultural chemical industry have made it possible to grow many cultivated grape varieties well outside their natural range and tolerance for disease. However, under organic management, pesticide choices and efficacy are often more limited, making disease resistance an important factor when deciding what variety to grow in the humid Northeast. Grape varieties with a strong native labrusca background are generally more resistant, tolerate more disease development, and often require fewer pesticide applications, than French hybrid and *Vitis vinifera* grape varieties. For example, in conventional systems, Concord grape (a native variety) routinely tolerates 2-3 months of powdery mildew development on leaves every summer without pesticide intervention and still produces a profitable, quality crop. Varieties of *Vitis vinifera* would not survive long, let alone produce a crop, without season-long pesticide coverage. Disease resistance by variety can be found in the *Vineyard Disease Management* section of the New York and Pennsylvania Pest Management Guidelines found at http://ipmguidelines.org/grapes/CH03/default.asp

Currently, copper and sulfur fungicides are the foundation of chemical control in organic viticulture. Although these materials are biocidal to many grape pathogens, they can also injure grapevines. Sensitivity to copper and sulfur fungicides varies with grapevine variety and may limit what varieties can successfully be grown profitably under current organic disease management recommendations.

Cultural methods

Many grape pathogens that cause diseases like downy mildew, black rot, Phomopsis, and Botrytis, survive the winter in infected plant material (dead leaves, dead clusters, live or dead canes, live older wood, dead wood). This material is like a nest egg for the pathogen, providing a starting point for the pathogen to build its population in the vineyard the following spring. The greater the volume of starting material or "over-wintering inoculum" in the vineyard, the more difficult it will be to limit disease development (pathogen populations) when weather conditions are favorable. Cultural methods that reduce over-wintering inoculum sources can reduce pathogen populations to levels that are manageable with the reduced efficacy of organic fungicides. Specific methods will be covered under discussion on each disease.

Other cultural considerations that can reduce disease development involve limiting humidity and promoting sun exposure of all parts of the vine. Planting in sites with good air circulation and sun exposure and using a training system that allows good air movement through the canopy, prevents excess shading, and promotes fungicide penetration to the cluster zone can greatly improve the effectiveness of chemical control. Proper nutrient management and bud number can limit shoot growth and excessive canopy shading. Excellent weed control, largely achieved in organic vineyards by various methods of mechanical cultivation, can also minimize humidity levels and discourage disease development.

Chemical control

Copper and sulfur fungicides are the foundation of most chemical control programs in commercial organic grape production in humid climates and grape growers have reported being able to achieve satisfactory control of diseases like powdery and downy mildew with these materials. For organic production, the pesticide component of disease management may have to be expanded over that of conventional; applications may have to begin earlier (when the pathogen population is smaller and easier to control), be applied at shorter intervals (to improve efficacy of materials), and end later (to achieve an end level of disease comparable to conventional systems) than in a typical conventional program. For example, in conventional systems, 3 fungicide applications (at immediate pre bloom and 2 and 4 weeks post bloom) provide nearly complete control of black rot fruit infections in most years (Hoffman et al. 2004). Less attention is paid to the prevention of black rot shoot infections occurring during early shoot growth, which may help to maintain the pathogen in the trellis from year to year. But shoot infections can contribute to crop loss (Becker and Pearson, 1996) and where effective fungicides for black rot are lacking, as in organic viticulture, the role of shoot infections in epidemic development should not be overlooked. Therefore, organic growers may need to apply a black rot material at earlier shoot growth stages (especially if weather is wet and there is high over-wintering inoculum) to achieve fruit rot control comparable to conventional systems.

The less efficacious a fungicide is, the less forgiveness there is for poor coverage, and the smaller the margin for error. Therefore spray coverage can be more critical in organic systems than in conventional systems. Organic growers can improve coverage by using higher volumes of water per acre, spraying every row (every time), and making sure the spray equipment is properly calibrated and aimed.

In the United States there are two major sources of information available to growers to determine what materials are approved for use in organic agriculture. Within the USDA, the NOP or National Organic Program compiles a generic list of materials approved for organic use by the Secretary of Agriculture. The national list can be accessed online at the NOP website. However, the list does not include brand names or manufacturers of commercially available products. OMRI or Organic Materials Review Institute, a non-profit organization separate from the USDA, offers a generic list and a brand name list of approved materials and their manufacturers. It uses the same standards as the NOP, but there is a fee for the list. These lists change as they are constantly updated. The OMRI list does not necessarily contain all brand name products approved for organic. If a brand name product is not on the OMRI list, it may still be approved under NOP rules. Keep in mind that inclusion of a material on the NOP or OMRI lists only means the material does not contain any prohibited substances. The lists do not provide information on their efficacy (Ferguson). Whichever way you locate approved materials for your organic operation, ***always contact your certifier for confirmation that a material is approved before you use it***.

