Western Regional IPM Grants Research/Extension Final Report – 15 October 2008

Project Title: Reduced Fungicide Use for Hop Downy Mildew Management

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Nontechnical Summary. The overall goal of this research and extension project is to improve hop grower profitability and sustainability with reduced-risk pest management tactics. Hop downy mildew is one of the most economically important diseases of hops grow in the US, and management relies largely on prophylactic fungicide applications. Disease forecast models can aid growers in improved use of pesticides. A growing degree-day model (based upon air temperature) that predicts the first emergence of hop shoots systemically infected with the downy mildew pathogen (i.e., primary basal spikes) was evaluated in small plots and commercial yards of cooperating growers. This model may predict when fungicide applications should begin to protect plants from the early season spread of spores from primary basal spikes. A downy mildew forecast model for secondary spread of disease was also validated in small plots. The model predicts the severity of infection events in response to weather (rainfall and hours of relative humidity about 90% in the previous 48 hr period). When an infection period is predicted to have occurred, a fungicide application is recommended to limit secondary spread of disease.

Introduction. Hop (*Humulus lupulus*) is an economically important crop in the western U.S., producing nearly the entire U.S. supply and greater than 30% of the world supply of hops. The cones of the female hop plants are used almost exclusively for imparting flavor and aroma to beer. Western U.S. hop production generates over $100 million in farm gate value annually and because nearly 50% of the crop is exported to overseas markets, hop production contributes positively to the U.S. agricultural trade balance. Because of the high value and input costs associated with hand labor of hop production, the crop is managed intensively for diseases and other pests to maximize yields and quality.

Downy mildew of hop, caused by the *Pseudoperonospora humuli*, is one of the oldest diseases of hop and remains a serious threat to sustainable and profitable hop production in the western U.S. In the wetter hop production regions of northern Idaho and western Oregon, downy mildew is an annual problem and epidemics may persist for the entire season. Hop production continues in these wetter growing regions because of the higher cone quality associated with aroma hops produced in these areas.

Because of limited cultural and biological control tactics, hop growers make regular and frequent calendar-based fungicide applications to produce crops of high yield and quality. Few effective fungicides are available for hop downy mildew suppression, and include copper formulations, cymoxanil, dimethomorph, phosphorus acid, potassium bicarbonates, trifloxystrobin, and dusting sulfur. The coppers, bicarbonates, and sulfurs have low efficacy and the more effective fungicides (cymoxanil, dimethomorph, and trifloxystrobin) have specific modes of action which are prone to resistance development. Indiscriminate use of these effective fungicides will likely select for tolerant *P. humuli* strains. A critical need exists for judicious use of these few fungicides for effective season-long downy mildew control.

The profitability of the U.S. hop industry has been seriously threatened by increased production costs and competition from foreign producers. Legislative mandates to protect threatened aquatic ecosystem in the Pacific Northwest, food safety standards established by the Food Quality Protection Act, and consumer concerns about pesticide residues underscore the need to develop and promote reduced risk pest management tactics. Disease management strategies that reduce unnecessary fungicide applications are essential to maintain and improve hop production profitability, sustainability, and ensure environmental stewardship.

A growing degree-day model that predicts the first emergence of hop shoots systemically infected with the downy mildew pathogen ("spikes") could determine when fungicide applications should commence to protect plants from the early season spread of inoculum. A downy mildew forecast model predicts the severity of infection events in response to weather. When an infection period is predicted to have occurred, a fungicide application is recommended to limit secondary spread of disease. By initiating fungicide applications based on an effective growing degree-day model and timing of necessary applications according to a downy mildew forecasting model, hop producers may provide disease suppression similar to that of the standard grower spray program, but with fewer applications.

Objective. Develop and validate disease forecasting systems for hop downy mildew in the western U.S. Research thus far has shown that at least three, perhaps four to five, fungicide sprays can be eliminated by use of the growing-degree day and infection risk model, without reducing control of the disease. Linkage of model outputs to forecasted weather resulted in overestimation of disease risk, resulting in nearly twice as many recommended fungicide applications as compared to model outputs obtained from weather measured on-site.

Approach. During each year of study, small plots of cultivar Nugget planted in experimental yards located near Corvallis were examined three to five times per week beginning from shoot emergence until the first primary spike was observed. Air temperature and soil temperature were collected. Additionally, two commercial hop yards of the cultivar Glacier were surveyed during 2005 and seven commercial hop yards (four of cultivar Willamette and three of cultivar Nugget) were surveyed during 2006 to detect the appearance of the first spike. Twenty one commercial yards (six of cultivar Willamette, ten of cultivar Nugget, and one of 'Liberty', 'Mt. Hood', 'Cascade', 'Centennial', and 'Crystal') were surveyed during 2007. Regional air and soil temperature were obtained from the nearest regional weather station.

