Disease Management
Fungal & Bacterial Diseases

At a Glance: Alternaria Cone Disorder

◆ Symptoms are easily confused with powdery and/or downy mildew.

◆ Confirm cone browning is caused by Alternaria cone disorder before implementing any control measures.

◆ Promote air circulation in the canopy.

◆ Time irrigations to reduce periods of wetness on cones.

◆ Some powdery and downy mildew fungicides likely provide some suppression of Alternaria cone disorder when applied later in the season.

Alternaria Cone Disorder

David H. Gent

Alternaria cone disorder is reported to be caused by the fungus *Alternaria alternata*. This organism is widespread in hop yards and other agricultural systems worldwide. Strains of the fungus are known to attack apple, potato, sunflower, wheat, and many other hosts.

While the fungus is widespread, its disease is not known to be associated with direct hop yield losses in the United Kingdom or Australia. Alternaria cone disorder is thought to be of minor importance in Pacific Northwest hop, occasionally reducing crop quality. However, cone browning incited by powdery mildew is commonly misdiagnosed as Alternaria cone disorder.

Symptoms

Alternaria cone disorder symptoms vary depending on the degree of mechanical injury to cones; they may be limited to one or a few bracts and bracteoles or in severe cases entire cones may become discolored. Symptoms appear first on the tips of bracteoles as a light, reddish-brown discoloration (Fig. 2). Bracts may remain green, which gives cones a striped appearance. When cones have been damaged by wind, disease symptoms may appear on both bracteoles and bracts as a more generalized browning that can cover entire cones (Fig. 3). The disease can progress rapidly; the killed tissue becomes dark brown and is easily confused with damage caused by powdery or downy mildew. Affected bracts and bracteoles may display a slight distortion or shriveling of the diseased tissues.

Alternaria alternata can be found even on healthy cones and it is easy to confuse late-season damage from powdery mildew with Alternaria cone disorder. *Alternaria alternata* is one of the most common fungi found on decaying organic matter and in the air of hop yards. Recovery of the fungus from discolored cones does not prove that it was the primary cause of cone discoloration. Because the powdery mildew (and downy mildew) pathogens cannot be cultured on artificial media, methods used to recover *A. alternata* will not detect the powdery mildew fungus.

Figure 2. Reddish-brown discoloration of the tips of bracts and bracteoles of a cone affected by Alternaria cone disorder. (D.H. Gent)

Figure 3. Discoloration of cones affected by Alternaria cone disorder. (S.J. Pethybridge)

Disease Cycle

Alternaria alternata generally is a weak pathogen that invades wounds created by insect feeding, mechanical injury, or lesions created by other pathogens. Some strains of the fungus may survive as a decay organism on textiles, dead plants, leather, or other organic materials. On hop, Alternaria cone disorder is primarily a disease of cones damaged by mechanical injury. In the United Kingdom, the disease is reported to occur most commonly on late-maturing varieties exposed to wind injury, humid conditions, and extended periods of wetness on cones. The pathogen may survive between seasons on decaying plant material, organic matter, and/or as a weak pathogen on other plants.

The severity of powdery mildew has a direct association with the frequency of recovery of *A. alternata* from hop cones. Cones infected with the powdery mildew fungus during bloom and early stages of cone development are the most likely to have *Alternaria* species associated with them at harvest (Fig. 4). It is well known that powdery mildew can cause discoloration and damage to hop cones, but is unclear to what degree secondary infection by *A. alternata* increases this damage.

Management

Management of Alternaria cone disorder requires accurate diagnosis of the disease. Simply recovering the fungus from discolored cones does not necessarily indicate that it was the cause of the browning since the pathogen is found on healthy cones as well. Adequate control of powdery mildew will reduce cone discoloration that often is attributed to Alternaria cone disorder.

The disease can be minimized by reducing damage to burrs and cones caused by wind abrasion, by arthropod pests, and by other pathogens; promoting air circulation in the canopy; and timing irrigations to reduce periods of wetness on cones. No fungicides are registered for control of Alternaria cone disorder. However, certain fungicides such as trifloxystrobin (Flint) and boscalid plus pyraclostrobin (Pristine) applied for control of powdery and downy mildew likely provide some suppression of Alternaria cone disorder when applied later in the season.

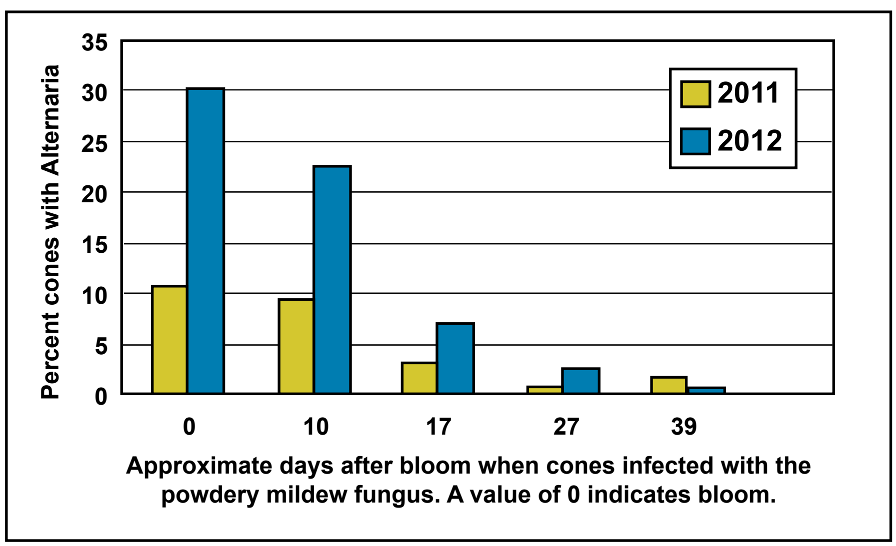


Figure 4. Association between stage when cones were infected with powdery mildew fungus and percent of cones with an *Alternaria* species at harvest in 2011 and 2012.

***At a Glance:* Black Root Rot**

◆ Plant resistant varieties when possible.

◆ Avoid poorly drained fields and excessive irrigation.

◆ Avoid damaging roots during cultivation.

◆ Phosphorous acid fungicides and various Ridomil formulations may provide some control.

Black Root Rot

Frank S. Hay and David H. Gent

The fungus-like organism *Phytophthora citricola* causes a crown-and-root rot of hop referred to as black root rot. The disease tends to be most damaging to hop plants in poorly drained soils and areas with high water tables. Certain Cluster varieties such as Cluster types E-2 and L-8 are particularly susceptible. The pathogen has a relatively broad host range that includes cherry, fir trees, raspberry, strawberry, and walnut.

Symptoms

Infected roots and crowns have a characteristic water-soaked and blackened appearance with a distinct boundary between diseased and healthy tissue (Fig. 5). Infection can spread from the crown for several inches up the base of the bine. In severe cases, leaves become yellow and bines wilt rapidly during warm weather or when plants become moisture-stressed. Young plants irrigated too heavily to encourage production in the first year can wilt later in the season as a result of black root rot. As the disease progresses, leaves turn black and remain attached to the bine. Severely infected plants are weakened and may die during winter or the following spring. Affected plants often are found in areas of hop yards with poor drainage. Wilting symptoms caused by black root rot can be mistaken for Verticillium wilt, Fusarium canker, or damage caused by California prionus beetle.

Disease Cycle

The black root rot pathogen survives in soil as dormant sexual spores (oospores), which can survive 18 months or longer. In the presence of free water and host roots, oospores or the asexual spores (sporangia) germinate and infect the plant directly or may release motile spores (zoospores) that are attracted to compounds released from host roots (e.g., ethanol and certain amino acids and sugars). The motile zoospores settle on roots and later produce mycelia that infect and grow through the host tissues.

Management

Avoid establishing hop yards in areas with poor water drainage, especially with highly susceptible varieties such as Cluster types E-2 and L-8. Cluster L-1 and Galena are considered partially resistant, while Brewer's Gold, Bullion, Cascade, Columbia, Comet, Eroica, Fuggle, Hallertau, Nugget, Olympic, Tettnanger, and Willamette reportedly are highly resistant to black root rot. Reducing cultivation and avoiding injury to crowns and roots can provide some reduction in disease since infection is favored by wounds. Certain phosphorous acid fungicides are registered for control of black root rot, but their efficacy has not been reported. Phenylamide fungicides (i.e., various formulations of Ridomil) applied for control of downy mildew may provide some control, although these products are not registered specifically for control of black root rot.

Figure 5. Extensive black discoloration caused by black root rot. Notice the distinct margin between healthy tissue and the black, diseased tissue. (R.A. Beatson)

Downy Mildew

David H. Gent, Dennis A. Johnson, Amanda J. Gevens, and Mary K. Hausbeck

Downy mildew is caused by the fungus-like organism *Pseudoperonospora humuli.* It is one of the most important diseases of hop in wet, humid production regions. Yield and quality losses from downy mildew vary depending on susceptibility of the variety, timing of infection, and weather conditions. Crop damage may range from non-detectable to 100% if significant cone infection or plant death from crown rot occurs.

Figure 6. Downy mildew "spikes" emerging in early spring. Note pale yellow color and down-curled leaves. (D.H. Gent)

Figure 7. Characteristic yellowing on young leaves of a shoot recently infected by the downy mildew pathogen. (D.H. Gent)

Symptoms

The disease first appears in spring on newly emerged, systemically infected shoots that are called "basal spikes" because of their resemblance to wheat spikes. Basal spikes are stunted and have brittle, downward-curled leaves (Fig. 6). A distinctive yellowing beginning at the center of affected leaves may be present on newly infected shoots (Fig. 7). A diagnostic characteristic of downy mildew is the presence of spores (sporangia) that appear purple to black in color and develop on the undersides of infected leaves (Fig. 8). After training, the main bines and lateral branches may also become infected, arresting the development of these shoots and leading to "aerial spikes" (Fig. 9). Typically, branches that become infected just as they begin to develop quickly desiccate and can be difficult to diagnose as downy mildew (Fig. 10). Infection of trained bines results in a cessation of growth, causing bines to fall from the string. These infected bines must be manually removed and healthy shoots retrained in their place. This often leads to yield loss because the optimal timing for training could have been missed and infected plant parts divert water and nutrients away from healthier, productive tissues.

Figure 8. Profuse sporulation on the underside of a hop leaf with downy mildew appears dark purple to black. (D.H. Gent)

Figure 9. Infection of shoots after training, a so-called "aerial spike." Notice the yellowing, stunting, and downward curling of leaves. (D.H. Gent)

Figure 10. Emerging lateral branch with downy mildew. (D.H. Gent)

At a Glance:
Downy Mildew

◆ Select the most resistant variety that is available for the intended market.

◆ Establish hop yards with disease-free planting materials.

◆ Thoroughly remove all foliage during spring pruning in regions where the growing season permits.

◆ Prune yards as late as possible without adversely affecting yield.

◆ Strip lower leaves from bines after training; remove basal foliage in mature yards.

◆ Manage the canopy to improve air flow and reduce humidity and wetness.

◆ Apply appropriate fungicides during the first year of production and when weather favors the disease.

◆ Rotate and tank-mix fungicide modes of action to delay development of resistance.

Downy Mildew Symptoms, cont.

Angular, vein-delimited lesions commonly occur on leaves next to spikes and are typically scattered on lower leaves (Fig. 11). Leaf lesions tend to be short-lived and desiccate in warm, dry weather, resulting in brown areas of dead tissue (Fig. 12).

Infected burrs turn dark brown, shrivel, dry up, and may fall from the plant. Infected cones become dark brown, harden, and cease development. Bracteoles of affected cones tend to become discolored more readily than bracts, and affected cones may develop a striped appearance. Under high disease pressure entire cones may become dark brown (Fig. 13). Infected cones may support sporulation on the underside of bracts and bracteoles, which is diagnostic for downy mildew when present, but is not always present on infected cones. The most severe yield damage results when infection occurs during bloom or the early stages of cone development.

Reddish-brown to black flecks and streaks are apparent in infected roots and crowns when roots are cut open (Fig. 14). The crown may be completely rotted in varieties susceptible to crown rot, such as Cluster varieties and Columbus.