DISEASES

Black rot is caused by the fungus *Guignardia bidwellii*. The fungus can infect all immature green parts of the vine including, fruit, shoots, leaves, and tendrils. Generally, fully expanded tissue will no longer develop lesions (Kuo and Hoch, 1996). This disease rarely causes serious damage to foliage and shoots in hand pruned juice grape vineyards, but can be devastating in its effect on fruit. On leaves, where the disease generally makes its first appearance, infections start out as small light green spots visible on the upper surface (Figure 1). The time required for the appearance of leaf spots depends on temperature during the incubation period. Under warm conditions (upper 70s F), on rapidly expanding leaves, leaf lesions may appear in as little as 5-6 days from the time of infection. Lesions gradually turn brown to reddish-tan as infected tissue dies. Small, black, pimple-like bodies (pycnidia) develop inside the spot or lesion, usually arranged in a loose ring just inside the dark brown edges of the spot (Figure 1). Spores of the fungus are formed within these pycnidia, and are released when they become wetted from dew or rainfall. Leaves may remain susceptible for only about a week to ten days after they emerge. The relative size of leaf lesions indicate when, during expansion, the leaf was infected. Small lesions result when leaves become infected near the end of their expansion. Large lesions indicate the leaf was infected early in expansion. However, numerous small lesions, when clustered, may coalesce to damage large portions of the leaf, resembling large early infections. The death of large portions of the leaf blade may cause the entire leaf to die and abscise. Leaf infections that take place at the very end of the susceptibility/expansion period may become manifest as small dark pinhead size spots that do not expand (Figure 4). On petioles, black, elongated lesions may induce wilting or abscission of leaves. Infections on berries initially appear as small, tan spots that develop a dark outer ring and expand rapidly in a circular pattern to rot the entire berry. As fungal colonization of the berry progresses, the soft brown berry shrivels until it becomes a hard, black, wrinkled mummy studded with spore producing pycnidia (Figure 2). Berries of Concord grape are highly susceptible for the first 3 weeks after bloom, gradually developing resistance over 2-3 weeks after that. Infections that take place during peak susceptibility generally show symptoms within 10-14 days. As berries gradually become more resistant, infections during that time take longer and longer to become manifest (Hoffman et al. 2002). Infections taking place toward the end of the susceptibility period may not develop symptoms until veraison. As berries develop resistance several weeks after bloom, the appearance of new infections may change: circular lesions are black, expand more slowly, and may remain small, often failing to affect the entire berry (Figure 4).

Fig. 1 Development of black rot lesions on grapevine leaf (Concord).

Fig. 2 Development of black rot lesions on grape berry (Concord).

On shoots, lesions appear as elongated or elliptical brown cankers. Pycnidia may be clumped in the center of the lesion and/or line the margins of the lesion (Figure 3). These pycnidia produce spores during the current season and can be a source of further infection to fruit. These lesions remain on the shoots after they have "hardened off" and can survive over winter to release spores again the following spring. Large shoot lesions may render the shoots susceptible to breakage by wind.

Fig. 3 Black rot shoot lesions (Concord).

Fig. 4 Limited black rot lesion development from infections occurring toward the end of the susceptibility period (Concord).

<u>Disease Cycle</u>

The fungus over winters primarily in mummified berries on the soil or in old clusters that hang in the vines, but can also over winter within cane lesions (Ferrin and Ramsdell 1977, 1978). Spores of the fungus are produced within the diseased fruit and canes, and released during spring rains, infecting leaves, cluster stems, succulent shoots, and young fruit. Spores within cane lesions are available for infection in early spring at bud break; however, the vast majority of spores (those within berry mummies) first become available about 2-3 weeks after bud break, then reach peak levels from about 1-2 weeks before bloom until about 1-2 weeks after, depending on the year (Becker and Pearson, 1990-1993). Shoot and leaf infection is most common in early spring, before bloom, when new growth is in close proximity to old wood, over-wintering cane lesions, and old clusters. Early shoot and leaf infections can serve as a source of spores (conidia) for later fruit infections and may need to be controlled in organic viticulture. For example, shoots inoculated at 10 and 20 days after bud break developed lesions on leaves, petioles, internodes, and cluster stems. Pycnidia that developed within these lesions provided spores during rain periods of the fruit susceptibility period leading to fruit rot (Hed and Travis, unpublished). Shoot lesions may be an important source of over-wintering inoculum, particularly since most occur on the most basal part of shoots that cannot be entirely pruned out and removed from the trellis.