A downy mildew forecast model developed in England (Royle, 1973) was validated in small plots described above. When an infection period is predicted to have occurred, a fungicide application is recommended to limit secondary spread of disease. Growers in England following this model often eliminated one fungicide application per season as compared to calendar-based applications, but disease control was improved significantly. Treatments included untreated, fungicide treatments applied preventatively (standard), and applications timed according to the infection risk forecast. A rotation of fosetyl-Al, cymoxanil and copper hydroxide, and trifloxystrobin and copper hydroxide were applied at the highest labeled rates. Disease severity was assessed by counting the number of primary and secondary basal spikes, in each treated hill every 7 to 14 days beginning in early April. The number of aerial spikes was counted on each plant during the evaluations. At harvest, 50 cones were collected from each plant and examined for infection. The infection risk model was further validated in assays with potted hop indicator plants. Pots of the Nugget variety were deployed for 24 or 48 h periods to expose the plants to environmental conditions and natural inoculum. Concentration of sporangia in the air was measured with a volumetric air sampler positioned near the trap plants. After the exposure period, the plants where placed in a greenhouse maintained at approximately 25ºC for 7 days. Downy mildew infection severity was assessed by counting the number of lesions per leaf area. A total of 28, 59, and 38 sets of plants (data sets) were collected for a 24-h period in 2005, 2006, and 2007, respectively. A total of 29 and 19 data sets were collected a 48-h period in 2006 and 2007, respectively. Weather and inoculum factors were related to infection severity by regression and nonparametric analyses. The Royle downy mildew model also was evaluated in 2007 using weather data measured at three sites in western Oregon or using weather data estimated from the Fox Weather, LLC/IPPC weather analysis and forecasting model (available online at http://pnwpest.org/wea). For the accuracy analysis, we calculated the difference between on-site and interpolated values (1-hour resolution) for air temperature, relative humidity, precipitation and leaf wetness on a daily basis.

Results. In 2005, a growing degree day model based on air temperature predicted the emergence of basal spikes in experimental plots of cultivar Nugget and two commercial yards of cultivar Glacier within three days of the actual emergence. During 2006, the growing degree day model based on air temperature predicted the appearance of basal spikes eight days after the first sporulating spike was observed in experimental plots of cultivar Nugget in Corvallis. In two commercial yards of cultivar Willamette, the first sporulating spikes were observed 12 days before the model predicted. Spikes were observed 5 days earlier than predicted by the model in the two other Willamette yards and three yards of cultivar Nugget, but still within the expected time range. Therefore, during 2006 the model was late in predicting disease appearance in the experimental plots and two 'Willamette' yards with very low incidence of disease (<1%), but the emergence of basal spikes was predicted within the expected range of the model for five of the commercial yards surveyed with moderate to high incidence of disease (>10%). During 2007, the growing degree day model based on air temperature was accurate in predicting the appearance of basal spikes in the experimental plots and commercial 'Nugget' yards with moderate to high disease incidence. Model performance in yards of cultivar Willamette and yards with low incidence of downy mildew has been inconsistent, although the model has been useful in timing the first fungicide application (described below).

Validation of a downy mildew forecast model that predicts the severity of infection events in response to weather (rainfall and hours of relative humidity about 90% in the previous 48 hr period) is promising. Initiating fungicide applications by the growing degree-day model significantly reduced disease as compared to the standard grower application timing in three of four years. Fungicide applications applied according to only the risk index provided disease suppression equivalent to that of the standard program in three of four years, but with three or four fewer applications during 2005 to 2008 (three fewer applications during 2005, four fewer applications in 2006, and four to five fewer applications in 2007). The infection risk model was further validated in assays with potted hop indicator plants. Disease incidence and infection severity on indicator plants varied among days when the plants were placed in the hop yard. For the plants deployed 24-hr, infection occurred on 18 of the 125 days. For the plants deployed 48-hr, infection occurred on 16 of the 48 sets of plants. Discriminate analysis was used to predict for days when disease did or did not develop on the bioassay plants. A quadratic discriminate function was developed for the 24-hr data sets that included the predictors hours of relative humidity >80%, degree-hours of wetness, and mean night temperature. In cross validation, a quadratic discriminate function with these variables classified 88.8% of days into the correct category, with 83.3% sensitivity and 89.0% specificity, assuming a nominal threshold of 0.5 for designating a day as an infection day. For the 48-hr data sets, the final model included predictor variables for hours of relative humidity > 80%, degree-hours of wetness, mean night temperature, and an interaction variable for the product of mean night temperature and hours of relative humidity > 80%. In cross validation, a quadratic discriminate function for the 48-hr data sets had 77.1% accuracy, 68.8% sensitivity, and 81.3% specificity, assuming a nominal threshold of 0.5. Optimal management action thresholds to minimize average costs associated with disease control and crop loss due to classification errors were determined using estimates of economic damage during vegetative development and on cones near harvest, and ranged 0.31 to 0.1. The value of the model in management decision making appears to be when disease prevalence is relatively low during vegetative development, which generally corresponds to the relatively dry periods from late spring to mid-summer in the Pacific Northwestern U.S.

Uncertainty analysis indicated that moisture elements (e.g., humidity and rain) were a more important source of error than temperature estimates. These errors affected model performance, resulting in nearly twice as many recommended fungicide applications as compared to model outputs obtained from weather measured on-site. Research is ongoing to reduce errors and improve the utility of weather forecasts to enhance the value of downy mildew forecasts.

Impacts. Research thus far has shown that at least three, perhaps four to five, fungicide sprays can be eliminated by use of the growing-degree day and infection risk model, without reducing control of the disease. Multiple growers also have utilized the information from the degree-day model validation studies to time the initiation of fungicide applications. If 50 % of the U.S. hop acreage is managed with the aid of this disease forecasting system, 15,000 pounds of fungicide would not be applied annually (assuming that three sprays were eliminated) and would save producers an estimated $900,000 annually in pesticide and application costs; helping grower profitability as well as reducing pesticide use and associated environmental impacts. Five presentations were made to grower groups during July 2005 (60 attendees), January 2006 (260 attendees), August 2006 (55 attendees), January 2007 (250 attendees), and August 2007 (50 attendees). Annual technical reports were provided to the hop industry during 2005 through 2007.