Figure 11. Angular leaf lesions on hop leaves. The black discoloration is sporulation by the pathogen. (D.H. Gent)

Figure 12. Dry, angular leaf lesions caused by downy mildew. (D.M. Gadoury)

Figure 13. Dark brown discoloration of bracts and bracteoles on cones with severe downy mildew. (B. Engelhard)

Figure 14. Left, dark discoloration of rhizomes infected with *Pseudoperonospora humuli*. Right, healthy rhizome. (C.B. Skotland)

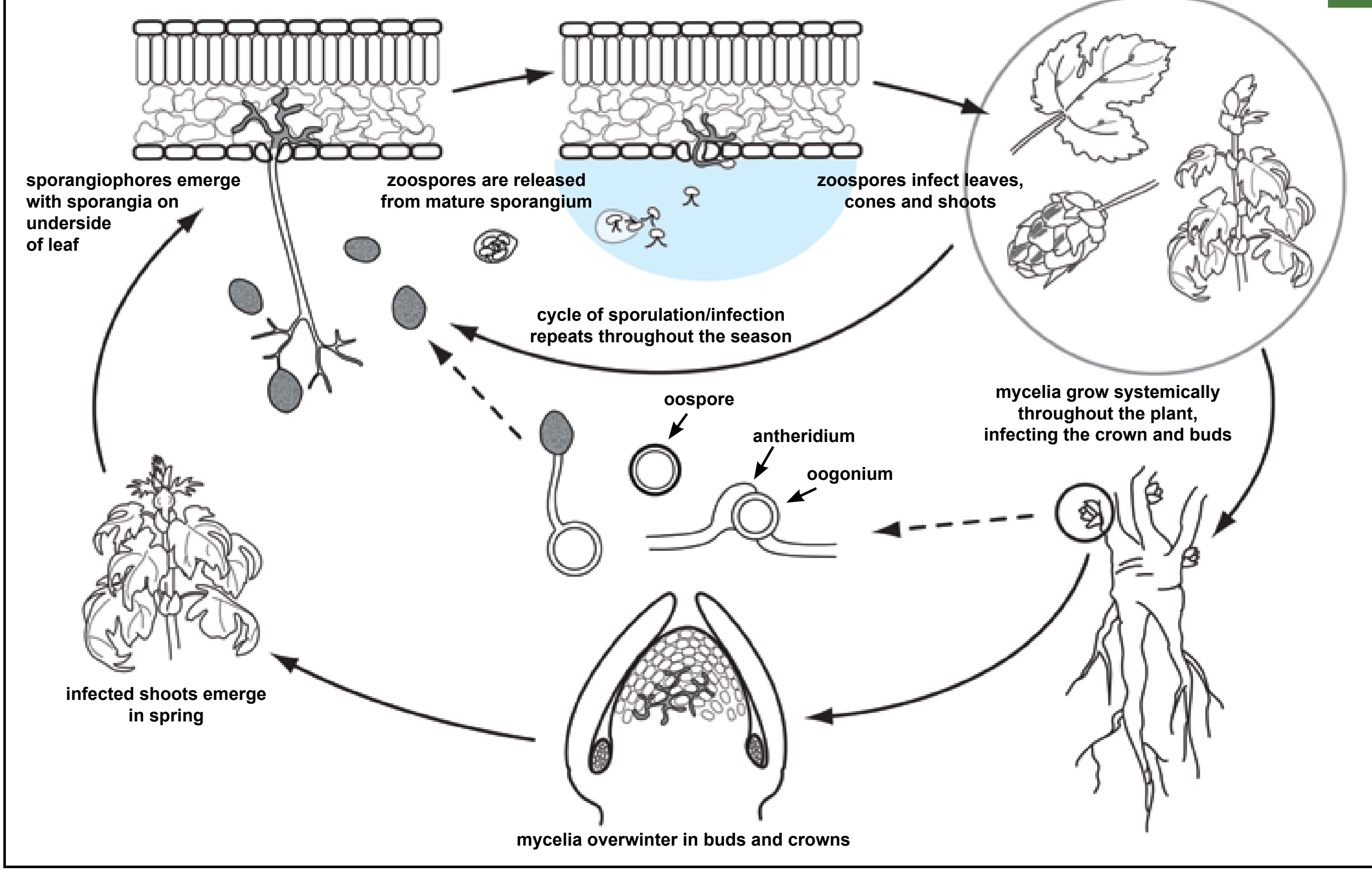


Figure 15. The life cycle of *Pseudoperonospora humuli* on hop. (Prepared by V. Brewster)

Disease Cycle

The downy mildew pathogen overwinters in infected dormant buds and crowns (Fig. 15). It spreads into developing buds during the winter and early spring, and some infected buds give rise to basal spikes when shoots emerge in the spring. The emergence of basal spikes is closely linked to plant growth and can be predicted using simple degree-day models. Sexual spores of the pathogen, termed oospores, are produced copiously in diseased tissue but their role in the disease cycle is unclear.

The pathogen sporulates profusely on infected tissues when nighttime temperatures are greater than approximately 43°F and relative humidity in a hop yard is greater than 90%. Sporangia are released daily in a cyclical pattern and are readily dispersed by air currents. Sporangia germinate indirectly to produce swimming zoospores when the temperature is favorable and free water is present. The most severe disease outbreaks often are linked to daytime rain because zoospores enter hop tissues through open stomata. Infection is favored by mild to warm temperatures (60 to 70°F) when free moisture is present for at least 1.5 hours, although leaf infection can occur at temperatures as low as 41°F when leaf wetness persists for 24 hours or longer. Shoot infection requires at least three hours of wetness.

Infection of shoots by the downy mildew pathogen can become systemic, producing spikes on previously healthy shoots and lateral branches. These infections produce sporangia that perpetuate the disease cycle. When shoots near the crown (approximately 6 inches in height or less) become infected, mycelia can progress through the shoot and invade the crown. Crown infection also may occur via infection at the base of stems. Some varieties may support chronic infection. A severe downy mildew outbreak in one year tends to lead to earlier and more severe outbreaks in the following season because of systemic infection of rhizomes and crown tissues. Carbohydrate reserves are reduced in systemically infected plants, resulting in progressive weakening of the plant over time that reduces yield and may lead to plant death.

A study in Europe indicated the potential for the hop downy mildew pathogen to infect certain cucurbit crops and the cucurbit downy mildew pathogen to infect hop. However, studies with strains of the pathogens from the U.S. indicate this rarely occurs or is insignificant. Genetic evidence does not support cross-infection of hop and cucurbits in the field.

Table 3. Disease Susceptibility and Chemical Characteristics of the Primary Public Hop Varieties Grown in the U.S.

Variety	Usage	Disease Susceptibility*		
		Powdery Mildew	Downy Mildew	Verticillium Wilt
Brewer's Gold	Bittering	S	S	MR
Bullion	Bittering	S	S	R
Cascade	Aroma	R/MS	S	MR
Centennial	Bittering	MS	S	U
Chinook	Bittering	S	S	R
Columbia	Aroma	MS	MR	S
Comet	Bittering	R	S	R
Crystal	Aroma	R	S	R
East Kent Golding	Aroma	S	S	MR
Fuggle	Aroma	MR	MR	S
Galena	Bittering	S	S	R
Glacier	Aroma	S	S	U
Hall. Gold	Aroma	MS	R	S
Hall. Magnum	Bittering	S	R	MR
Hall. Mittelfrüh	Aroma	MS	S	S
Hall. Tradition	Aroma	MR	R	MR
Horizon	Bittering	MS	S	MR
Late Cluster	Aroma	S	S	R
Liberty	Aroma	MS	S	U
Mt. Hood	Aroma	MS/R	S	S
Newport	Bittering	MR/R	R	U
Northern Brewer	Bittering	S	S	R
Nugget	Bittering	S/MS/R	S	S
Olympic	Bittering	S	MS	R
Perle	Aroma	S	R	MR
Saazer	Aroma	S	MS	S
Saazer 36	Aroma	S	MS	S
Spalter	Aroma	S	R	MR
Sterling	Aroma	S	MR	U
Teamaker	Aroma	MR	MR	S
Tolhurst	Aroma	S	S	U
TriplePearl	Aroma	S/R	S	U
U.S. Tettnanger	Aroma	S	MR	S
Vanguard	Aroma	S	S	U
Willamette	Aroma	S	MR	S

* Disease susceptibility ratings are based on greenhouse and field observations in experimental plots and commercial yards in the Pacific Northwest as of 2015. Disease reactions may vary depending on the strain of the pathogen present in some locations, environmental conditions, and other factors, and should be considered approximate. S = susceptible; MS = moderately susceptible; MR = moderately resistant; R = resistant; U = unknown. For powdery mildew, some cultivars have multiple susceptibility ratings that reflect their potential reaction based on region and whether virulent strains of the powdery mildew fungus occur.

Management

No single management tactic provides satisfactory control of downy mildew. Strict attention to cultural practices, prudent irrigation management, and timely fungicide applications are needed to manage the disease successfully. Varieties vary widely in their susceptibility to downy mildew (Table 3), although no variety is completely immune. When possible, select the most resistant variety that is available for the intended market especially for use in areas with known downy mildew pressure (e.g., next to rivers or in low-lying areas with cool air pooling). The best resistance to downy mildew is found in European varieties such as Magnum, Perle, Orion, and Wye Challenger. Varieties derived from North American germplasms such as Cascade, Centennial, Chinook, Columbus, and Nugget, and many others that are popular with craft brewers, tend to be among the most susceptible to the disease.

Healthy rhizomes and softwood cuttings should be selected when establishing new hop yards since planting material may harbor the pathogen. In well-established yards, thorough removal of all foliage during spring pruning substantially reduces later disease development (Figs. 16 and 17). Pruning yards as late as possible and removing all green tissue generally reduces the severity of downy mildew (Fig. 18). Timing of pruning needs to be balanced with the optimal training timing for maximizing yield. In regions with short growing seasons, such as parts of the Upper Midwest, delayed pruning may not be possible without reducing yield.

Implementing tactics to reduce the relative humidity in a hop yard can decrease disease. Improving air flow, stripping leaves from bines after training, removing basal foliage, cultivating the soil, and minimizing weeds may reduce disease spread (Fig. 19). Stripping of leaves is not recommended in the planting year, and in areas where plant establishment is slow, basal foliage removal should be minimal even in the second year after planting. Decisions on stripping foliage and the extent of basal foliage removal also depend on the severity of downy mildew, presence of powdery mildew, and weeds. The presence of spider mites should also be considered since late-season basal foliage removal can stimulate mites to move up the

Figure 16. Examples of hop plants pruned thoroughly mechanically (A) or chemically by using a desiccant herbicide (C) in early spring. Notice in A and C that all shoots on the sides of the hills have been removed. Incomplete mechanical (B) or chemical (D) pruning can result in more severe outbreaks of both downy mildew and powdery mildew. (D.H. Gent)

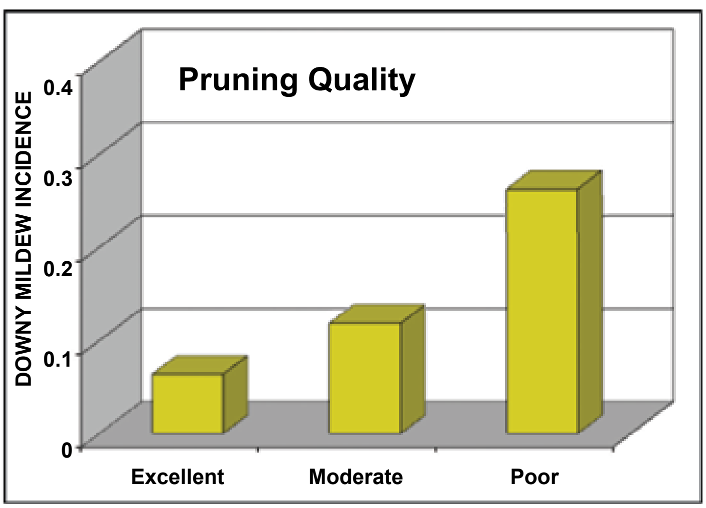


Figure 17. Association of spring pruning quality to the incidence of plants with downy mildew in 110 commercial hop yards in Oregon during 2005 to 2010. Excellent = No foliage or green stems remaining after pruning, Moderate = Foliage or green stems on some hills after pruning, and Poor = No pruning was conducted or foliage and green stems were present on all hills after pruning.

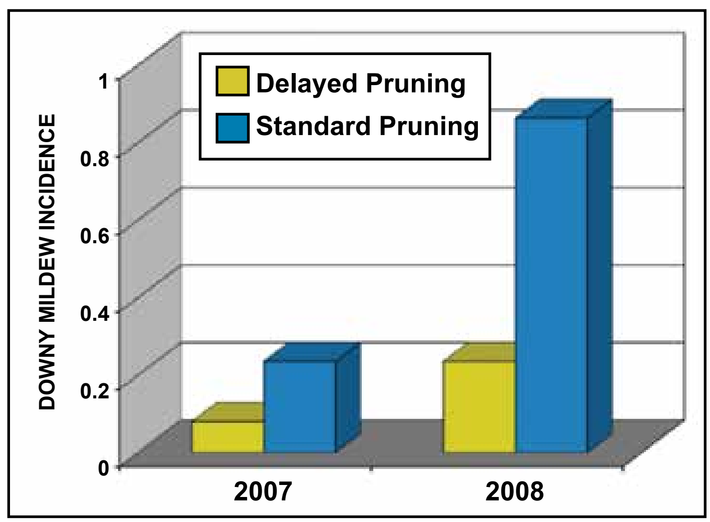


Figure 18. Association of spring pruning timing to the incidence of plants with downy mildew in 6 commercial yards of Willamette in Oregon. Hop yards that received the delayed pruning treatment were chemically pruned 10 to 14 days later than the growers' standard pruning timing.

Downy Mildew Considerations for Production Regions Outside of the Pacific Northwest

Environmental conditions differ significantly in hop production regions outside of the Pacific Northwest. For this reason, several components of the integrated disease management approach adopted by western states are in need of further validation in other regions. While pruning early hop growth to limit downy mildew provides a sound approach for limiting inoculum in the yard, the shorter production season in the Upper Midwest and other regions may be insufficient for adequate development of the crop if this technique is employed. Because many hop yards outside the Pacific Northwest are relatively new, downy mildew is not yet a major problem in every yard. Growers are encouraged to seek out planting material that has been tested for important pathogens. Preventive fungicides, including phosphonates, coppers, and downy mildew-specific active ingredients, are commonly used in Wisconsin and other areas in the Midwest and eastern U.S.

Figure 19. Example of stripping of lower leaves to aid in disease management (D.H. Gent)

plant. In wet environments, cover crops present during the growing season tend to create conditions which increase downy mildew, especially when not mowed or planted close to the hop row. Soil cultivation in general tends to reduce downy mildew.

In situations where downy mildew has developed late in the season, yards can be harvested early to minimize cone infection. However, yields can be reduced in both current and subsequent seasons when plants are harvested too early.