Fruit can be directly infected from capfall until 4-6 weeks after bloom, depending on grape variety. Mature leaves and ripe fruit are not susceptible. Black rot infection depends on rainfall for spore release and on the right combination of temperature and the length of time susceptible tissues remain wet. Although this disease does not spread as quickly as powdery and downy mildew, it is always present in the vineyard.

Table 1. Combinations of temperature (F) and hours of continual leaf wetness required for black rot infection to occur after rainfall.

Temperature (F)	Hours of leaf wetness
50	24
55	12
60	9
65	8
70	7
75	7
80	6
85	9
90	12

From: R.A. Spotts, Ohio State University

Disease management

Resistance:
Cayuga white, Chancellor, Cynthiana/Norton, DeChaunac, Elvira, Ives, Leon Millot, Traminette, Vidal, and Vignoles are some varieties that are least susceptible to this disease.

Cultural control:
The black rot pathogen survives the winter in infected grape tissue which serves as a source of inoculum (spores) of the pathogen during the next growing season. These inoculum sources include infected shoots, leaves, leaf petioles, and fruit clusters. Inoculum that remains in the trellis poses a much greater risk than inoculum dropped to the ground. Therefore, one of the most important methods of cultural control of black rot in organically managed vineyards is removal of infected material, particularly fruit and cluster material, from the trellis.

During the season, infected berries are often easily dislodged from their attachments in the cluster and many are shaken from the trellis naturally by wind and weather. Hand harvesting of wine grapes can remove all infected fruit from the trellis. Mechanical harvesting shakes much of the remaining infected fruit from the trellis, but will not remove all of it. Therefore, where grapes are harvested mechanically, efforts to consciously remove all remaining mummies during or just after dormant pruning, are critical to good control of black rot in organic viticulture. Once on the ground, mummy viability can be reduced to further improve control. Burial of mummies with cultivation can greatly reduce spore release into the air (Becker and Pearson, 1990-1993). Row middles can be plowed and hilling up under the row can bury mummies directly under vines.

Canopy management can be important in black rot control. An open canopy, where fruit and other susceptible tissue dry out as quickly as possible after rainfall will help minimize fungal disease development. Canopy management can take several forms. In the case of Concord (and other natives), where high wire cordon trellis (no tie) is standard practice, canopy density can be managed by proper nitrogen fertilization and bud number. For wine grapes, cultural practices like leaf removal and shoot thinning can hasten drying of the fruit after rainfall and improve fungicide penetration and coverage of the fruit. Removal of diseased clusters from the trellis can also be achieved at this time to prevent further spread. Larger row spacing can also promote faster drying.

Scouting for black rot can begin by observing for lesions on leaves and shoots shortly after shoot and leaf expansion in spring. Under warm conditions, leaf lesions may take only 10 days to appear; longer under more typical early spring temperatures. Only leaves infected during expansion will show symptoms. The Spott's infection model illustrates the combinations of leaf wetness and temperature needed for infection to occur. Pre-bloom leaf infections can indicate the degree of risk a grower faces during the fruit protection period, as leaf lesions can provide spores for infection of fruit during and after bloom and indicate the presence of an over-wintering source of inoculum in the trellis that can be removed before the fruit susceptibility period. A rough quantification of leaf lesion development in various parts of the vineyard may help a grower determine, well before bloom, that some areas need more attention than others. Start looking for leaf infections about 10-14 days after the first infection period after budburst, on leaves that were expanding during that infection period. Fruit infections can occur during bloom and anytime up to 4 (Concord) to 6 (vinifera) weeks after bloom. Fruit infections that take place during bloom through 3 weeks post-bloom can first become observable 10 days after the infection period, but may take another week or so to become fully manifest. Generally after that the incubation period (time from infection to manifestation) lengthens, the degree of which depends on temperature and other conditions not well understood. Periodic scouting can help a grower keep tabs on disease development, determine the need for protection and where failures in the control program occurred, and create a detailed disease history of the block for future reference.

Management with organic fungicides:

In conventional systems, fungicide applications at immediate pre bloom and 2 and 4 weeks post bloom, provide nearly complete control of black rot fruit infections in most years (Hoffman et al. 2004). Therefore, integrated management of black rot is often ignored in conventional viticulture, especially in juice grape production where economic returns may be lowest. For this reason, growers making the transition from conventional to organic management often find that black control has become their biggest, most unexpected, challenge. There are few fungicides available for control of this disease under organic management, and they provide modest control at best. Currently, copper fungicides provide the highest, most consistent level of control of this disease on fruit. Generally, the higher the rate and the shorter the spray interval (every 7 days rather than 10-14 days), the better the control, especially in wet years. However, the use of copper fungicides is 'restricted' in organic agriculture. Their use must be minimized and must be accompanied by other efforts to control the disease. Some grape varieties are injured by copper fungicides further restricting copper use. Copper sensitivity should be an important consideration when choosing what variety to grow organically.

