Effect of Downy Mildew Epidemics on the Seasonal Carryover of Initial Inoculum in Hop Yards

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ABSTRACT

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Incidence of hop downy mildew was reduced significantly by a spray-band application of metalaxyl over hop crowns bearing small shoots, whereas it was not reduced when metalaxyl was injected into the soil near the hop crown. Incidence of primary spikes of downy mildew was significantly less the year after downy mildew was controlled with metalaxyl than when the disease had not been controlled. Incidence of primary spikes increased when severity of the epidemic had increased the preceding season. Severity of hop downy mildew one year has an effect on the level of initial inoculum the following year.

The hop downy mildew pathogen *Pseudoperonospora humuli* (Miyabe & Takah.) G. W. Wilson overwinters as mycelium in the perennial crown of hop plants (1,2,10,12). Shoots growing from infected crowns in the spring may become systemically infected by the fungus, forming typically stunted, chlorotic shoots with brittle, down-curled leaves. These shoots are known as "primary basal pikes." In Washington State, one, several, or no primary basal spikes may be produced from an infected crown (14). Sporangia that serve as an initial source of inoculum for a growing season are borne on the abaxial leaf surfaces of the primary basal spikes.

Moisture and mild temperatures favor sporulation and secondary infection (9,15). Secondary infections on shoot meristems become systemic, forming secondary spikes. Localized infection occurs on leaves, flowers, and cones. Crowns become infected by mycelial growth of the pathogen downward in secondary spikes to the crown or by zoospores infecting bine bases, probably through lenticels or wounds (10,12,15). Oospores are not known to be important in the overwintering of the pathogen (10,12). Many of the cultivars in the semiarid areas of the Pacific Northwest are particularly susceptible to crown infection and crown die out (6,13).

Severe epidemics of hop downy mildew occur sporadically in the Yakima Valley of Washington (4). Sanitation and timely applications of fungicides are needed for control (13). The systemic fungicide metalaxyl has been effective in controlling hop downy mildew (3,10,13). This study was initiated to determine the effect of controlling downy mildew with metalaxyl on the quantity of primary spikes produced the following season in hop yards.

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MATERIALS AND METHODS

Metalaxyl (Ridomil 2EC) was applied at 0.56 kg a.i./ha to plots in commercial hop yards of the Cluster cultivar L-1 in 1982 and 1983. In 1982, metalaxyl was applied in yards near Mabton, Sunnyside, and Toppenish, WA, in 1.7–2.8 hl of water per hectare the first week of May as follows: 1) a spray band about 1 m wide applied to the row over crowns bearing small shoots, 2) injected with shanks into soil on one side of crowns about 15 cm deep and 30 cm from the crown, and 3) not applied. Plot size was about 0.7 ha (15–36 × 205–450 m; 2,197 hop hills per hectare) and treatments (methods of application) were designed as a randomized complete block with four blocks each at Mabton and Sunnyside and two at Toppenish. Near Wapato, WA, in 1982, metalaxyl also was applied through a drip-irrigation system to half of a 2.4-ha yard in 371 hl of water per hectare.

In 1983, metalaxyl was applied as a spray band and compared with untreated checks in randomized complete blocks with four blocks each at Moxee, Toppenish, and Mabton, WA. Applications were made from 28 April to 6 May at 3–4.7 hl of water per hectare with individual plot sizes of 0.5–1 ha (15–38 × 260–452 m).

Disease incidence was monitored from mid-May through June at 7- to 10-day intervals by determining the percentage of hop hills with systemically infected shoots along transects running the length of each plot. The area under the disease progress curve (AUDPC) was calculated (5) for each plot from disease incidences for epidemics lasting 49 days in 1982 and 1983.

The year after metalaxyl application, primary spikes along transects through each plot were determined from 20 April to 2 May in 1983 and from 25 April to 14 May in 1984. In 1983 and 1984, the percentage of hop hills with primary spikes was determined. In 1984, the total number of primary spikes per 1,000 hills was determined. Differences between treatments at each location were statistically tested with single degree-of-freedom contrasts.

RESULTS

In 1982, secondary infections were seen first on 1 June in all plots at Mabton and

Toppenish and in two of four plots at Sunnyside in both the check and soil-injection treatments on 17 June. Mean incidences of secondary spikes at the peak of the epidemics where metalaxyl was not applied were 4.7% at Mabton, 11.3% at Toppenish (Table 1), and 0.5% at Sunnyside. Data from Sunnyside were not included in the analyses of variance because infections occurred late and were few.

The spray-band application of metalaxyl over hop crowns in 1982 significantly reduced ($P < 0.05$) the number of secondary infections of downy mildew as measured by the AUDPC and the incidence of secondary spikes at the peak of the epidemic (Table 1). Injecting metalaxyl into the soil next to the hop crown did not reduce the incidence of secondary infections (Table 1).

Fewer secondary infections of downy mildew occurred in the half of the 2.4-ha yard treated with metalaxyl through a drip-irrigation system than where it was not applied. The AUDPC was 152 and incidence of secondary spikes at the peak of the epidemic was 2.2% where metalaxyl was applied, whereas the AUDPC was 442 and incidence of secondary spikes was 18.3% where metalaxyl was not applied.

Treatments were not replicated because of the design of the drip system. Disease monitoring in this yard before metalaxyl was applied in 1982, however, showed that the incidence of primary spikes was 4.7% in the section later treated with metalaxyl and 6.5% in the section randomly selected for no metalaxyl.

