C. B. Skotland and Dennis A. Johnson
Irrigated Agriculture Research and Extension Center
Washington State University, Prosser

Control of Downy Mildew of Hops

The hop plant (*Humulus lupulus* L.) is a perennial with clockwise twining vine (bine) that dies back to the ground each year. The male and female flowers are borne on separate plants. The papery bracts and bracteoles of mature hop cones (Fig. 1) are used almost exclusively to flavor fermented malt beverages.

Hop downy mildew, caused by *Pseudoperonospora humuli* (Miyabe & Takah.) G. W. Wilson, is a major disease in many hop-growing areas of the world. It was first reported on wild hops in Japan in 1905 and in Wisconsin in 1909 (12). It was found in England in 1920 and 7 years later had spread throughout the hop-growing areas of Europe (12). Hop downy mildew was reported in New York State and western Washington's Puyallup Valley in 1928, in western Oregon in 1930, in California in 1934, and in the Yakima Valley of south central Washington in 1937. So far, the disease has not been found in Australia, Tasmania, New Zealand, or South Africa.

Downy mildew was a factor in the decline and loss of hop production in New York, Wisconsin, and the coastal areas of California, and its occurrence in the high-rainfall areas of western Oregon and Washington led to the demise of the cultivars Early Cluster and Late Cluster in those areas. In Oregon, the industry survived by growing the more resistant cultivar Fuggle. The susceptible Cluster cultivars were shifted to the arid regions of the Sacramento Valley of California and the Yakima and Boise valleys of the Pacific Northwest. In 1982, 82% of the United States hop acreage was concentrated in the Yakima Valley (12,150 ha), Boise Valley (1,518 ha), and Sacramento Valley (199 ha). Approximately 3,007 ha of hop are grown annually in the Willamette Valley of Oregon, where environmental conditions in the spring are conducive to mildew epidemics.

Downy mildew is a constant threat in the European hop-growing areas and is controlled by use of resistant cultivars, rigid sanitation practices, and chemicals; fungicides are often applied 8–16 times in England, Yugoslavia, and Germany (12). Epidemics occur even in the arid regions of California, Idaho, and Washington. In the Yakima Valley, the potential for an epidemic exists every year because of the extremely susceptible host and the pathogen's method of overwintering, with a serious epidemic occurring 1 year out of 3 (6).

Symptoms and Disease Cycle

The pathogen overwinters as mycelium in infected buds and infected crowns, and the mycelium spreads into developing buds and shoots (1,2,13). The role of oospores is not well understood, but in New York (7) they were considered important in the overwintering of the pathogen. Oospores can be readily found in infected hop tissue in most of the hop-growing areas of the world (1,7,10). In the arid areas of California, Idaho, and Washington, oospores are rare except in infected cones, where considerable numbers may be found. In the Yakima Valley, infected cones are rare even in mildew years because the dry, hot summer weather prevents spread and infected tissue rapidly becomes necrotic. In the spring, infected and healthy shoots may be growing from the same crown. Many infected crowns have only healthy shoots, while others have one to many infected shoots (Fig. 2). These infected shoots, with short internodes and yellow-green leaves that cup downward (Fig. 3), are called basal spikes and are the source of the primary inoculum. The Cluster cultivars are particularly susceptible to crown infection. Often, the crown is killed or so weakened that many shoots die before harvest.

Control Measures

Resistance. The first hop cultivars resistant to downy mildew were released in Germany in 1962 (10), but the brewing industry is reluctant to accept new cultivars. A cultivar accepted by the industry in one area may be rejected by the industry when grown in another area. Apparently, the environment affects the organoleptic properties of a cultivar in some indefinable manner when the hop cones are used directly in the brewing process. The mildew-resistant cultivars being grown in Europe are primarily the "extract" type, ie, the bittering agents are extracted from the hop cones and the extract is used. Some of these cultivars require only two or three fungicide sprays in wet environments (12). In the United States, 75% of the hops planted in arid areas are the extremely susceptible Cluster cultivars. The remaining 25% are the cultivars Bullion, Brewers Gold, and Cascade, which are tolerant to crown and foliage infection but require fungicide sprays to control foliage infection in high-rainfall areas.