Trials have shown that dormant and seasonal applications of lime sulfur may suppress black rot, especially at low disease pressure, but efficacy is not as good as copper. Also, lime sulfur may damage leaves of sulfur sensitive varieties. In a recent fungicide trial, Concord vines that received 5 applications of lime sulfur (0.5 %) during the fruit susceptibility stage, showed an increase in the loss of leaves along the oldest 4 nodes on shoots and an increase in damage (burning or bronzing of leaves) on remaining leaves along the oldest 6 nodes by late summer.

The application of cultural control can improve the effectiveness of chemical treatments. For example, in research plots where black rot infected mummies were hung in the trellis, five applications of Champion (copper hydroxide; 2 lb/A) + lime (4 lb/A) or lime sulfur (1 %) only suppressed black rot on fruit by 31 and 28 %, representing a 55-57 % crop loss. However, in subplots without mummies the efficacy of these spray programs improved dramatically: control with Champion + lime and lime sulfur jumped from 31 to 97 % and 28 to 71 %, respectively (a 0.4 and 4 % crop loss, respectively). Strict adherence to cultural disease management practices will increase production costs for organic producers but can lower disease pressure to levels more manageable with organic fungicides.

Shoot infections can contribute to crop loss (Becker and Pearson, 1996) and where effective fungicides are lacking, their role in epidemic development should not be overlooked. Infections that occur on the first few internodes of shoots cannot be completely removed from the trellis during pruning as they are the source of next year's crop. These infections become established during the early shoot growth period well before bloom and failure to control them with fungicides can help to maintain the pathogen in the trellis from year to year. Fruit are more difficult to protect than leaves and shoots. Whereas leaves and shoots may only be susceptible for a week, fruit are susceptible for several weeks. The most critical period for fruit protection is from immediately before bloom through 4 (Concord) to 6 (susceptible wine varieties) weeks post-bloom. Copper fungicides will provide the best control of black rot and should be used throughout most of this period, especially if conditions are wet. Concord fruit generally remain highly susceptible through 3 weeks post-bloom, after which they *gradually* develop resistance from 3 through 5 weeks after bloom. Some control of earlier (before immediate pre-bloom) cane and leaf infections may be achieved with lime sulfur (on varieties not sensitive to sulfur) in order to reduce the overall use of copper fungicides, while helping to reduce Phomopsis cane and leaf lesions (Becker and Pearson 1990-1993).

Downy Mildew, caused by a fungus-like organism *Plasmopara viticola*, affects all green tissues of the vine. On leaves, downy mildew appears as a yellowish 'oil spot' on the top of the leaf that coincides with a white, fluffy or downy patch of sporulation on the lower surface. Leaf symptoms may take 7-12 days to appear after infection has occurred, and young leaves are more susceptible than older leaves. P. viticola aggressively colonizes young, expanding grape tissue and once infected, whole shoots, clusters, and leaves may turn brown and die. Leaves that become infected while still expanding may become distorted and cupped and severe leaf infection can result in defoliation. Expanded leaves infected late in the season may not show the classic 'oil spot' symptom on top but rather a mosaic of yellow/orange/brown angular spots and blotches, often along leaf veins (Figure 2). On the underside of the leaf , downy white sporulation can be seen coinciding with spots and blotches above. On young shoots and clusters, early symptoms may first cause cluster rachises and shoots to thicken and curl (Figure 1). Following wet or dewy nights, downy sporulation on young infected tissues may be abundant and quite striking (Figure 1). Young infected organs are eventually destroyed. For example, young clusters of susceptible varieties like the French hybrid 'Chancellor' can be completely destroyed during the pre bloom and early post bloom stages. When berries are infected later in the season their development is hindered and they fail to soften at veraison, turning a pale mottled green (white varieties) to red or pink (red varieties, Figure 2). Inflorescences and fruit clusters are most susceptible from about 2 weeks pre bloom to about 2 weeks post bloom, but susceptible varieties will require protection through 3-4 weeks post bloom. Cluster stem tissue may remain susceptible until later in the season and pedicel infections can result in fruit loss. Young leaves and shoots are very susceptible, but become more resistant as they mature.

Fig.1 Infection of downy mildew on young cluster and shoot showing curling and thickening of diseased tissue (Chancellor). The white sporulation after a warm humid night can be striking.