Timely fungicide applications are needed to manage downy mildew when weather is favorable to the pathogen. Fungicide applications made during the establishment year may be beneficial to help minimize crown infection and reduce disease levels in subsequent seasons. Under high disease pressure in western

Table 4. Approximate Period of Protection for Selected Downy Mildew Fungicides

Fungicide	Protection	Kickback	Notes
Aliette/ phosphonates	4-5 days	5-7 days	Heavily influenced by sensitivity of strains; kickback may only be suppression of sporulation.
Copper	5-7 days	None	Repeated application over many years may result in copper accumulation in soils. Some formulations may be allowable for use in organic systems.
Curzate	3 days	2 days	Active ingredient is unstable at high pH; avoid tank mixes with products that increase pH (e.g., bicarbonates).
Flint/Pristine	3-5 days	6 hours	Pristine also contains boscalid, a fungicide with good activity against powdery mildew. Pristine provides some suppression of hop looper when applied late in the season.
Forum/Revus	7 days	1-2 days	Post-infection activity for leaf infection is more pronounced than for shoot infection.
Tanos	5-7 days	2 days	Premix of two fungicides, including the active ingredient in Curzate.

Data are derived from greenhouse and field experiments in Oregon and literature for related diseases. Efficacy of any fungicide is heavily influenced by use history of a compound and sensitivity of the pathogen population. Data are approximate; actual performance is determined by weather, plant growth rate, disease pressure, and other factors. Avoid post-infection sprays whenever possible.

Oregon, a fungicide applied just after the first spike emerges and before spring pruning can provide substantial control of downy mildew later in the season. This can be timed using degree-days. Degree-day models are currently under evaluation for use in other production regions. Later fungicide applications should be timed to coincide with major infection events; several disease risk indexes are available as decision aids. Most fungicides have only limited activity after infection (Table 4) and should be applied preventively whenever possible; timing of fungicide applications is critical (Fig. 20).

The downy mildew pathogen has a high potential for developing resistance to certain fungicides. Strict adherence to resistance management tactics is essential to delay the development of resistance. Resistance to phenylamide fungicides (e.g., various Ridomil formulations) and fosetyl-Al (Aliette WDG) is common in the Pacific Northwest. Phenylamide fungicides should not be used where resistant populations have been detected, since resistance to this class of fungicides appears to persist for many years (>15 years) in the pathogen population. Where phosphonate fungicides such as fosetyl-Al have been used extensively, resistance to low rates (e.g., 2.5 pounds Aliette WDG per acre) of these products is likely to occur. High rates of phosphonate fungicides, more frequent applications, and tank-mixes with other fungicides are needed where this resistance is present. Phytotoxicity may occur on some varieties treated with high rates of phosphonate fungicides. Strobilurin fungicides (e.g., Flint and Pristine) applied for management of powdery mildew can provide suppression of downy mildew. The activity of strobilurin fungicides against both downy mildew and powdery mildew can be exploited on varieties susceptible to both diseases. Note, however, that strobilurins have a high risk of inciting resistance in both the downy mildew and powdery mildew pathogens. Similarly, copper and folpet are primarily downy mildew fungicides but can provide some suppression of powdery mildew. Most products have increased efficacy when applied when disease is less severe, as illustrated for Aliette WDG and Flint in Figure 21.

See the
Pacific Northwest Plant Disease Management Handbook
at
http://pnwhandbooks.org/plantdisease/
for a current list of registered fungicides for Pacific Northwest states.

Always make sure that any fungicide is registered for use in your geographic area before applying it.

Figure 20. Left, a hop leaf treated with the fungicide Curzate 24 hours before inoculation. Right, treated with Curzate 72 hours after inoculation. (D.H. Gent)

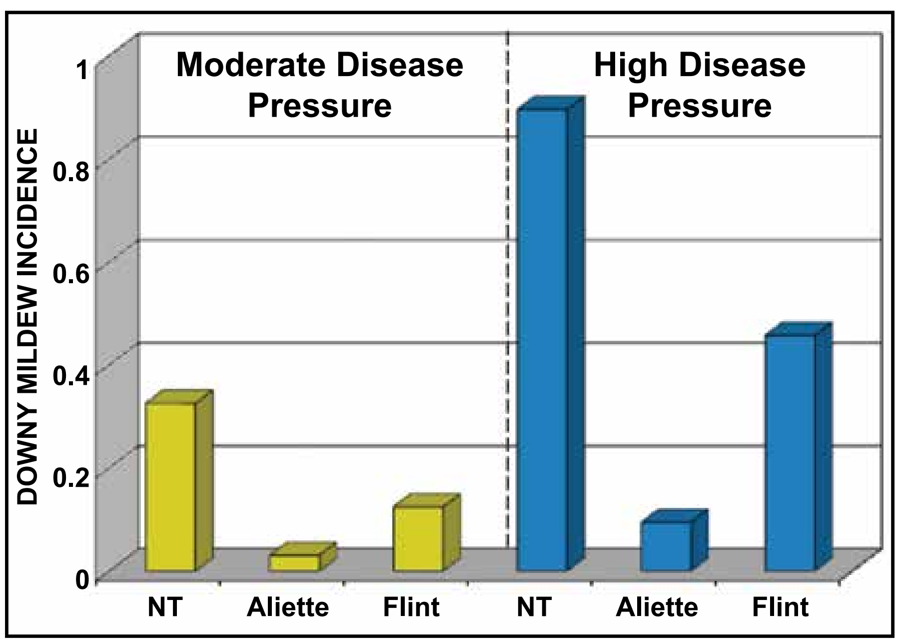


Figure 21. Efficacy of Aliette WDG and Flint under moderate and high disease pressure in Washington. NT = Non-treated.

At a Glance:
Fusarium Canker

◆ Avoid propagation from cankered hills.

◆ Ensure plants are free of *Hop stunt viroid*.

◆ Avoid water-logging soils near the crown.

◆ Mound soil around the base of bines to promote growth of healthy, new roots and reduce wilting.

◆ Add lime around the crown to increase pH of acidic soils.

◆ Avoid use of ammonium nitrogen fertilizers.

◆ Minimize injury to plants during field operations, from wind, and from arthropod pests.

◆ Arching strings and maintaining tight trellis wires may help to reduce bine injury.

Fusarium Canker

Cynthia M. Ocamb and David H. Gent

Fusarium canker is caused by the fungus *Fusarium sambucinum*. Diseased plants are conspicuous and easily identified when affected bines wilt. Affected hills may not exhibit canker symptoms every year. Severe outbreaks can occur, however, especially following excessively wet conditions. Yield losses from Fusarium canker have not been quantified rigorously but are expected due to bine die-off or plant death. The disease is commonly present at a low incidence in hop yards, although in some circumstances (such as when plants are propagated from *Hop stunt viroid*-infected material) a high incidence may occur.

Symptoms

The base of an affected bine is swollen, tapering over a short distance (about 1/4 inch) near the point of attachment on the crown (Fig. 22). The decay progresses inward toward the center of the stem, weakening the point of crown attachment such that affected bines may break away from the crown before harvest with a tug or other pressure (e.g., wind or air-blast sprayer). Older leaves on the lower part of the bine may become yellow and then turn brown as they die. Leaves on wilted bines remain attached (Fig. 23). Disease symptoms often are not recognized until affected bines wilt suddenly, which is most common when water demand is greatest, such as at flowering or in response to high temperatures. Bine wilting is often evident after cultivation, pesticide applications with an air-blast sprayer, or high winds, since diseased bines may break off from crowns at these times. Severely affected plants, particularly young plants, may die out during winter or under periods of high soil moisture. Affected bines may be covered with whitish-pink to reddish-brown mold produced during growth and sporulation by the fungus on the outer portion of the lower stem (Fig. 24). Other pests such as Vertcillium wilt and California prionus beetle can cause wilting symptoms similar to Fusarium canker. The distinguishing characteristics for Fusarium canker are the swelling of the lower stem, constriction near the soil level, and lack of extensive vascular browning.

Disease Cycle

The disease cycle of Fusarium canker has not been investigated thoroughly. The fungus that causes the disease is widespread in soil and is considered a soil inhabitant after introduction to a site but can also be found in association with plant debris, diseased crowns, and apparently healthy planting materials. It is thought that the pathogen infects hop plants through natural openings or wounds created by mechanical or chemical damage (e.g., wind, cultivation, insect feeding, or herbicide injury) around the soil line. High humidity and persistent moisture near the crown favor the disease.

Figure 22. Swollen basal portions of bines affected with Fusarium canker. (D.H. Gent and N.R. Cerruti)

Figure 23. Wilted bine due to Fusarium canker. Notice that wilted leaves remain attached to the bine. (D.H. Gent)

Figure 24. Whitish-pink sporulation of the Fusarium canker fungus on an infected stem. (D.H. Gent)

Management

Growers should remove diseased tissue from affected hills, if practical, and avoid propagation from diseased hills. Hilling up soil around the base of bines promotes growth of healthy, adventitious roots and can reduce incidence of bine wilting. Reducing free moisture near the crown due to irrigation can help, both in greenhouses and the field. Applying lime to increase pH to near neutral or slightly alkaline around the crown in acid soils and avoiding use of acidifying ammonium nitrogen fertilizers may help to reduce disease incidence. Minimizing injury to bines during field operations, reducing bine movement by tying bines and strings together, maintaining tight trellis wires to minimize bine sagging, and preventing damage to bines from arthropod pests help to reduce wounds that allow the fungus to gain entry into the plant. No fungicides are registered for control of Fusarium canker.

Fusarium Cone Tip Blight

David H. Gent and Cynthia M. Ocamb

Cone tip blight generally is a disease of minor importance, but in some instances 30% or more of cones can be affected. The disease can be incited by several *Fusarium* species, including *F. avenaceum*, *F. crookwellense*, and *F. sambucinum.*

Symptoms

Affected bracts and bracteoles at the tip of the cone turn medium to dark brown as the cone matures (Figs. 25 and 26). The browning may be limited to a small portion of the tip of the cone or, in severe cases, encompass as much as 60% of the cone. It is characteristic of cone tip blight that all bracts and bracteoles of the symptomatic whorl(s) are affected. Browning and death of the strig (central axis that bears the nodes) along the region of affected whorls generally is apparent when the affected bracts and bracteoles are removed (Fig. 27).

Disease Cycle

Little is known about the disease cycle. The implicated *Fusarium* species can survive in soil, plant debris, other plant species, and/or in association with hop crowns. The cone tip blight pathogens, as well as other *Fusarium* species, may be recovered from apparently healthy burrs, bracts, strigs, and stigmas. Observation suggests that the disease is favored by high humidity, dew events, or rainfall during bloom and cone development. A more closed-cone architecture at the tip, as found in Nugget and Sorachi Ace, may make certain varieties more susceptible than others.

Management

Control measures have not been developed for cone tip blight, as the disease occurs sporadically and control is not warranted in most hop yards. Little is known about differences in variety susceptibility, although field observations suggest some variation exists. Sorachi Ace and Centennial seem to be commonly affected by cone tip blight. Limited evaluations of fungicides indicate *Fusarium* spp. are recovered at a lower rate from burrs and cones treated with strobilurin fungicides (FRAC group 11). However, these treatments have not been successful for management of cone tip blight and strobilurin fungicides would be prone to developing fungicide resistance when used alone. Demethylation-inhibiting fungicides (FRAC group 3) that are registered for powdery mildew control may also suppress *Fusarium* species.

AT RIGHT: Figures 25 and 26. Top two images show medium brown discoloration of bracts and bracteoles due to cone tip blight. (D.H. Gent and S.J. Pethybridge)

Figure 27. Bottom image shows discoloration of strig, bracts, and bracteoles from cone tip blight. (D.H. Gent)

At a Glance:
Fusarium Cone Tip Blight

- ◆ Control seldom warranted.
- ◆ Time overhead irrigations to reduce humidity and periods of cone wetness, especially during bloom.
- ◆ Fungicide applications do not appear to be effective.

At a Glance
Gray Mold

◆ Minimal damage to hop.

◆ Control measures generally not needed.

◆ Manage irrigation and promote air movement to reduce wetness on cones.

◆ Manage arthropod pests at economic thresholds to prevent injury to cones.

◆ Fungicide applications can reduce gray mold damage to hop cones during wet weather.

Gray Mold

David H. Gent

Gray mold generally is a disease of minor importance in hop. The disease is favored by prolonged wet, humid conditions, and can result in cone discoloration and poor cone quality. The disease is caused by the fungus *Botrytis cinerea*, a widespread and common pathogen found on numerous crops including bean, blackberry, strawberry, and tree fruit.

Symptoms

Affected cones have light to dark brown spots on the tips of bracts and bracteoles, which can enlarge with time and cause discoloration of entire cones. Bracteoles are more susceptible to damage than bracts, and diseased cones can develop a striped appearance. Gray mold symptoms are similar to Alternaria cone disorder but can be distinguished by the presence of gray, fuzzy fungal growth that begins at the tip of the cone (Figs. 28 and 29). Signs of the pathogen may not be present in dry weather.

Disease Cycle

The gray mold fungus may survive as a decay organism on organic materials, in and on leaves, and in the soil as dormant resting structures known as sclerotia. The pathogen is active over a range of temperatures when free moisture is available, with an approximate temperature of 68°F being optimal. The fungus can remain dormant in or on plant tissues during unfavorable conditions and become active when weather or host factors are favorable. Infection on cones is favored by wet weather and injury caused by field operations, insect feeding, or other diseases.

Management

Fungicide applications can reduce gray mold damage in hop. Strobilurins (FRAC group 11) are particularly effective. However, in most years the disease causes minimal damage in regions with dry climates, and special control measures have not been necessary. Cultural practices such as increasing row and plant spacing and managing overhead irrigation to shorten the duration of wetness on cones may help to reduce the incidence of gray mold. Damage to cones from insect feeding can exacerbate gray mold, and efforts should be made to manage arthropods at economic thresholds.