Sanitation. Removing the source of primary infection effectively reduced the severity of epidemics in 1962 (14). In Idaho, weekly spike removal reduced mildew infections by 75% and enhanced control by spraying. In Washington, only 9–10% of the hills where spikes were removed weekly had spikes at the end of May, compared with 21 and 33% of the hills in yards where spikes were not removed. Romanko (9) tested various desiccant sprays for destroying the source of primary inoculum, and dinoseb (Dinitro) rapidly and almost completely eradicated infected shoots (Fig. 4). Hop vines must be trained and 2 m high before dinoseb can be applied, however, and environmental conditions during this period could favor spread of mildew.

Crown pruning. In Washington, late pruning provides some control by shortening the downy mildew season. Hops pruned early in April have considerable growth by the first of May, whereas those pruned late in April are not ready to train until mid-May. Since June weather is usually unfavorable for infection, late pruning shortens the period of potentially favorable weather from 1 month to 2 weeks. Late pruning is effective only in an environment where the downy mildew season is relatively short, however, as in the Yakima Valley.

The epidemic of 1963 in Washington provides an excellent example of the benefits of late pruning (14). Disease was severest in yards with a history of downy mildew where crowns were not pruned or

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Fig. 1. Mature hop (*Humulus lupulus*) cones.

Fig. 2. Shoots growing from hop crown infected with downy mildew (*Pseudoperonospora humuli*).

Fig. 3. Infected shoots (basal spikes) with short internodes and yellow-green leaves cupping downward.

Fig. 4. Hop vines with bases sprayed with dinoseb to eradicate infected shoots.

were pruned early. By the first week of May, when weather favored infection, hops pruned early had spikes and hops pruned late did not.

Chemicals. The first recorded control measures—systematic removal of spikes and spraying with Bordeaux mixture—were in Japan in 1905. Bordeaux mixture and various copper spray materials are effective but must be coupled with sanitation practices.

Zineb has been the primary fungicide for downy mildew control in recent years. Because the ethylenebisdithiocarbamates decompose to ethylene thiourea (8), however, the brewing industry has requested that such residue be eliminated. Even though health hazards do not exist (4), the industry is concerned about possible adverse publicity. In England, zineb cannot be used within a month of harvest (12).

In Oregon, calcium cyanamide dusted over the top of the crown before shoots emerged reduced the development of basal spikes and also destroyed hop seedlings, which often are infected, presumably the result of oospore germination. Similar success was achieved in England with Bordeaux mixture and captan (2). Streptomycin sulfate reduced secondary infection and enabled shoots to recover from systemic infection in Oregon and England but has not been effective in Washington and California.

Metalaxyl has been used commercially in Europe and under emergency exemption registration during 1981–1983 in the United States. The compound has been effective in controlling downy mildew in experimental plots and growers' yards (5). The incidence of downy mildew during 1980 and 1981 in Washington ranged from 0 to 3% (percentage of hills with spikes) in replicated field plots and yards treated with metalaxyl and from 25 to 80% in adjacent plots, yards, and sections of yards not treated with metalaxyl.

Fungal resistance to metalaxyl has been reported and precautions are being taken to delay the selection and increase of resistant populations of *P. humuli*. A formulation of metalaxyl containing copper oxychloride is used in Europe as a foliar spray. For use in the United States, the manufacturer has suggested applying metalaxyl over the hop crowns before shoots emerge. When applied as a soil drench, metalaxyl is taken up by the hop roots. This application method has worked well in Oregon and during wet springs in Washington. In 1982, however, rainfall in Washington was sufficient for several infection periods but not adequate to carry the chemical into the root zones, so control was not effective.

Metalaxyl's success in controlling hop downy mildew has been outstanding in Oregon but not in Washington. The explanations for this could be that: 1) in Oregon, the cultivars are less prone to crown infection and the chemical acts on the oospores, whereas in Washington, the systemically infected shoots growing from the infected crown are the source of primary infection; 2) under the high-rainfall conditions of Oregon, metalaxyl is readily moved to the root system; 3) Oregon cultivars have a more developed root system than Washington cultivars; and 4) Washington grows more of the extremely susceptible Cluster cultivars. In Washington, spraying the foliage with metalaxyl shortly before or after training has been more effective than spraying the soil surface over the crown.