Fig. 2 Berries of red varieties (Concord (left) and Chancellor (center) at harvest) often turn red or pink after infection and fail to soften and develop properly. Late season leaf infections are yellowish to reddish brown and appear angular or blocky.

<u>Disease Cycle</u>

Technically, *Plasmopara viticola* is not a fungus or a plant, but belongs to a group of organisms known as 'water molds'. As the name implies, this organism is very dependent on the presence of wet plant surfaces to carry on its parasitic lifestyle. Also, *P. viticola* can only grow and reproduce on living grape tissue. In order for it to survive through the dormant period of its host, it must go dormant itself, passing the winter as a tiny egg-like 'resting structure' called an oospore. Oospore development begins within infected plant tissue during the previous summer. As infected tissues die, they fall to the vineyard soil, where the oospores within survive the winter. In spring, at about the 5-6 leaf stage of grapevine development, rainfall periods with temperatures above about 52 F initiate germination of oospores, from which a sac-like sporangium filled with zoospores emerges. Sporangia or zoospores can be rain-splashed to susceptible green grape tissue. Splash dispersed sporangia then burst to release their zoospores. Zoospores 'swim' through the water film on wet plant surfaces, encyst or encapsulate within a membrane near stomata, and grow through the stomata to infect and colonize plant tissue. This is the primary infection cycle (Compendium of Grape Diseases. 1988). On leaves, colonized areas generally become visible in 7-12 days as yellowish 'oil spots' and spore producing structures begin to protrude through stomates on the underside of the leaf or on shoots and cluster tissue generating the 'downy' sporulation characteristic of the disease. The secondary spores from these colonies are produced at night under high (> 95 %) relative humidity and are dispersed by wind and rain to new susceptible tissue in the vineyard. Under adequate temperature and wetness duration, these spores will infect to begin the first of the secondary infection cycles that may occur throughout the summer. At optimum temperatures (upper 70s), this organism can complete its life cycle in as little as 4 days. Warm, wet conditions with humid nights can produce explosive development of this disease.

Disease Management

Resistance
Baco noir, Chelois, Concord, Foch, Diamond, and Steuben are only slightly susceptible to downy mildew. Chancellor grape has very susceptible clusters, but relatively resistant leaves, whereas Delaware has very susceptible leaves, but the clusters are only slightly susceptible.

Cultural Control
Soil cultivation during the dormant period or in early spring can help to bury over-wintering oospores in old leaves and clusters on the ground, reducing primary inoculum in spring. This may be particularly helpful if disease was severe the previous year. Because primary inoculum originates from the vineyard soil, the first infections in spring come from within the vineyard and often occur on shoots and sucker growth near or on the ground. Sucker growth originating from buds at or below the soil surface may emerge covered with sporulation of the pathogen (picture at right). These diseased shoots can serve as a launching pad for inoculum, and prompt elimination of this tissue can delay the occurrence of the first infections in the canopy. In conventional systems, removal of suckers is conveniently accomplished with herbicides. In organic systems, hand removal may be necessary.

Mulches may provide a physical barrier to primary inoculum in spring, and organic mulches may improve microbial break down and incorporation of infected plant tissues on the ground. However, in one study, a heavy fall application of compost stimulated the germination of grape seeds the following spring. Grape seedlings served as hosts of primary inoculum of downy mildew, and therefore sources of secondary inoculum for upper canopy infections. The stimulation of seedling growth by compost was not observed during the second spring after compost application. The use of mulches for downy mildew control requires further examination.

An open canopy, where fruit and other susceptible tissue dry out as quickly as possible after rainfall and dew will help minimize disease development. In the case of Concord (and other more susceptible natives like Niagara), where high wire cordon trellis is standard practice, canopy density can be managed by proper nitrogen fertilization and bud number. For wine grapes, trellis training systems and cultural practices like leaf removal and shoot thinning can hasten drying of developing fruit after rainfall and improve fungicide penetration and coverage of the fruit. Growers busy with a multitude of tasks in their vineyards in spring should observe their vine canopies for infection centers shortly after the 5-6 leaf stage. These initial infection centers in the canopy are often easy to spot, and should promptly be destroyed when they are discovered to prevent further spread. Trimming of young susceptible shoot tissue later in the season can help to reduce fuel for late summer epidemic development and improve fungicide penetration and aeration without adversely affecting fruit maturation. More open row spacing and a vineyard site with good air movement and soil drainage can also promote faster drying.