Figures 28 and 29. Medium brown discoloration and fungal growth on the tip of a cone due to gray mold. (S. Radišek)

Powdery Mildew

David H. Gent, Mark E. Nelson, David M. Gadoury, Amanda J. Gevens, and Mary K. Hausbeck

Powdery mildew, caused by the fungus *Podosphaera macularis*, is one of the most important diseases of hop worldwide. The disease can cause severe crop damage, and in some cases crop failure is complete due to lost production and unacceptable cone quality.

Podosphaera macularis is prevalent throughout the Pacific Northwest, and powdery mildew is a major pest of hop in much of this region. The pathogen is also prevalent in the Upper Midwest and the eastern U.S., where it is relatively common on feral bines and on wild hop. At the time of this writing, powdery mildew has been confirmed from only a few commercial hop yards in Michigan, North Carolina, New York, and Quebec. The relatively few outbreaks of the disease outside of the western U.S. may be due in part to the relative newness and small acreage of the emergent hop industry in the Upper Midwest and eastern North America. It also may be due in part to the widespread planting of powdery-mildew resistant varieties in these regions. Historically, however, powdery mildew was a very important disease in New York in the early 1900s. This history, along with recently documented breakdown of resistance in some varieties, would indicate that powdery mildew could return rapidly to damaging levels as observed during 2015.

Symptoms

Disease signs appear as powdery white colonies on leaves, buds, stems, and cones (Fig. 30). During periods of rapid plant growth, raised blisters often are visible before sporulation can be observed. Infection of burrs and young cones causes abortion or severe distortion of the cone as it develops (Fig. 31).

Figure 30. Powdery white colonies on leaves, stems, and cones. (D.H. Gent)

Figure 31. Powdery mildew damage on very young (left) and more mature cones. (D.H. Gent)

At a Glance
Powdery Mildew

- Select early-maturing or resistant varieties when possible.
- Apply adequate but not excessive irrigation and fertilizer.
- Remove all green tissues during spring pruning if practical in your growing region.
- Apply appropriate fungicides as soon as possible to protect regrowth after pruning and throughout season.
- Eliminate mid-season basal growth in established yards.
- Apply highly effective fungicides to protect burrs and young cones.
- Harvest timely to minimize crop losses in the field when powdery mildew occurs on cones.

Powdery Mildew Considerations for Production Regions Outside of the Pacific Northwest

In the Upper Midwest and northeastern U.S., powdery mildew has been observed in only a few instances and has not yet become established or common in most hop yards. Powdery mildew has been found on wild and feral hop plants in Maryland, Minnesota, and New York, and on cultivated plants in Michigan, New York, North Carolina, and Quebec, Canada. Scouting and accurate diagnosis is advised so as to limit early disease onset. Producers outside of the Pacific Northwest should also carefully consider the source of their planting materials, as strains of the pathogen exist in the western U.S. that can cause disease on varieties typically considered resistant such as Nugget, Cascade, Mt. Hood, Newport, and TriplePearl. Such strains were confirmed in Michigan, New York, and North Carolina in 2015 and may have been introduced into these states on diseased planting materials.

Powdery Mildew Symptoms, cont.

Affected cones may develop a characteristic white, powdery fungal growth, although in some cases fungal growth is visible only under bracts and bracteoles with magnification. Affected cones become reddish-brown as tissues are killed (Fig. 32) and may "bleach out," turning pale green or light brown after kiln drying (Fig. 33). The pathogen grows exclusively upon the surface of the plant, with the exception of microscopic absorptive structures (haustoria) that invade epidermal cells. Unlike downy mildew, which emerges and sporulates primarily through stomata on the lower surface of leaves, symptoms and signs of powdery mildew can occur on any surface of any green tissue of the hop plant.

Figure 32. Reddish-brown discoloration associated with powdery mildew.

Figure 33. Bleaching and loss of green cone color after kiln drying caused by powdery mildew. (Both photos D.H. Gent)

Disease Cycle

In all growing regions, the pathogen is thought to survive in a vegetative state as hyphae within dormant, infected buds on the crown. Crown buds infected in one season give rise to infected shoots the following year. These infected shoots are called "flag shoots" because of their resemblance to a white flag on the otherwise green foliage in spring (Fig. 34). Flag shoots occur on a small percentage of plants (typically less than 1%) and provide the initial spores to initiate outbreaks each year. Flag shoots emerge in sync with plant growth. A few can be found as soon as shoots begin to emerge in spring, and they continue to emerge until as late as May or even early June, provided that infected buds are not removed during spring pruning operations. The number of flag shoots produced in a given yard is related to prior occurrence of flag shoots in that yard, disease levels in the previous year, spring pruning practices, and winter temperature.

The disease initially centers on the flag shoots, then the pathogen moves via airborne spores (conidia) from infected crowns to young leaves as new growth emerges. This shifts the distribution of disease throughout a planting, into neighboring yards, and eventually throughout a growing region.

In the Pacific Northwest, the pathogen is known to overwinter only in association with crown buds, but east of the Rocky Mountains there are two distinct mating types of the pathogen, the presence of which can result in the development of a second form of overwintering. If disease builds to a level where the two mating types become paired on the same tissue, they can fuse to form durable resting structures called chasmothecia or cleistothecia (Fig. 35). This life stage of the pathogen may persist over winter on crop debris that was infected in the previous season. Chasmothecia mature gradually during winter and can release infectious spores during spring rains. The optimal conditions for infection by these spores, called "ascospores," are generally the same as those for the asexual spores (conidia). Infection by ascospores produces mildew colonies that are identical in appearance to those that result from conidia. Both versions of the life cycle of the pathogen are illustrated in Figure 36.

Figure 34. A young shoot in spring with severe powdery mildew (“flag shoot”) resulting from bud infection the previous year. (D.H. Gent)

Figure 35. Small, yellow to black chasmothecia of the powdery mildew fungus on a leaf. (S.N. Wolfenbarger)

Powdery mildew development is favored by rapid plant growth, mild temperatures (50 to 82°F), high humidity (especially at night), and cloudy weather. Under ideal conditions of 65 to 70°F, the fungus can complete its life cycle in as few as five days on highly susceptible varieties.

Burrs and young cones are very susceptible to infection, which can lead to cone distortion, substantial yield reduction, diminished alpha-acids content, color defects, and premature ripening. Cones become somewhat less susceptible to powdery mildew with maturity, although they never become fully immune to the disease. Infection during the later stages of cone development can lead to cone browning and hastened maturity, with the degree of these effects directly linked to how much disease is present. Alpha-acids typically are not influenced greatly by late-season attack of powdery mildew, but yield can be reduced by 20% or more because of shattering of overly dry cones during harvest due to early maturity. Several weak pathogens and secondary organisms can be found on cones attacked by powdery mildew; control of powdery mildew reduces presence of these secondary organisms.

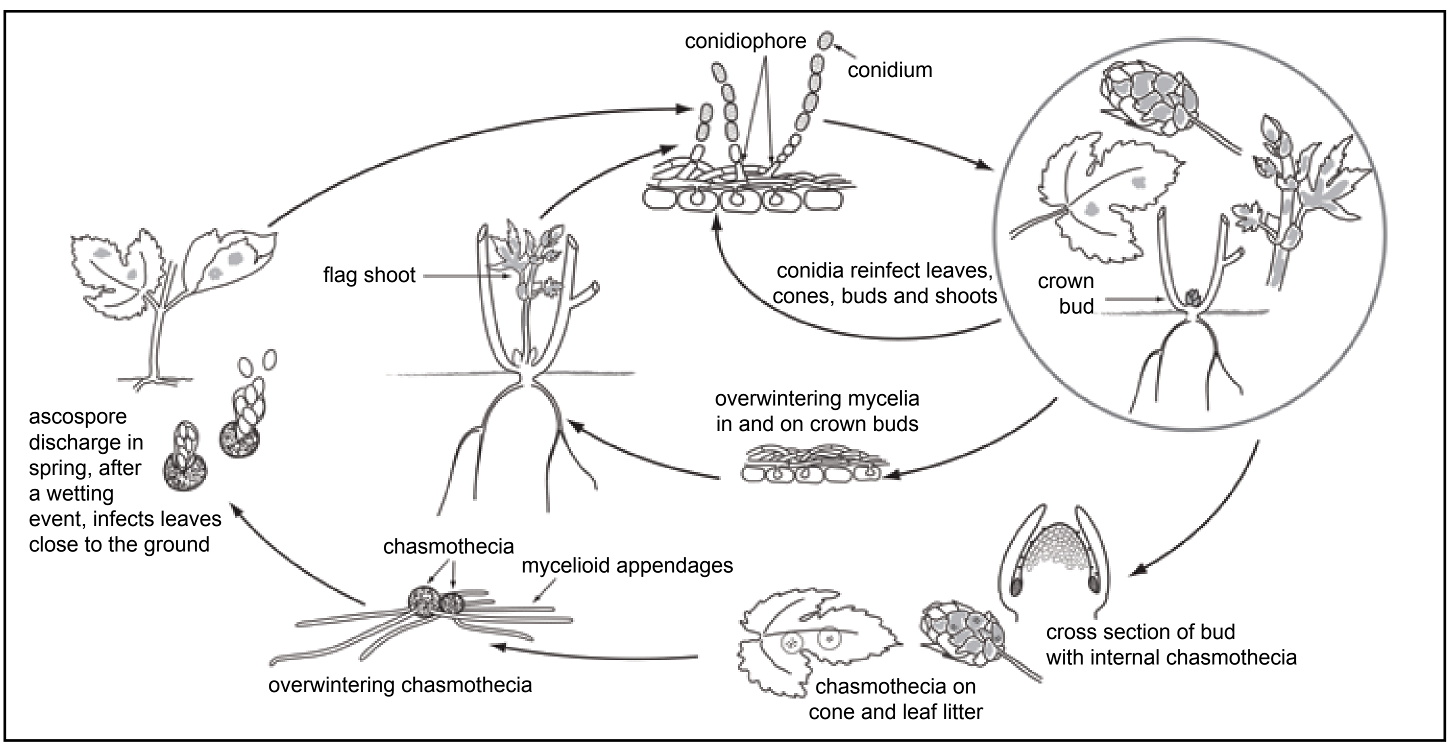


Figure 36. Life cycle of *Podosphaera macularis* on hop. The sexual stage of *P. macularis* (shown by arrows on the bottom and left side of the figure) is not known to occur in the Pacific Northwest. (Prepared by V. Brewster)

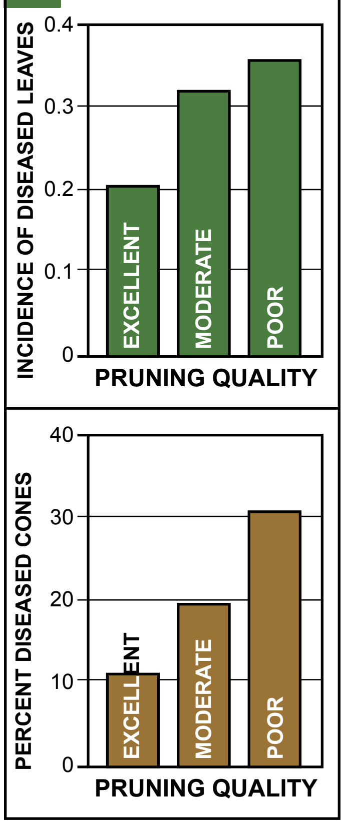


Figure 37. Association of thoroughness of spring pruning to the incidence of leaves (top) and cones (bottom) with powdery mildew in hop yards examined in Washington and Oregon in 2000 and annually from 2005 through 2010. Excellent = No foliage or green stems remaining after pruning. Moderate = Foliage or green stems on some hills after pruning. Poor = No pruning conducted or foliage and green stems present on all hills after pruning.

Management

Control of powdery mildew requires integration of varietal resistance, crop sanitation practices, adequate but not excessive fertilization and irrigation, and well-timed fungicide applications throughout the production season as well as during cone development. While growers may not be able to select resistant varieties because of market factors, some resistant varieties are available (Table 3, page 18).

The reaction of a hop variety to powdery mildew varies depending on where it is grown and which strains of the fungus are present. Mt. Hood, Newport, Nugget, TriplePearl, and several proprietary varieties possess a similar form of resistance that has historically rendered them immune to powdery mildew. However, strains of the pathogen capable of infecting these varieties are now widespread in the Pacific Northwest. Cascade has a different form of resistance to powdery mildew, but, similarly, strains of the fungus exist in the Pacific Northwest that can also overcome its resistance. Many varieties have useful levels of field resistance or tolerance, such as Comet. Selection of early-maturing varieties (e.g., Fuggle) can also help to escape late-season powdery mildew.

It is extremely important to obey the quarantines in place regarding interstate transport of hop planting material. This will delay the introduction of the second (mating) type into the Pacific Northwest and also the dissemination of virulent strains of the fungus into other production regions.

Successful management of powdery mildew begins in early spring. In the Pacific Northwest, thorough removal of all green tissue during pruning, including shoots on sides of hills and around poles or anchors, is an important component of powdery mildew management (Fig. 37). Mechanical pruning tends to be more effective than chemical pruning in eliminating flag shoots. In regions outside of the Pacific Northwest with short growing seasons, and where there is little to no powdery mildew pressure at this time, early-season pruning has not gained wide adoption, as it can result in poor productivity.