Disease prediction. Disease prediction models have been developed to strategically time fungicide applications in England, Germany, Yugoslavia, and Czechoslovakia (12). In general, these models use environmental factors, such as rain wetness duration, amount of rainfall, and relative humidity, and some include an inoculum variable to identify infection periods. Models in England (11,12) couple infection periods with the time delay of the subsequent incubation period so fungicide applications can be scheduled to protect against a second infection cycle. This does not prevent the first infection period of the season, however, which could be costly where cultivars are very susceptible to crown infection and when initial inoculum levels are high. The model has accurately predicted infection periods and aided disease control in England (11) but missed infection periods in Washington during the 1980 and 1981 epidemics, probably because of the susceptibility of the Cluster cultivars.

A Washington model has been developed that schedules protective fungicide sprays based on the amount of initial inoculum of *P. humuli* and the likelihood of weather conditions favorable for infection. During the spring, the National Oceanic and Atmosphere Administration provides daily weather forecasts. Levels of primary inoculum are determined by visually monitoring hop yards for spikes and by monitoring environmental conditions for sporulation on spikes. Inoculum potential is estimated from the number of spikes, night temperatures, and relative humidity. Nights with temperatures higher than 5 C and relative humidity above 70% favor sporulation, whereas cool nights can delay sporangia production on spikes for several weeks. Rainy periods with temperatures above 8 C favor infection when sporangia are present.

The Washington model has had limited testing, but forecasts during the severe downy mildew epidemics in 1980 and 1981 allowed adequate scheduling of fungicide applications. Final disease incidences were 25–80% in yards where the forecasts were not followed and 0–3% in yards where they were.

Integrating the Components

Hop downy mildew exemplifies the interactions of the various components—host, pathogen, and environment—of the disease triangle. Satisfactory control in wet environments requires sanitation practices, resistant cultivars, and timely application of fungicides. In arid environments, sanitation practices and either resistant cultivars or timely application of fungicides are needed. The cultivars grown in arid environments are susceptible to crown infection, so production losses are due to crown rot and death and rarely to infected cones. The cultivars grown in wet environments are mostly resistant to crown infection, and losses result from cone infection.

In wet environments, oospores are often abundant in infected leaves, shoots, and especially cones. In dry environments, oospores are rarely found in infected leaf and stem tissue because the tissue of the very susceptible cultivars becomes necrotic, particularly when temperatures are over 30 C. The overwintering role of oospores is unclear, but in wet environments where cultivars resistant to crown infection are grown, the germinating oospore may be an important source of primary inoculum. In arid environments, *P. humuli* perennates as mycelium in crowns of susceptible cultivars, and oospores are not a means of overwintering. Control measures may reflect the overwintering method: Chemicals have been used in high-rainfall areas to prevent the development of basal spikes (3) but have not been consistently effective in arid areas on the extremely susceptible cultivars.

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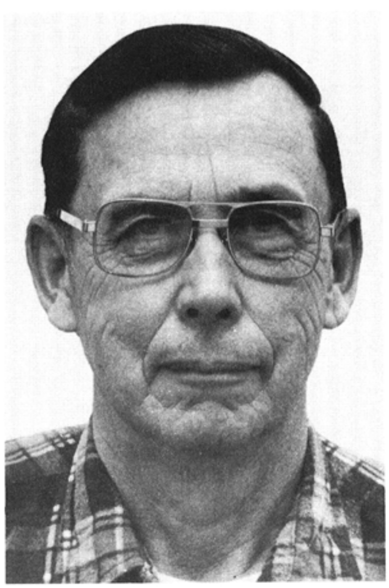

C. B. Skotland

Dr. Skotland is a plant pathologist with Washington State University, stationed at the Irrigated Agriculture Research and Extension Center in Prosser. He obtained his B.S. degree from Utah State University and his Ph.D. degree in 1953 from the University of Wisconsin. He investigated diseases of soybeans with the USDA at North Carolina State University, Raleigh, and has been with Washington State University since 1956. His research is on diseases of hops and mint.

Dennis A. Johnson

Dr. Johnson is extension plant pathologist and assistant plant pathologist at the Irrigated Agriculture Research and Extension Center in Prosser. After receiving his Ph.D. in plant pathology from the University of Minnesota, he was an assistant plant pathologist at the Texas Agricultural Experiment Station in Vernon. In 1980 he moved to Prosser, where he specializes in epidemiology and integrated pest management of irrigated crops.