Management with organic fungicides
The first primary infections can occur (if its wet) when grapes average about 5-6 leaves per shoot, and fungicidal management of downy mildew should be initiated at this time. Years of experimentation in New York have shown that two pre bloom applications plus two post bloom applications (at 14 day intervals) of an effective, *conventional*, fungicide provide nearly complete control of downy mildew fruit infections (2006 New York and Pennsylvania Pest Management Guidelines for Grapes). Although there are few materials for downy mildew control in organic systems, copper fungicides are very effective. For example, in an evaluation of organic fungicides in Pennsylvania, copper hydroxide plus lime was applied as two pre bloom and three post bloom applications at 10 day intervals (covering roughly the same period as the New York conventional trials). This program provided nearly complete control (98 %) of downy mildew fruit infections under extremely high disease pressure on Niagara grape (Hed and Travis, 2006).

After the fruit susceptibility period, fungicidal protection should focus on preventing leaf infections. Late summer leaf infections can be very serious if they result in premature defoliation. Defoliated vines cannot ripen fruit or canes and are more sensitive to subsequent winter cold damage. However, excessive copper use should be avoided as copper is restricted in organic production and excessive use can damage vines. A combination of good control of the disease early in the season, the use of less susceptible varieties, and proper fertilization to limit late summer shoot growth (leaf and shoot susceptibility decrease with age) all help to reduce the need for late summer fungicide applications.

Phomopsis cane and leaf spot is caused by the fungus, *Phomopsis viticola*. As the name implies, symptoms of this disease are most often observed on shoots and leaves. However, this pathogen can also infect cluster rachises and developing fruit, and it is this phase of the disease that can cause far more serious damage to the crop with significant economic loss. This fungus becomes active very early in the season and typically infects new shoots, leaves, and clusters from bud break through the early post bloom period. Most lesions generally form on tissue closest to the vine, that is, the first few internodes, leaves, and clusters on shoots. Lesions on green shoots are dark in color, and elliptical in shape. As infected shoot tissue dies and stops growing, a split may occur within the lesion as the girth of the growing shoot expands. Where numerous lesions are concentrated, such as at the base of the oldest internodes, they result in larger scabby areas that weaken the shoot (Figure 1). Green shoots that are severely infected are more apt to break under windy conditions (2006 New York and Pennsylvania Pest Management Guidelines for Grapes). Leaf infections appear as pinhead sized black spots surrounded by a yellow halo (Figure 2). These tiny lesions are easily visible if the leaf is viewed against the sky. These infections often appear to be of little consequence, other than revealing the presence of the pathogen. However, when numerous leaf spots become concentrated, they can coalesce and distort leaves (infected tissue fails to expand with the rest of the leaf) or cause large areas of the leaf to turn brown and die (Figure 2). Lesions on cluster stems are black and sunken, and can girdle parts of the cluster rachis causing the cluster or parts of the cluster to break off or shrivel. Cluster stem infections can also creep into berries later adding to losses from fruit rot (Compendium of Grape Diseases. 1988).

Fig. 1 Numerous lesions concentrated at the base of the oldest internodes result in larger scabby areas that weaken the shoot.

Fig. 2 Leaf infections of Phomopsis cane and leaf spot on Concord grape.

When berries are infected, they can remain symptomless until ripening when they turn brown and become studded with small pimple-like fruiting structures of the fungus (Figure 3). As with black rot, these berries shrivel, become mummified, and serve as a source of inoculum the following year if left in the trellis.

Fig. 3 Phomopsis fruit rot on ripe Vignoles and Niagara grapes.

There are a couple of points worth mentioning here regarding the differences between black rot and Phomopsis symptom expression. First, timing of fruit rot symptoms: even though initial fruit infection by both pathogens can occur during the same peak susceptibility period (bloom through 3-4 weeks after bloom), black rot fruit rot symptoms become observable while berries are still green and are generally "done" by veraison, whereas Phomopsis fruit infections can lay dormant or 'latent' until after ripening and symptoms generally develop during the ripening period. Second, leaf symptoms of these two diseases (although less important economically) are very different from each other and can be used to determine which pathogen(s) are present and most likely to have caused disease on nearby clusters, although this is not always reliable.

<u>Disease Cycle</u>

Phomopsis viticola over-winters in lesions on infected living and dead grape wood, cluster stems, and canes. Studies in New York have shown that this fungus can actually produce far more inoculum from older, dead wood left in the trellis. During spring rains, spores of the fungus ooze from wood infected during previous seasons and are splashed or drip down onto green shoots and clusters below. Symptoms can appear in 2-4 weeks and often reveal the source of inoculum. Infections can take place at very low temperatures (45-50 F) under prolonged periods of rainfall from bud break on. Clusters may need protection from the time they emerge (shortly after bud break) until about pea-size berries when inoculum sources generally run dry. Shoot and leaf infections are generally a concern only during early growth (pre-bloom) stages.