Where powdery mildew is problematic, regular fungicide applications are essential for economic production of most susceptible varieties. Appropriate timing of the first fungicide application after pruning is important to keep disease pressure at manageable levels. This application should be made as soon as possible after shoot regrowth in high-risk situations or when the disease is first detected in a region through scouting.

Many fungicide programs can give adequate disease control on leaves when applied preventatively. On cones, however, differences among fungicides are substantial. Mid-July through early August is an essential disease management period. The fungicide quinoxyfen (Quintec) is especially effective during this time. The powdery mildew pathogen has an extremely high risk of developing fungicide resistance, therefore careful attention to resistance management guidelines is critical.

Several factors influence the development and severity of powdery mildew on cones, including disease severity on leaves, temperature and rain during cone development, late-season fungicide applications, and harvest date. Applying highly effective fungicides such as Quintec to young, developing cones can significantly reduce incidence of powdery mildew on cones at harvest.

The efficacy of any fungicide varies greatly depending upon disease severity (Fig. 38). The incidence of cones with powdery mildew is reduced when fungicide applications are made as late as possible during the growing season, as specified by the label. However, multiple years of trials in Washington have failed to demonstrate a consistent impact of these very late-season

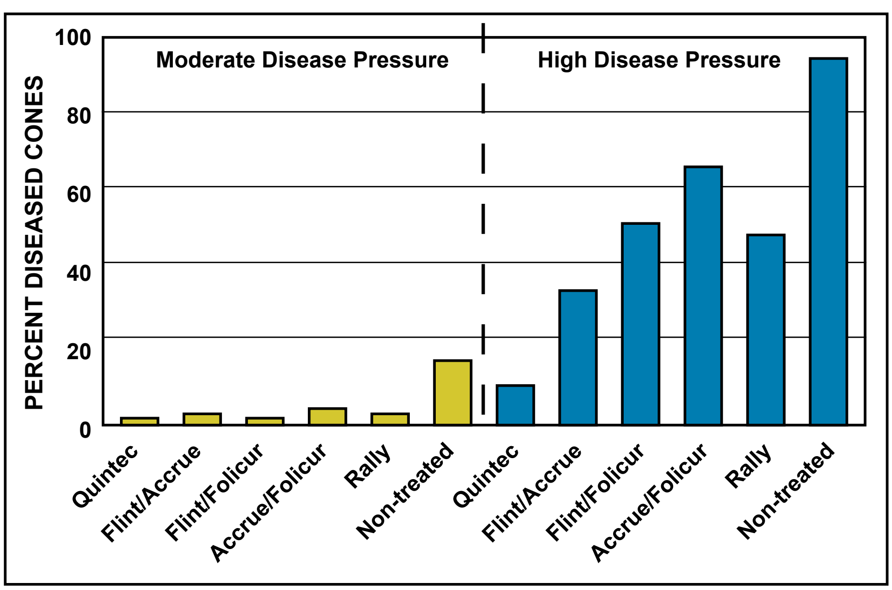


Figure 38. Efficacy of powdery mildew fungicides under moderate and high disease pressure in Washington. Notice that most fungicides provide acceptable control when disease pressure is moderate.

applications on yield, while their impact on cone color depends on disease pressure.

Fungicide applications alone are not sufficient to manage the disease. Under high disease pressure, mid-season removal of diseased basal foliage delays disease development on leaves and cones. Desiccant herbicides should not be applied until bines have grown far enough up the string so that the growing tip will not be damaged and bark has developed. In trials in Washington, removing basal foliage three times with a desiccant herbicide provided more control of powdery mildew than removing it once or twice, particularly on cones (Fig. 39). Established yards can tolerate some removal of basal foliage without reducing yield. This practice is not advisable in first-year plantings, and may need to be considered cautiously in the second year after planting in some situations.

Late-season powdery mildew can be easily confused with other diseases such as Alternaria cone disorder or gray mold, and even with spider mite damage. In the overwhelming majority of instances in the Pacific Northwest, however, the primary cause of late-season discoloration of cones is powdery mildew.

Crop damage can increase with later harvests. When powdery mildew is present, CTZ and Galena crops should be harvested by about 26% dry matter to maintain cone color and minimize losses due to shattering during picking.

The above recommendations apply to both hops produced for conventional commercial markets and those grown under guidelines for organic production. Under the additional constraints imposed by organic production guidelines, particular attention must be paid to selection of disease-resistant varieties. This is the foundation upon which organic production will succeed or fail with respect to the major fungal diseases. Available fungicide options for organic production are minimal and generally mediocre in efficacy under high disease pressure. Although frequently cited in popular literature, optimal fertilization, soil health, and water management alone are inadequate for disease control. Likewise, biorational compounds, biological controls, manure teas, and various botanicals and natural products have shown minimal to no efficacy against this pathogen under moderate to severe disease pressure.

Practice sound fungicide resistance management to prolong utility of key powdery mildew fungicides.

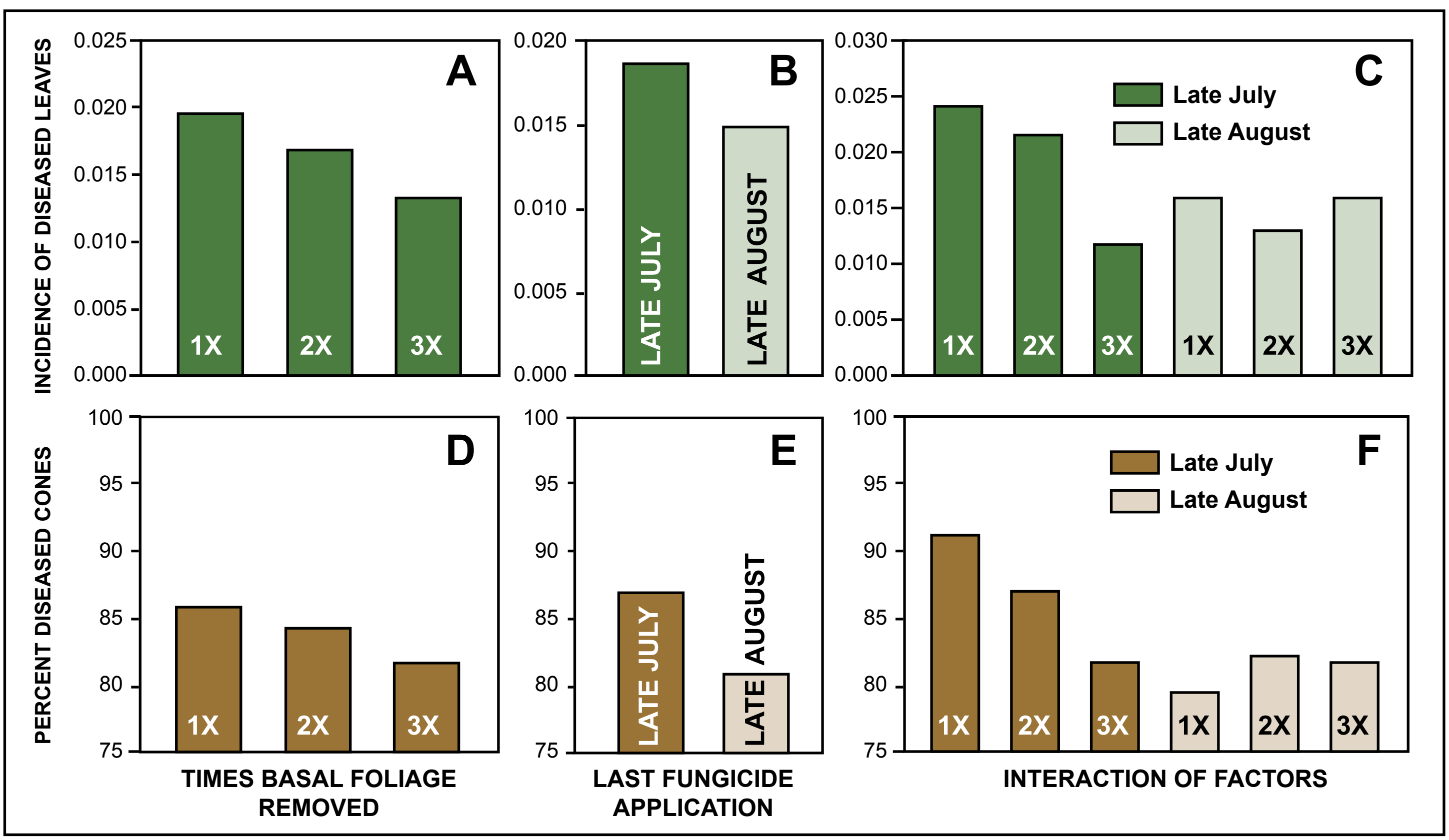


Figure 39. Incidence of leaves (A to C) and percent of cones (D to F) with powdery mildew depending on how many times basal foliage was removed (A and D), how late into the season fungicide were applied (B and E), and the interaction of these factors (C and F). Notice that intensity of basal foliage removal and date of the last fungicide application interact to influence disease levels on cones. Data from variety Zeus in Washington, 2012 to 2014.

At a Glance
Red Crown Rot

◆ Select and plant only high-quality planting materials.

◆ Avoid wounding crowns during spring pruning.

◆ Maintain plant vigor by avoiding early harvests, maintaining basal foliage, and avoiding soil-applied herbicides that reduce root development.

◆ Avoid replanting in the hole left by removing a diseased plant.

◆ Fumigation can improve plant vigor and yield, but seems unnecessary in most situations.

Red Crown Rot

David H. Gent

Red crown rot has been described on hop plants in Australia and Oregon. The disease is caused by the fungus *Phomopsis tuberivora*. The disease generally is of minor importance and seems to cause crop damage only when other factors weaken plants. Data from Australia indicate affected plants may suffer yield losses of up to 20%. In extreme cases in Oregon, plants have been killed by red crown rot and yield losses appear to be higher than 20% in these instances.

Symptoms

The pith tissue of affected roots and crowns is orange to red and develops into a progressive dry rot of the root (Fig. 40). There is a distinct boundary between diseased and healthy tissue (Fig. 41). Roots and crowns of apparently healthy plants typically have this appearance, but the severity of dry rot is more pronounced in diseased plants. Entire crowns may be destroyed in the advanced stages of the disease, leading to weak, uneven shoot growth, and yellowing of lower leaves (Fig. 42). Bines on severely affected plants often fail to reach the top wire and have limited development of lateral branches. Severely affected plants can be killed. Affected plants may be aggregated in roughly circular patches, although in some young plantings diseased plants may be more generally scattered across a yard.

Disease Cycle

Little is known about the disease cycle of red crown rot. In Victoria, Australia, the disease was thought to be associated with planting poor quality rootstock, injury to crowns during spring mowing of shoots, and cultural practices that reduced plant vigor, such as early harvest and leaving insufficient foliage on plants after harvest. The causal organism can be recovered from soil, plant debris, and healthy crowns. The host range of the pathogen includes alfalfa, beet, potato, and several trees and woody ornamentals. The fungus is a weak pathogen, and disease symptoms rarely develop on these hosts. In Oregon, damage from red crown rot has been observed only in a few instances, and in most cases plants were weakened by some other predisposing factor.

Figure 40. Reddish-brown decay and dry rot of a crown affected by red crown rot. (D.R. Smith)

Figure 41. Distinctive boundary between healthy and affected tissue in a root with red crown rot. (D.H. Gent)

Figure 42. Weak plant growth and yellowing of older leaves due to severe red crown rot. (D.H. Gent)

Management

Control measures for red crown rot have not been thoroughly investigated in the U.S. However, the disease currently appears to cause economic damage in relatively few yards, and specific management efforts generally do not appear necessary. Red crown rot has been managed successfully in Australia through a combination of careful selection of high-quality, disease-free planting materials, avoidance of crown wounding during spring pruning, and cultural practices that maintain plant vigor and carbohydrate reserves. Other management recommendations promoted in Australia include removing diseased plants and avoiding replanting in the hole left by removing a diseased plant.

Efforts should be made to improve plant vigor by avoiding early harvests, maintaining as much foliage as possible after harvest to help plants increase carbohydrate reserves, and avoiding soil-applied herbicides that reduce root development. Boron deficiency has been implicated in red crown rot in Australia, although conclusive evidence of a link between boron deficiency and the disease is lacking. In Australia, fumigation with dazomet provided an approximate 60% increase in yield in year one and 14% in year two. This practice has not been adopted in Australia due to the high cost of fumigation. In Oregon, fumigation has improved establishment in yards where red crown rot was present (Fig. 43). A study in Oregon found a link between high soil pH and red crown rot within a severely affected yard; it is unclear if pH is important for disease development in other situations.

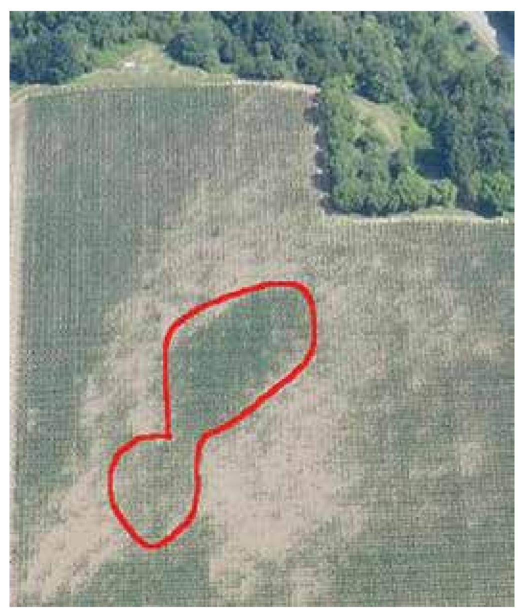


Figure 43. Weak and dead plants in a hop yard affected by severe red crown rot. The area indicated in red was fumigated before replanting. (D. Sbur)

At a Glance
Sclerotinia Wilt or White Mold

◆ Control measures usually are not needed in the Pacific Northwest.