In 1983, secondary infections were first seen in plots where metalaxyl was and was not applied on 16–20 May at the three locations. Mean incidences of secondary spikes at the peak of the epidemics where metalaxyl was not applied were 10.6% at Mabton, 5.5% at Moxee, and 4.2% at Toppenish (Table 1).

The spray-band application of metalaxyl over hop crowns in 1983 significantly reduced ($P < 0.01$) secondary infections at the three locations combined as measured by the AUDPC and incidence of secondary spikes. Differences between the drench application and no application of metalaxyl at the three locations are shown in Table 1.

The incidence of primary spikes was significantly reduced when downy mildew was controlled the previous season with a metalaxyl application at Toppenish ($P < 0.05$) in 1982 and at Mabton ($P < 0.01$) and Moxee ($P < 0.01$) in 1983 (Table 1).

In 1983, the season after metalaxyl was applied through a drip system, the incidence of primary spikes was 1.9% where metalaxyl was applied and 4.6% where it was not applied.

When analyzed by linear regression, the incidence of primary spikes increased significantly ($P < 0.001$) when either AUDPC or incidence of secondary spikes had increased during epidemics the preceding season. When incidence of secondary spikes was used as the independent variable, the two sets of data for 1982–1983 and 1983–1984 were combined for analysis because linear regression equations for the separate data sets were not significantly different. The coefficient of determination (R^2) was 0.70. When AUDPC was used as the independent variable, the regression equations for the two data sets were significantly different ($P < 0.05$); coefficients of determination were 0.77 for the 1982–1983 data and 0.66 for the 1983–1984 data.

DISCUSSION

Metalaxyl spray-banded over hop hills significantly reduced secondary infections in both years. When injected into the soil near the hop crown, however, metalaxyl did not reduce the incidence of secondary infections of downy mildew. The reason for this is unknown. Perhaps metalaxyl did not reach the root zone, where it could be taken up by the plant, because of soil compaction and root pruning from frequent cultivation of hop yards for weed control or because of insufficient moisture to move the fungicide into the root zone. Total rainfall in May 1982 at the National Oceanic and Atmospheric Administration's recording station in Sunnyside, WA, was only 8.6 cm, and the largest amount within a 24-hr period was 2.4 cm.

Initial inoculum exerts a great influence on epidemic development (8,11,17). Large amounts of inoculum have compensated for unfavorable or marginal environmental conditions during the development of epidemics (7,8). The amount of initial inoculum influences the occurrence of hop downy mildew epidemics in the Yakima Valley of Washington (4).

We found that controlling hop downy mildew in 1982 and 1983 reduced the number of primary spikes the following springs. This probably resulted from fewer crowns being systemically infected, thus fewer crowns with overwintering mycelium occurred where the incidence of downy mildew was less.

Primary spikes bear sporangia that serve as the initial inoculum for epidemics. Quantity of sporangia in a hop yard is a function of the number of spikes and of environmental conditions favoring sporulation (10,13). A magnitude of two to 10 times more hills had primary spikes and up to 12 times more primary spikes per 1,000 hills occurred where downy mildew was not controlled the previous season.

This difference in potential inoculum would have an effect on epidemic development and control strategies. A reduction in initial inoculum of a multiple-cycle disease such as hop downy mildew is most effective when the

Table 1. Incidence of hop downy mildew as measured by the area under the disease progress curve (AUDPC) and the incidence of secondary spikes at various locations where metalaxyl was and was not applied in 1982 and 1983 and the incidence of primary spikes the following years

Treatment	AUDPC	Incidence of secondary spikes[a] (%)	Primary spikes the following year: Incidence[b] (%)	Primary spikes the following year: Spikes per 1,000 hills
		1982[c]		
Mabton[d]				
Spray band	69*[e]	1.8*	0.15	...
Soil injection	156	3.5	0.66	...
Not applied	149	4.7	0.37	...
Toppenish[f]				
Spray band	205*	6.0*	1.51*	...
Soil injection	346	9.9	3.71	...
Not applied	360	11.3	3.44	...
		1983		
Mabton[d]				
Spray band	14*	0.4**	0.55**	9.6**
Not applied	192	10.6	3.42	62.2
Moxee				
Spray band	66*	1.9	0.20**	2.8**
Not applied	151	5.5	2.01	34.2
Toppenish[d]				
Spray band	48	2.3	0.09	0.9
Not applied	86	4.2	0.45	9.4

[a] Number of hop hills with secondary spikes per total number of hills counted when the epidemic at a location was at its peak, 14–17 June in 1982 and 25 May to 1 June in 1983.
[b] Number of hop hills with primary spikes per total number of hills counted.
[c] Error mean squares for data from Mabton and Toppenish were pooled.
[d] Means of four blocks.
[e] * = Significantly different from the not-applied treatment within a location, using single degree-of-freedom contrast, at $P < 0.05$. ** = Significantly different from the not-applied treatment within a location, using single degree-of-freedom contrast, at $P < 0.01$.

duration of the epidemic is relatively short or the infection rate is low (16). Severe epidemics of hop downy mildew in the semiarid environment of the Yakima Valley in Washington rarely endure longer than 4 or 5 wk (C. B. Skotland, *personal communication*).

A reduction of primary spikes of the magnitude observed in this study probably would contribute toward disease control but would need to be coupled with other sanitation practices and fungicide applications (13). An increase of inoculum, as observed in the plots where downy mildew was not controlled the previous season, would probably result in either high disease levels or additional control costs if accompanied by an environment favoring or marginally favoring disease development.

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