<u>Disease Management</u>

Resistance: Baco noir, Cayuga white, Elvira, GR7, and Vidal are most resistant to Phomopsis.

Cultural Control

Phomopsis can grow and sporulate well on dead grape wood, making it more difficult to control in hedged vineyards that leave an abundance of such material in the trellis (Pscheidt and Pearson, 1989). Methods that reduce the substrate or “food” available for this fungus to grow and reproduce will help to reduce its presence in the vineyard. Hand pruning to remove all dead wood from the trellis removes much of the over-wintering inoculum. When hand pruning, do not leave large stubs. Pruning stubs die and provide more substrate for the pathogen.

Choice of trellis system can have an effect on the reservoir of over-wintering inoculum. A cane pruning trellis system that limits older wood can reduce the disease compared to a double cordon system that retains a maximum amount of older wood. Trellis systems that train shoots upward reduce opportunities for infections on the oldest shoot internodes and clusters. As with other diseases, an open canopy, where fruit and other susceptible tissue dry out as quickly as possible after rainfall will help minimize disease development. For wine grapes, trellis training systems and cultural practices like leaf removal and shoot thinning can hasten drying after rainfall and improve fungicide penetration and coverage. More open row spacing can also promote faster drying.

Soil cultivation during the dormant period or in early spring can help to bury over-wintering inoculum from infected debris dropped to the ground. Large older pieces of wood pruned from the vine should be removed from the vineyard and buried or burned.

Management with organic fungicides

Phomopsis management with fungicides should be initiated early in the growing season when shoots, leaves, and clusters on the first few inches of growth are susceptible. Fungicides should first be applied to protect the initial appearance of inflorescences just after bud break and continue until berries are pea-sized (about 7-8 mm in diameter). Although fruit remain susceptible throughout the growing season, inoculum of the fungus is generally spent within 2-3 weeks after bloom (2006 New York and Pennsylvania Pest Management Guidelines for Grapes). Copper and lime sulfur are currently the most effective Phomopsis fungicides available to organic producers. Because these materials can injure green tissue, trials have been conducted by various universities to examine the efficacy of dormant applications (just before bud break) of copper and lime sulfur. After bud break, lime sulfur can be applied as a more dilute solution (read the label) to provide significant control of early shoot, leaf, and rachis infections before bloom. This also helps to control early black rot and powdery mildew infections, limiting copper use to the more critical fruit infection period from bloom through 3-4 weeks post bloom.

Powdery Mildew, caused by the fungus *Uncinula necator*, affects all green tissues of the vine. Infection on leaves appears mainly on the upper surface as white, powdery patches. But powdery mildew colonies can also appear (although less commonly) on the lower surface of leaves, becoming confused with downy mildew. As the leaf surface becomes covered with the fungus, leaf function is impaired. Infection by *U. necator* can stunt growth of new tissues and severe infection of young expanding leaves often results in cupping and distortion of leaves. When grape cluster stems become covered with the fungus, the stems can shrivel and considerable losses from shelling of the fruit may occur in susceptible wine varieties. Cluster infections around bloom may lead to poor fruit set, while slightly later infection can cause berry splitting. Fruit infection may also reduce wine quality on varieties intended for that use.

Fig. 1 Powdery mildew on 'Concord' berries.

Disease Cycle

Much like the downy mildew pathogen, *Uncinula necator* can only grow and reproduce on living grape tissue. To survive through the dormant period of its grape host, it too must go dormant, passing the winter as a 'resting structure' called a cleistothecium. Cleistothecia actually begin developing within mildew colonies throughout the previous summer. They start out as light, circular, pin point sized structures that gradually become black (melanized) by late summer/autumn. Cleistothecia are covered with long appendages, and when rain-washed from infected leaves, shoots and fruit clusters, they become trapped in protective bark crevices on the vine trunk and arms, where they spend the winter. Spores (ascospores) develop within the cleistothecia that are capable of infecting new grape tissue the following spring. Starting at about bud break until just after bloom, periods of rainfall of about 0.1 inch or more cause the cleistothecia to swell and split resulting in the release of the ascospores. The ascospores are dispersed to susceptible grape tissue by air currents and can infect tissues that are wet or dry, when temperatures are at 50 F or higher (primary infections) (2006 New York and Pennsylvania