◆ Limit excessive foliage and canopy wetness.

◆ Time irrigations to reduce wetness on plants and soil.

Sclerotinia Wilt (White Mold)

David H. Gent

Sclerotinia wilt, also referred to as white mold, affects nearly 400 weed and crop plant species, including green bean, pea, lima bean, canola, carrot, lettuce, potato, sunflower, and squash. The disease is caused by a fungus, *Sclerotinia sclerotiorum*, and is only an occasional problem on hop in wet, cool climates such as those found in the hop production regions in western Oregon and northern Idaho. Sclerotinia wilt can cause damage when soil and plants remain continuously wet and temperatures are mild.

Symptoms

Disease symptoms generally appear in late spring or early summer as soft, water-soaked lesions on bines just below or near the soil surface at the crown. The infected tissue collapses, creating a light brown to grayish lesion approximately 1 to 4 inches long. In some instances, the fungus can colonize stems higher on the plant. In one case in western Oregon, the fungus was found growing only high up on the stems near the string used to tie the bines for arching.

Figure 44. White, fluffy growth of the Sclerotinia wilt fungus on hop stems. The small black structures on the lesions are a diagnostic characteristic of the fungus. (M.L. Putnam)

Figure 45. Wilted bine in the variety Nugget caused by Sclerotinia wilt. (D.H. Gent)

During wet weather, fluffy white growth of the fungus may form on the infected tissue (Fig. 44). Small (about 1/16 to 1/8 inch), hardened black overwintering structures (sclerotia) form on and in diseased bines. As the disease progresses, the lesions expand and may girdle the bine, causing a wilt. Bines with smaller diameter seem more likely to fully wilt than larger diameter bines. Leaves generally remain green until the bine is girdled completely. Disease symptoms may appear similar to those caused by Fusarium canker or Verticillium wilt (Fig. 45). However, the presence of fluffy white mycelia and sclerotia are diagnostic for Sclerotinia wilt.

Disease Cycle

The pathogen overwinters as long-lived resting structures (sclerotia) in infested crop debris and in the soil. In some crops, sclerotia can germinate directly and infect roots or, if conditioned by exposure to moist conditions and cool temperatures, can germinate to produce one or numerous small mushroom-like structures called apothecia (Fig. 46). The soil surface must remain wet for several days or longer for apothecia to form, and with hop this generally occurs when plants produce abundant, lush foliage that shades the soil near the crown. A sclerotium may produce one or numerous apothecia, and each apothecium may produce several million airborne spores (ascospores). The airborne spores require a nutrient source upon which to grow before invading a host, and often this nutrient source is senescent leaves or other plant tissues near the crown. Severe epidemics of Sclerotinia wilt on hop reportedly are associated with hilling soil infested with sclerotia onto crowns and with frost injury of developing basal shoots. New sclerotia are formed in and on infected bines and are returned to the soil, where they may survive five years or longer and perpetuate the disease cycle. The pathogen also may survive on broadleaf weeds in and around hop yards.

Management

Control measures for Sclerotinia wilt of hop usually are not needed. In Oregon and northern Idaho, the disease tends to be most problematic during spring. Cultural practices that reduce the duration of wetness on plants and the soil surface can reduce disease incidence. These practices may include limiting nitrogen fertilization, removing excess basal shoots and leaves, stripping leaves from lower bines, delaying the first irrigation as long as possible, and timing irrigations to allow the top two inches of the soil to dry completely between irrigations. Avoid planting susceptible hosts such as canola in idle hop yards. A parasitic fungus, *Coniothyrium minitans* (marketed under the trade name Contans WG), is used in some crops as a soil treatment to reduce the number of sclerotia of the Sclerotinia wilt pathogen. The efficacy of this product for Sclerotinia wilt in hop has not been investigated.

Figure 46. A germinated sclerotium of *Sclerotinia sclerotiorum* with a mushroom-like structure (apothecium). (D.H. Gent)

Sooty Mold

David H. Gent

Sooty mold is not a disease, but rather a complex of common fungi that grow superficially on insect excretions deposited on leaves and cones. The appearance of sooty mold on hop is due to the presence and development of phloem-feeding insects, most importantly the hop aphid. Hop aphids probe the phloem strands of hop plants, ingesting more plant fluids than can be processed by their digestive systems. Aphids expel the excess plant fluids as a dilute solution known as "honeydew," comprising sugars, amino acids, and other substances. This solution provides a food source that supports the growth of dark-pigmented fungi that grow conspicuously on the surface of leaves and cones, reducing the quality of cones.

Symptoms

Once aphids colonize and begin feeding, plant tissues become covered with sticky honeydew and develop a shiny appearance. Signs of sooty mold soon develop on the honeydew as a flattened, black mass of fungal growth that resembles a fine layer of soot (Fig. 47). Burrs and developing cones later may become covered with honeydew when aphids are present later in the season, quickly becoming black and sooty in appearance. Entire bracts, bracteoles, and lupulin glands may become black and sticky, but sooty mold tends to be most prevalent on the undersides of bracts and bracteoles and on leaves shaded from the sun (Fig. 48).

Management

Sooty mold is managed by controlling hop aphids (Fig. 49) when populations exceed economic thresholds. Natural enemies of hop aphid can provide some level of control when not disrupted by insecticides, therefore broad-spectrum insecticides should be avoided when possible.

PHOTOS AT RIGHT, FROM TOP

Figure 47. Black sooty mold on hop leaves. (D.H. Gent)

Figure 48. Black sooty mold on a hop cone. Notice the white aphid castings present under the bracts and bracteoles. (D.H. Gent)

Figure 49: Hop aphid (winged form). For aphid photos and control information, see pp. 47-48. (L.C. Wright)

At a Glance

Sooty Mold

◆ Sooty mold is controlled by controlling hop aphid.

◆ Natural enemies of hop aphid can provide some control when not disrupted by broad-spectrum insecticides.

At a Glance Verticillium Wilt

◆ Plant resistant varieties, especially in areas where lethal strains of the pathogen occur.

◆ Clean equipment between yards to minimize spreading the pathogen.

◆ Plant only disease-free rhizomes and plants.

◆ Do not return trash or compost from yards with Verticillium wilt to hop yards.

◆ Control weeds with herbicides and reduce cultivation where possible.

◆ Reduce nitrogen fertilization as much as possible.

◆ Do not plant hop where heptachlor residues are present.

Verticillium Wilt

David H. Gent and Mark E. Nelson

Verticillium wilt is a potentially damaging disease of hop and numerous other hosts. On hop, Verticillium wilt has been reported from most production regions of the world. The disease may be caused by two related fungal species, *Verticillium nonalfalfae* (formerly V. *albo-atrum*) and *V. dahliae*. The host range and severity of disease caused by these pathogens varies; in general, *V. nonalfalfae* is of much more economic concern than *V. dahliae*.

Multiple strains of *V. nonalfalfae* have been described, which generally display a continuum of aggressiveness on hop. Some may cause relatively minor wilting symptoms (sometimes called non-lethal or fluctuating strains), while others can cause severe symptoms (lethal or progressive strains) that can rapidly kill susceptible varieties. Non-lethal strains of *V. nonalfalfae* have been reported on hop in Oregon. Lethal strains of the pathogen have not been reported from the U.S., but occur in England, Germany, and Slovenia. *Verticillium dahliae* causes a relatively minor wilt disease on hop. This pathogen has a broader host range than *V. nonalfalfae* and occurs commonly on hop in the U.S. and elsewhere.

Figure 50. Upward curling and wilting of leaves associated with Verticillium wilt caused by a non-lethal strain of *Verticillium nonalfalfae* (D.H. Gent)

Figure 51. Swollen bine with wilted leaves resulting from infection by a non-lethal strain of *Verticillium nonalfalfae*, one of the Verticillium wilt pathogens. (D.H. Gent)

Symptoms

Disease symptoms vary depending on the aggressiveness of the *Verticillium* pathogen that is attacking the plant. With non-lethal strains of *V. nonalfalfae*, disease symptoms often appear initially on lower leaves as yellowing and death of tissue between major veins and upward curling of leaves (Fig. 50). Affected bines become noticeably swollen (Fig. 51), and when these bines are cut open the vascular tissue exhibits a prominent medium to dark brown discoloration (Fig. 52). These symptoms generally develop near flowering or when plants become moisture stressed. Eventually, one or all of the affected bines on a plant completely wilt (Fig. 53). The severity of symptom development may vary from year to year depending on weather and other factors. Plants affected by non-lethal strains of the pathogen in one season may fully recover and appear healthy in the following year. All reports of Verticllium wilt caused by *V. nonalfalfae* in the U.S. to date have been associated with non-lethal strains of the pathogen.

In contrast, lethal strains of *V. nonalfalfae* cause rapid collapse of leaves and branches, killing plants of susceptible varieties. Bine swelling is less apparent with lethal strains of the pathogen, but the degree of vascular browning is more severe than that associated with non-lethal strains. With these more aggressive strains of the pathogen, disease symptoms become progressively more severe with time and are less affected by year-to-year variation in weather and grower management practices.

Symptoms of Verticillium wilt caused by *Verticillium dahliae* may vary depending on environment and variety. In some cases, such as with the variety Willamette, plants may be infected but the only noticeable symptom is swelling of the bines and a general yellowing of lower leaves near the main bines. Some degree of browning often is present when these bines are cut open. *Verticillium dahliae* tends to cause more severe symptoms on hop plants in Washington than it does on plants in Oregon.

Disease Cycle

Verticillium wilt pathogens survive in soil, invade hop roots, and later grow into water-conducting tissues. Fungal growth and plant toxins produced by the pathogen disrupt the movement of water and nutrients, leading to wilt symptoms. The fungus also spreads systemically in the plant and may invade leaves.

Verticillium nonalfalfae is known to infect potato, tomato, spinach, the ornamental plant tree-of-heaven *(Ailanthus altissima)*, and numerous broadleaf weeds that may occur in hop yards. *Verticillium dahliae* has a broader host range that includes more than 400 plants. Important hosts include cherry, maple, mint, potato, cantaloupe and other melons, as well as several herbaceous plants, woody ornamentals, and common weeds.

The Verticillium wilt pathogens are spread in hop yards during soil cultivation, in hop trash, in planting materials from infested yards, and in soil moved on equipment and workers. Weeds common to hop yards that can be infected by *Verticillium* spp. include common lambsquarters, pigweed, and shepherd's purse; these weeds can allow the pathogens to survive even after hop plants have been removed from a yard. The pathogens produce long-lived survival structures that can persist in soil. In the absence of a host, *V. nonalfalfae* can survive three to four years in soil, and *V. dahliae* can survive for 15 years or longer.

Management

Planting resistant varieties and using strict sanitation procedures are essential where lethal strains of the pathogen exist to limit its spread. Most varieties produced in the U.S. are highly susceptible to lethal strains, with Fuggle being particularly susceptible. Planting materials should only be obtained from disease-free yards. Hop trash from yards with Verticillium wilt should not be returned to hop yards. A small percentage of Verticillium wilt propagules can survive composting, therefore composted trash from yards with the disease should not be spread on hop yards.

In the Pacific Northwest, where only non-lethal strains of Verticillium wilt are present, a minimum crop rotation of four years to a non-host (e.g., small grains, corn) can help to reduce levels of *V. nonalfalfae* in soil. Cascade and Perle are reported to be less susceptible to non-lethal strains. Reduced cultivation, weed control, and limited nitrogen fertilization (i.e., less than 140 pounds per acre per year) also help to reduce the incidence of Verticillium wilt. Although *V. dahliae* usually causes only minor Verticillium wilt symptoms, management practices for *V. nonalfalfae* minimize damage from this pathogen as well. Residues of the insecticide heptachlor are reported to increase susceptibility of hop plants to Verticillium wilt caused by *V. dahliae.*

Figure 52. Diagnostic browning of vascular tissues caused by Verticillium wilt. A healthy bine is shown on the right. (D.H. Gent)

Figure 53. Wilting of bines affected by Verticillium wilt caused by a non-lethal strain of *Verticillium nonalfalfae*. (D.H. Gent)

Figure 54. Bines affected by the fungus *Diplodia seriata*. (D.H. Gent)

Figure 55. Reproductive structures (pycnidia) of the fungus *Diplodia seriata* formed externally (left) and internally (right) on affected hop stems. (D.H. Gent)

Diseases of Minor Importance

Armillaria Root Rot (Shoestring Root Rot)

Armillaria root rot, also known as shoestring root rot, is a common disease of numerous forest and orchard trees, shrubs, and vines. It is caused by species of the fungus *Armillaria*. On hop, disease symptoms appear initially as wilting of plants. Plaster-white sheets of the pathogen grow under the bark of infected bines near the soil surface. As the disease progresses, the crown may display a powdery rot. The disease generally is a minor concern for hop. However, new yards should not be planted after susceptible tree crops. If a hop yard must be established following a tree crop in which the disease was present, all roots and stumps should be removed and destroyed.

Black Mold

Black mold is caused by an unidentified species of the fungus *Cladosporium*. The disease can cause a brown discoloration of bracts that gives affected cones a striped appearance somewhat similar to Alternaria cone disorder. In the case of black mold, the bracts become brown and the bracteoles remain green. The darkly pigmented spores of the fungus are easily observed on affected bracts under low magnification. The discoloration is most prominent on cones protected from direct sunlight, such as those on low lateral branches. The disease causes negligible damage, but black mold is easily confused with downy mildew or Alternaria cone disorder, and misdiagnosis may lead to unnecessary management actions.