Pest Management Guidelines for Grapes). The number of these 'infection periods' before bloom may serve as an indicator of the severity of disease pressure and the need for protection of fruit during the critical fruit susceptibility period. Germinating ascospores develop into mats of fungal tissue that spread over the surface of the plant, sending down feeding structures into the epidermis of the plant to extract water and nutrients and sending up tiny stalks on which egg shaped secondary spores called conidia develop. As the microscopic colony grows, it eventually becomes visible to the naked eye as a white/grayish patch on the plant surface. The conidia are wind-dispersed and do not require rain for release or infection. As each conidium disperses to and infects new grape tissue, it develops into another colony that produces more conidia to spread the disease. Under optimum weather conditions (temperatures in the mid 60s to mid 80s F) this cycle of infection, spore production, spore dispersal, and re-infection can occur in just 5 to 7 days. Note that optimum temperatures are the norm through most of the summer in Pennsylvania and New York and that starting around bloom, nearly every day is an infection period. This enables powdery mildew to explode to epidemic proportions quickly unless early disease development is controlled.

Disease Management

Resistance: Cayuga White, Ives, Steuben, and Traminette are all listed as only slightly susceptible to powdery mildew. In general, native varieties are less susceptible or more tolerant than French hybrids. Varieties of *Vitis vinifera* are most susceptible.

Cultural control
There are several cultural considerations that can reduce opportunities for powdery mildew disease development. Most involve limiting humidity and promoting sun exposure of all parts of the vine. For example, planting in sites with good air circulation and sun exposure and use of a training system that improves air movement through the canopy, prevents excess shading and promotes fungicide penetration to the cluster zone and will reduce powdery mildew development. Young grape tissues are more susceptible than older tissues. Proper nutrient management, particularly nitrogen, can limit shoot growth and excessive canopy shading, thereby discouraging mildew growth. Good weed control can also minimize humidity levels that contribute to mildew development.

Management with organic fungicides
On highly susceptible *vinifera* and hybrid wine grapes, fungicides may be needed during early shoot growth stages, especially if disease was heavy the previous year. For Concord and other less susceptible varieties, protection may not be needed until around 10 inches of shoot growth or the immediate pre bloom period. Studies in New York have demonstrated that berries are highly susceptible to infection from the immediate pre-bloom stage until about 2-3 weeks after fruit set, and efforts to protect fruit with fungicides should concentrate on this critical period with timely applications at 7-14 day intervals. Berries of Concord grape become resistant to infection after this time, but French hybrid and *V. vinifera* fruit may require protection through bunch closure (2006 New York and Pennsylvania Pest Management Guidelines for Grapes). Infection that takes place during this period of high susceptibility can lead to splitting of berries as they expand later in the season. This greatly increases the susceptibility of clusters to insect invasion and bunch rot during ripening. Rachises and leaves remain susceptible until harvest. Their need for protection depends on varietal susceptibility, crop size, and weather. After the fruit susceptibility period, further management of leaf and rachis infections may not be necessary on Concord and

other related juice varieties unless vines are heavily cropped or ripening conditions are poor. On the other hand, minimizing summer leaf disease will reduce the over-wintering population of cleistothecia that initiate disease cycles the following spring. This may be a more critical consideration in organic systems than in conventional vineyards. *V. vinifera* and susceptible hybrids, may require management of foliar mildew until veraison or beyond.

Fortunately, there are several tested options available to growers of organic grapes for powdery mildew control. However, the most effective ones must be used with caution. Sulfur and lime sulfur fungicides are very effective against powdery mildew at 7-14 day intervals, but their use is limited to sulfur tolerant varieties and application under slow drying or excessively hot conditions can exacerbate phytotoxicity. Seasonal sprays of petroleum based oils like JMS Stylet-oil and PureSpray Organic are also very effective at 1.5 % solution. However, several experiments have shown that oil applications can reduce leaf photosynthesis, and excessive use late in the season may limit sugar accumulation and fruit maturity. Oils should not be tank mixed with sulfur or applied within 14 days of a sulfur containing fungicide application. Copper, is only moderately effective on powdery mildew, but is necessary through the fruit susceptibility period for its control of other grape diseases especially on varieties susceptible to black rot and downy mildew. Copper fungicides are generally applied with lime to limit solubility and reduce the risk of phytotoxicity (read the label). Avoid applying copper under slow drying conditions. Copper may be tank mixed with some other fungicides to improve powdery mildew control during the critical fruit protection period (read the label for compatibility), particularly if susceptible vinifera and hybrids are grown. Other materials include potassium bicarbonates such as Kaligreen, Armicarb O, and Milstop and the biological Serenade. These materials generally produce modest results, and must be applied at short intervals (7 days) to achieve satisfactory control on susceptible varieties. They may be best applied outside the critical fruit protection period (during the early season when disease pressure is low or after the fruit protection period to control leaf infections) and in rotation with other more effective materials rather than alone season long.

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