Crown Gall

Crown gall, caused by the bacterium *Agrobacterium tumefaciens,* is the only bacterial disease of hop reported in the United States. The disease results in fleshy to hard tumors (galls) on bines at or near the soil surface close to the crown and roots, resulting in weak bine growth, wilting of affected bines, and, in severe cases, plant death. Fuggle, Late Cluster, and Southern Brewer are known to be susceptible to the disease. Crown gall appears to be most damaging in nurseries and on young plants;

older plants can be affected without obvious symptoms or damage. Generally, no special disease management strategies are needed for crown gall. Softwood cuttings and rhizomes should be harvested only from plants free of the crown gall bacterium.

Diplodia seriata

A wilt disease caused by the fungus *Diplodia seriata* was reported from Upstate New York in 2012. Affected bines exhibit black discoloration and wilt late in the season; leaves remained attached to the wilted bines (Fig. 54). Reproductive structures of the fungus (pycnidia) form externally and internally on affected stems, most prominently in the cortex (Fig 55). These symptoms were reproduced on greenhouse-grown plants over a nine-month period. Little is known about the disease on hop. The low infectivity of the fungus and long incubation period required for symptom development may indicate that the organism is a weak pathogen and capable of causing plant damage only under certain conditions.

Drippy Stem Blight

A disorder of unknown cause has been observed from several hop yards in Washington and southern Idaho since 2012. In the reported instances, symptoms were first recognized during mid to late July. The main bines crack and become colonized with a sticky, putrid ooze that may drip onto leaves and the soil (Fig. 56). Flies and other insects are attracted to the exudate. Foam may be observed at the base of affected bines (Fig. 57). Affected bines may later wilt and desiccate. A yeast-like fungus, *Galactomyces geotrichum*, and several bacteria have been recovered from affected plants. To date, multiple attempts to reproduce symptoms with the yeast fungus under greenhouse conditions have failed. Inoculations with multiple bacteria are ongoing, although the cause of this problem remains unknown. The variety Cashmere appears especially susceptible, as occurrences of the problem have been reported to be widespread in multiple, first-year yards of Cashmere in both Idaho and Washington. Reports of drippy stem blight also have been made on Cluster and two proprietary varieties.

Rhizoctonia solani

Rhizoctonia solani has been reported in rare instances to cause lesions on young shoots of the variety Brewer's Gold in British Columbia and, more recently, in North Carolina. Lesions are sunken and brick red to black in color. Affected shoots are stunted and may collapse if girdled by a lesion near the crown. The occurrence of the disease in British Columbia was attributed to hilling soil on top of plants immediately after spring crowning. This practice is uncommon and should continue to be avoided.

Figure 56. (FROM TOP) Sticky exudate on the main bine associated with drippy stem blight (D.H. Gent), stem cracking and decay on Cashmere (D.H. Gent), and slime dripping from the stem on Cluster (D. Whitener).

Figure 57. Foam produced at base of a Cashmere plant with drippy stem blight. (D.H. Gent)

At a Glance
Minor Diseases

◆ Avoid planting hops following trees susceptible to Armillaria root rot.

◆ Black mold symptoms are easily confused with those of downy mildew or Alternaria cone disorder.

◆ Crown gall can impact young plants; take care to harvest cuttings and rhizomes from uninfected plants.

◆ The fungus *Diplodia seriata* has been confirmed in New York State, but appears to be of minor importance.

◆ Drippy stem blight, a disorder of unknown origin, is under investigation.

◆ While rare, *Rhizoctonia solani* may be favored by hilling plants after spring crowning.

At a Glance
Carlavirus Complex

◆ Use only certified virus-free planting stock when establishing new yards.

◆ Carlaviruses are transmitted by aphids and through mechanical means.

◆ Insecticide use for aphid control is inefficient for limiting the introduction of viruses, but can reduce the rate of spread within a yard.

Carlavirus Complex: *American hop latent virus, Hop latent virus, and Hop mosaic virus*

Kenneth C. Eastwell and Dez J. Barbara

Three carlaviruses are known to infect hop plants: *American hop latent virus, Hop latent virus,* and *Hop mosaic virus*. All are known to occur in mixed infections and all but *American hop latent virus* are found worldwide. *American hop latent virus* is found primarily in North America.

Symptoms

Hop latent virus and *American hop latent virus* do not cause visually obvious symptoms on any commercial hop varieties. Of the three carlaviruses, *Hop mosaic virus* is the most likely to cause both symptoms and crop damage. On sensitive varieties, chlorotic mosaic mottling can develop between major leaf veins (Fig. 58). Severely affected plants may establish poorly when planted, have weak bine growth, and often fail to attach to the string. The varieties that develop these symptoms typically are those of the Golding type or those that have Golding parentage. However, some strains of *Hop mosaic virus* appear to cause infections that may be almost symptomless on Golding hop plants.

Figure 58. Yellow mosaic pattern on Chinook due to *Hop mosaic virus*. (K.C. Eastwell)

The three carlaviruses reduce growth, which is particularly detrimental when establishing new plantings and when attempting to achieve optimal yields early in the life span of a hop yard. Yield can be reduced by some 15%, but varieties sensitive to *Hop mosaic virus* can suffer losses up to 62%. Changes in brewing characteristics induced by these viruses are minor and appear to be analogous to over maturity of cones at harvest.

Disease Cycle

Carlaviruses are transmitted largely through mechanical means. Propagation and distribution of virus-infected plants is the primary mode through which they are spread long distances. Root grafting and mechanical transmission are thought to contribute to localized spread.

Carlaviruses are also transmitted in a non-persistent manner by aphids. This means that when an aphid feeds on an infected plant, it can acquire the virus and immediately transmit it to the next host plant on which it feeds. Transmission to subsequent plants is either very inefficient or does not occur at all. All three carlaviruses are transmitted by the hop aphid *(Phorodon humuli)*. *Hop mosaic virus* and *Hop latent virus* are also transmitted by the potato aphid *(Macrosiphum euphorbiae)* and green peach aphid *(Myzus persicae)*.

Carlaviruses typically have narrow host ranges, therefore the only hosts likely to be near hop yards are other hop plants. Over the life of a hop planting, a high percentage of plants in a particular hop yard may become infected if the viruses are present.

Management

Use of certified virus-free planting stock is the most practical method of limiting any virus disease. Application of insecticides to control aphids is inefficient for limiting the introduction of virus since the virus will be transmitted before the viruliferous aphids are killed. However, reducing aphid populations can reduce the rate of secondary transmission within a hop yard.

Apple mosaic virus

Kenneth C. Eastwell and Dez J. Barbara

Apple mosaic virus is considered the most important virus disease of hop around the world. Originally, it was believed that the disease was caused by either *Apple mosaic virus* or the closely related virus *Prunus necrotic ringspot virus*. Recent data indicate that all natural infections of hop are by *Apple mosaic virus* and that previously described isolates of *Prunus necrotic ringspot virus* in hop plants were genetic variants of *Apple mosaic virus.* Infection by *Apple mosaic virus* reduces the ability to propagate hop plants from cuttings and reduces the success in establishing new hop yards.

Symptoms

Apple mosaic virus induces chlorotic rings or arcs that can become necrotic. Frequently, these merge to create oak-leaf line patterns on leaves (Figs. 59-61). The severity of symptoms is dramatically affected by environmental conditions. Symptoms are usually most severe when a period of cool weather with temperatures below 80°F is followed by higher temperatures. Plants can be infected for several seasons without disease expression until appropriate environmental conditions occur. Under conditions where severe symptoms are expressed, cone and alpha-acids yield can be reduced up to 50%. A mixed infection of *Apple mosaic virus* and *Hop mosaic virus* may result in enhanced disease severity and crop damage.

Figure 59. Necrotic ringspots and oak-leaf line pattern on Nugget due to *Apple mosaic virus*. (D.H. Gent)

Figure 60. Oak-leaf line pattern caused by *Apple mosaic virus*, without the development of ringspot symptoms. (D.H. Gent)

Figure 61. Necrotic ringspot due to *Apple mosaic virus*. Development of this symptom is temperature dependent; necrotic ringspots may not be apparent in all seasons. (D.H. Gent)

Disease Cycle

Propagation of *Apple mosaic virus*-infected plants is the primary mode of transmission, although mechanical transmission in the hop yard and root grafting appear to be significant factors in the local spread of the virus. Since *Apple mosaic virus* is not expressed every growing season, infected plants may be selected inadvertently for propagation and spread the virus to other hop yards.

Apple mosaic virus belongs to a genus of viruses that includes some pollen- and/or seed-transmitted viruses, but these routes of spread do not appear to be significant for *Apple mosaic virus*. The rate of spread is dependent on hop variety, climatic conditions, and farm management practices. No known insect or mite vectors transmit *Apple mosaic virus*. *Apple mosaic virus* has a host range that bridges several major plant groups that include apple, pear, and rose but there is no evidence to suggest that the virus is naturally transmitted from one host species to another.

Management

Selection and propagation of planting materials free of *Apple mosaic virus* are essential for disease management. The use of contact herbicides rather than mechanical pruning to control basal growth may reduce mechanical transmission of *Apple mosaic virus* to adjacent plants.

At a Glance
Apple mosaic virus

- Use only certified virus-free planting stock when establishing new yards.
- Use of contact herbicides rather than mechanical pruning to control basal growth may reduce mechanical transmission of *Apple mosaic virus* to adjacent plants.

At a Glance
Hop stunt viroid

◆ Use only certified viroid-free planting stock when establishing new yards.

◆ If a small number of plants are infected, promptly remove to minimize spread.

◆ Thoroughly kill all volunteer plants when replanting hop yards.

◆ Use contact herbicides rather than mechanical pruning to control basal growth to reduce mechanical transmission to adjacent plants.

◆ Thoroughly wash farm equipment to remove plant residue and sap.

◆ Disinfecting knives and cutting tools may reduce transmission.

Hop stunt viroid

Kenneth C. Eastwell

Hop stunt viroid is a sub-viral pathogen that causes a serious disease of cultivated hop. It spread throughout Japan in the 1950s and 1960s. Presence of the viroid in North American-grown hop plants was confirmed in 2004. The disease has been reported in hop-growing regions of Japan, Europe, and North America. *Hop stunt viroid* can reduce alpha-acids yield by as much as 60% to 80%.

Symptoms

The severity of symptoms caused by *Hop stunt viroid* is dependent on the hop variety and the weather. Visible symptoms of infection may take three to five growing seasons to appear after initial infection of mature plants. This long latent period before the appearance of discernible symptoms frequently leads to the propagation and distribution of infected planting material. Early-season growth of infected bines is delayed and foliage is generally pale relative to healthy bines (Fig. 62). During active growth, the length of the internodes of infected bines is reduced by as much as two-thirds compared to healthy bines. The degree of stunting is temperature-dependent, with more severe stunting occurring in warmer growing regions or seasons. As bines mature, the development of lateral branches is inhibited (Fig. 63). The cones borne on the sparse and shortened lateral branches are smaller and development is delayed compared to cones on healthy plants. The development of yellow-green foliage continues to appear at the base of infected bines throughout the season. The response of different varieties to infection is not well known but on some sensitive varieties yellow speckling appears along the major leaf veins (Fig. 64). This may be the result of a mixed infection of *Hop stunt viroid* and a carlavirus.

Disease Cycle

The only known mechanisms of transmission are through propagation of infected plants and mechanical transmission. There is no evidence that *Hop stunt viroid* is transmitted through hop seeds or via an arthropod vector. *Hop stunt viroid* has a greater tendency to move along rows rather than across rows, suggesting that transmission by bines rubbing together on a wire is inefficient. Observation suggests that agricultural operations are the primary mode of viroid transmission once an infection has become established in a planting. *Hop stunt viroid* is readily transmitted mechanically by workers, cutting tools, and equipment during cultural activities such as pruning, thinning, and mechanical leaf stripping. Mechanical transmission is most likely to occur in the spring, when sap pressure is high and abundant contaminated sap is forced from cut or wounded surfaces, contaminating wound sites on other plants. *Hop stunt viroid* can remain infectious in dry plant debris in the field for three months, but it is unknown if this contributes substantially to transmission of the viroid.

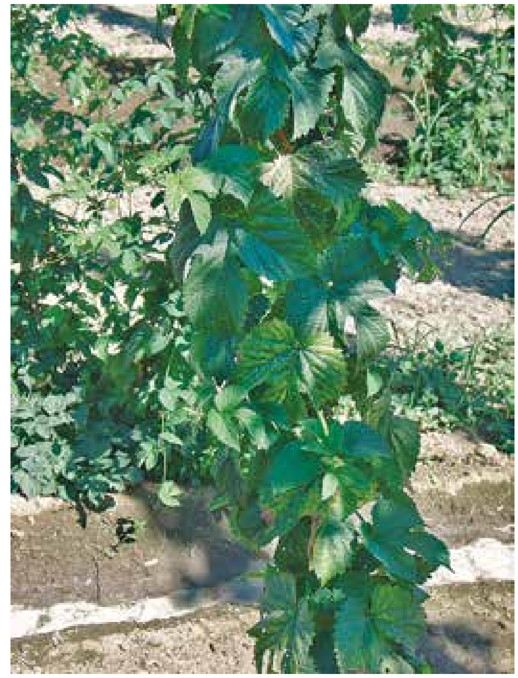
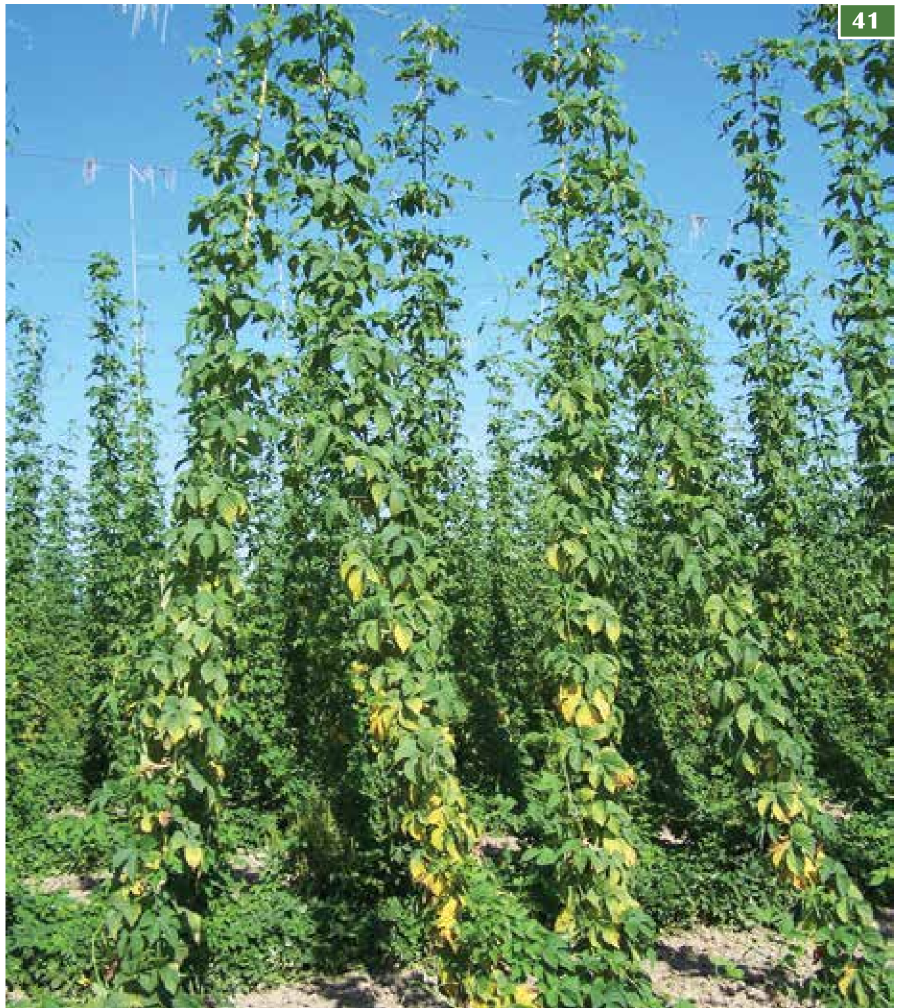


Figure 62. Pale green and yellow leaves on Willamette associated with *Hop stunt viroid*. (K.C. Eastwell)

Management

Since propagation is the major route of *Hop stunt viroid* spread, the use of planting material certified free of this pathogen is the best means of limiting its distribution. *Hop stunt viroid* spreads by mechanical means and presumably also by root grafting. If a small number of plants are infected, they should be removed promptly, with care to remove as much root tissue as possible. Because of the latent period, removal of only symptomatic plants may allow nearby infected plants to remain in the hop yard. Several plants adjacent to symptomatic plants should also be removed. If possible, plants to be removed should be treated in late summer with a systemic herbicide, such as glyphosate, to kill roots. If possible, sites should be allowed to lay fallow for one season so that remaining living roots will produce shoots that can be treated with herbicide. Soil fumigation may also be helpful in killing infected root pieces that remain after roguing if larger areas are affected.

Precautions should be employed to limit spread within a hop yard and between yards. The use of contact herbicide for spring pruning is preferable to the use of mechanical mowers that may transmit the viroid. Similarly, removing basal vegetation later in the season by chemical rather than mechanical means also reduces the risk of transmission. Thorough washing of farm equipment to remove plant residue and sap may help reduce the likelihood of transmission to new fields. Treating knives and cutting tools with a disinfectant solution for 10 minutes may reduce transmission. Many products including bleach (sodium hypochlorite), calcium hypochlorite, and hydrogen peroxide have been suggested but results are inconsistent.



ABOVE RIGHT: Figure 63. Reduced growth and sidearm development of Willamette due to *Hop stunt viroid*. (D.H. Gent)

AT RIGHT: Figure 64. Prominent yellow speckling along and between leaf veins associated with infection by *Hop stunt viroid*. (D.H. Gent)

Other Viruses, Viroids, and Virus-like Agents

Kenneth C. Eastwell and Dez J. Barbara

At a Glance
Other Viruses, Viroids, and Virus-like Agents

◆ These viruses and viroids do not merit control at this time, but growers should be aware of symptoms.

◆ Some of these viruses are problematic in Europe and/or other countries, but are not currently an issue in the U.S.

◆ Use of virus- and viroid-free planting stock is a first line of defense.

Several virus and viroids are known to occur in hop that are not addressed by current management practices in the United States. However, growers should continue to be vigilant for the appearance of symptoms that may indicate the presence of one of these agents.

Apple fruit crinkle viroid

Apple fruit crinkle viroid (AFCVd) is a sub-virus pathogen first reported to occur in hop in Japan in 2004. This viroid is not known to occur in North America in either its hop or fruit tree hosts. Very little additional information is available about this viroid in hop. Symptoms are reported to be very similar to those induced by *Hop stunt viroid* and appropriate control measures are similar (see *Hop stunt viroid*, preceding two pages).

Citrus bark cracking viroid

In 2007, *Citrus bark cracking viroid* was identified as the causal agent of a severe disease of hop in Slovenia. This viroid has been known as a minor pathogen of citrus in the United States since 1988, and has been identified in citrus in many countries. Currently, the outbreak in Slovenia is the only known occurrence in hop. The symptoms are described as being similar to those induced by *Hop stunt viroid* on the most sensitive cultivars. *Citrus bark cracking viroid* is easily transmitted through sap by physical contact with infected plants or contaminated equipment or workers. In Slovenia, the viroid spread very rapidly in hop. The precautions used for the management of *Hop stunt viroid* are applicable to *Citrus bark cracking viroid*.

Hop latent viroid

The group of sub-viral hop pathogens that contains *Hop stunt viroid* also includes *Hop latent viroid*. The presence of *Hop latent viroid* has been confirmed in most hop-producing regions of the world including the United States; wherever it is known to occur, it is widely distributed. *Hop latent viroid* has a very limited natural host range so the primary source of new infections is the use of infected propagation material or

Figure 65. Yellowing of leaves and weak growth of Omega variety caused by *Hop latent viroid*. The pathogen is widespread in hop yards in the U.S. but symptoms are rarely produced on varieties currently grown in the U.S. (D.J. Barbara)

mechanical transmission from other hop plants. Infection by *Hop latent viroid* does not cause overt symptoms on most varieties, but it can reduce alpha-acids production up to 20% in the limited number of symptomless varieties that have been studied. The variety Omega is sensitive to *Hop latent viroid* and infected plants of this variety express obvious symptoms including general chlorosis, poor growth, and retarded development of lateral branches (Fig. 65). Total alpha-acids production in infected Omega plants can be reduced by 50 to 60%. The epidemiology of *Hop latent viroid* is still not totally clear but control measures adopted elsewhere have centered on producing viroid-free hops and planting away from sources of infection such as older plantings.

Humulus japonicus latent virus

Humulus japonicus latent virus was first isolated from *Humulus japonicus* (Japanese hop) seedlings grown from seed imported into the United Kingdom from China. The infected plants were destroyed and the virus was not detected by subsequent testing conducted in the U.K. or by limited testing in North America. This virus seems to have been common in both wild *H. japonicus* and commercial hop plants in China but is little studied and its current status is unknown. No symptoms have been described on current commercial hop plants experimentally inoculated with this virus, and the virus did not move beyond the inoculated leaves. In China, the virus was widely spread within plants that were naturally infected. Symptomless infection of commercial hop plants is of concern because production losses from this virus are unknown. No control measures are required at this time beyond enforcement of quarantine measures to prevent the introduction of foreign plant material.

Tobacco necrosis virus

Tobacco necrosis virus is transmitted by the soil-borne fungus *Olipidium brassicae,* which infects a wide range of plant species. Sporadic infection of hop has been reported in Europe, but no specific symptoms or reduction in yields have been ascribed to this virus. *Tobacco necrosis virus* is occasionally associated with field crops near major hop production areas in North America but infection of hop has not been confirmed on this continent.

Other Viruses and Phytoplasma of Minor Importance

Several different viruses have been associated with mottling and chlorotic rings on infected hop plants.

Alfalfa mosaic virus and *Cucumber mosaic virus* have wide host ranges and are transmitted by several aphid species, mechanical inoculation, and seed. These viruses occur frequently in field crops grown in North America, but confirmed reports of infection of hop plants are absent. Most reports of disease caused by these viruses have originated in eastern Europe. The impact of infection beyond the appearance of foliar symptoms is unknown.

In addition to producing leaf chlorosis and mottling, *Petunia asteroid mosaic virus* induces leaves that are deformed and rugose (i.e., rough, wrinkled). There are no known natural vectors for *Petunia asteroid mosaic virus*. It is likely transmitted through mechanical means although details of the mechanism of natural spread remain unclear.

Historical records suggest that the hop strain of *Arabis mosaic virus* occurred in North America. However, failure to detect the virus in recent widespread testing of hop plants in commercial production areas suggests that it may have been eradicated. The virus causes a range of symptoms including leaf mottling and deformation. In combination with a sub-viral satellite of *Arabis mosaic virus,* the disease known as "nettlehead" develops, which can be one of the most damaging virus diseases of hop. Some symptoms associated with *Arabis mosaic virus* are shown in Figures 66-68. *Arabis mosaic virus* is transmitted by propagation and also by the dagger nematode *Xiphinema diversicaudatum*, which is widely distributed in Europe but has an extremely limited presence in North America. A related virus, *Strawberry latent ringspot virus,* infects hop plants in eastern Europe and is also vectored by *X. diversicaudatum.* No clear symptoms have been described, and the impact on hop production is unknown.

In 2004, a phytoplasma was reported to naturally infect hop plants in Poland; some of the infected hop plants exhibited severe shoot proliferation accompanied by severe dwarfing. Further characterization of DNA sequences obtained from the infected plants indicated that the phytoplasma is similar to Aster yellows phytoplasma *(Candidatus* Phytoplasma asteris). Aster yellows and related phytoplasmas are frequently detected in hop production regions of North America but no natural infections of hop have been reported on this continent.

Figure 66. Stunted shoots and leaf curling caused by *Arabis mosaic virus*. (A. Eppler, Justus-Liebig Universität, Bugwood.org)

Figure 67. Severe stunting of plants caused by *Arabis mosaic virus*. (A. Eppler, Justus-Liebig Universität, Bugwood.org)

Figure 68. "Nettlehead" disease caused by *Arabis mosaic virus* resulting in severe distortion. (A. Eppler, Justus-Liebig Universität, Bugwood.org)

At a Glance
Heptachlor Wilt

- Do not plant hop yards where heptachlor was previously applied.
- Avoid planting sensitive varieties in fields that may contain heptachlor residues.
- Heptachlor residues may increase hop susceptibility to Verticillium wilt.
- A negative soil test may not be a reliable indicator of the risk of heptachlor wilt.

Abiotic Diseases

Heptachlor Wilt

Mark E. Nelson and David H. Gent

Heptachlor is an insecticide that was used in the Pacific Northwest and likely other areas of the United States on several crops, including potato, strawberry, and sugar beet. It was used extensively in 1955 and 1956 for control of strawberry root weevil on hop and this led to severe die-out in treated hop yards. Heptachlor was removed from the U.S. market in 1972, but residues of the pesticide are extremely persistent and still can cause injury to hop plants planted in soil with levels below current detection thresholds (i.e., 1 to 10 ng/g soil). Fields treated with chlordane can also lead to wilting since this closely related pesticide also contained heptachlor. Chlordane was banned in 1983.

Symptoms

Young hop plants initially grow normally, but often cannot establish a root system and wilt and die during the summer or following season. Affected plants have a rough and corky bark that cracks and bleeds sap; stems may also exhibit a characteristic brown spotting that develops into a rot (Fig. 69). The bases of bines may swell and become brittle, causing them to break off from the crown. Leaves become yellow and die, followed by cone desiccation and wilting of entire bines (Fig. 70). Eventually entire crowns may rot, leading to plant death. The pattern of affected plants is influenced by where heptachlor was applied in the past, and often there is a distinct boundary between healthy and affected plants. Heptachlor residues also may increase the susceptibility of hop plants to Verticillium wilt.

Figure 69. Stem of a plant with heptachlor wilt shows rough, corky bark as well as brown spots that can develop into a rot. (D.H. Gent)

Figure 70. Yellowing of leaves (left) and desiccation of cones (right) due to heptachlor wilt. Symptoms often are more pronounced at the top of the plant. (D.H. Gent)

Management

Economic production of hop often is impossible in fields that were treated with heptachlor and therefore hop should not be planted to fields with a history of heptachlor wilt. Varieties vary in their sensitivity to heptachlor, although specific information on variety sensitivity is limited. Some varieties sensitive to heptachlor include Willamette, Mt. Hood, Liberty, and Crystal, while Late Cluster and some super-alpha varieties appear less sensitive.

Although soil tests can be used to detect heptachlor residues, some varieties are susceptible to heptachlor damage at levels below current detection limits. Therefore, a negative soil test may not be a reliable indicator of the risk of heptachlor wilt. In suspect fields, plants of the desired variety should be planted and observed for heptachlor wilt symptoms for at least one year before planting the entire yard.