Cultural, biological and chemical management of downy mildew of hops

Annual report for the OMAFRA-UofG Research Program
11 July, 2017

Katerina Jordan, Asifa Munawar and Cathy Bakker
University of Guelph, Dept. of Plant Agriculture, Simcoe Research Station

UNIVERSITY of GUELPH

Ontario

Cultural, biological and chemical management of downy mildew of hops
Annual report – OMAFRA-UofG Research Program

Katerina Jordan, Asifa Munawar and Cathy Bakker

University of Guelph, Dept. of Plant Agriculture, Simcoe Research Station, 1283 Blueline Rd, Simcoe ON, N3Y 4N5

1.0 Introduction

Hop downy mildew, caused by *Pseudoperonospora humuli*, is one of the most devastating diseases of hops. Depending on the susceptibility of the cultivar and the timing of infection, yield loss can range from nondetectable to 100% crop loss if cones become infected or if the plant dies from infected, rotted crowns. The pathogen can overwinter in dormant hop buds or crowns causing a persistent systemic infection and subsequent infection of the bines and cones whenever weather conditions are favourable.

Timing of fungicide applications for downy mildew is critically important, and most growers apply sprays at routine intervals or rely on weather forecasts for their area, which are often inaccurate, leading to unnecessary or ineffective applications. Downy mildew forecasting models exist for other hop growing regions, however these have not been scientifically validated on hops in eastern North America. Determining appropriate timing of application will allow growers to optimize fungicide treatments.

In 2015, Regalia Maxx was registered for emergency use on hops, but this registration will soon expire leaving Copper 53W as the only organic downy mildew fungicide registered in Canada. Currently, organic growers do not have enough registered products to provide season long control or follow a proper rotation. Evaluation of new organic products with potential for registration and efficacy data to support registration is needed.

Since downy mildew infection can become systemic, applying fungicides with systemic activity in the plant is an important management tool. The only systemic fungicide registered for hops in Canada is Ridomil (metalaxyl). However, metalaxyl products are no longer recommended in parts of the U.S. due to resistant pathogen strains. There is concern among Ontario growers that metalaxyl resistant strains are present in Ontario but no work has been done to verify this. Reports of insensitivity to Aliette (fosetyl-Al), another systemic fungicide, is also widespread in the U.S. Ontario growers consider Aliette to be a high priority product for registration in Canada, but concerns regarding resistance have discouraged efforts to pursue registration.

Knowledge of the susceptibility to downy mildew of hop cultivars is lacking. There is considerable inconsistency from source to source in U.S. literature regarding disease susceptibility, making it difficult for growers to select appropriate cultivars. Growing tolerant/resistant cultivars will decrease the need for fungicide applications and will be especially useful for organic growers who have limited control options.

Successful management of hop downy mildew requires an integrated approach. In this project, we will assess various strategies (cultural, biological and chemical) for controlling hop downy mildew under Ontario conditions. This research will provide Ontario hop growers with a better understanding of downy mildew management and more options for disease control methods.

The goal of this project is to improve management of hop downy mildew (DM) by:

1) Validating existing DM forecasting models for use by Ontario hop growers. This will be achieved by: a) identifying monitoring sites to record environmental data and DM incidence; and b) establishing a replicated field trial to evaluate the accuracy and efficacy of a DM model.
2) Evaluating biological/organic fungicides for control of hop DM and cone diseases.
3) Evaluating differences in susceptibility of DM in hop cultivars.
4) Test DM from Ontario hop yards for resistance to metalaxyl-M and fosetyl-AL fungicides.

This report summarizes the results from year 1.

2.0 Materials and Methods

2.1 Validation of an existing hop downy mildew (DM) forecasting model

Downy mildew and weather monitoring sites were set up at the University of Guelph, Simcoe Research Station near Simcoe ON, and at three commercial hop farms near Meaford, Tavistock and Caledon. Farms will be identified using a randomly assigned number for confidentiality purposes. Hops at all sites were managed according to typical commercial practices, including application of fungicides for downy mildew control. Downy mildew assessment data collected as part of the cultivar evaluation described in section 2.3 of the methods were used to validate the downy mildew forecast model. At the commercial farms, weather monitoring equipment (HOBO brand, Hoskins Scientific) were installed in late July. Due to the delay in setting up the weather stations, data from the nearest Environment Canada weather station was used. At the Simcoe Research Station, weather data was collected by the on-site weather station, maintained by Weather Innovations Network. Air temperature, relative humidity and rainfall was recorded at each site and used to calculate the Disease Risk Index (DRI), according the following formula developed by Royle (1973, 1979):

(i) If no rain was recorded during the previous 48 h, then DRI = 0, else;

(ii) If mean temperature was less than 8°C during a period of rain, then DRI = 0;

(iii) DRI = -63 + (22*RH) + (84*Rain), where 'RH' is the number of hours of relative humidity ≥90% in the previous 48 h, and 'Rain' is millimeters of rain in the previous 48 h.

Values of DRI were calculated daily and a threshold of 500 DRI units was considered to be a severe infection event that warranted a fungicide application.

2.2 Evaluating biological/organic fungicides for control of hop downy mildew (DM) and cone diseases.

A new hop trellis system was erected at the Simcoe Research Station in spring 2017. Plants (cv. Chinook, Centennial) are on order from a propagator in New York State and will be planted by the end of July 2017. Plants will be inoculated and treatments applied in 2018, 2019 and 2020. Treatments will consist of an unsprayed check, Regalia Maxx and a maximum of 5 additional biological/organic fungicides. The list of products will be finalized based on input from growers, industry and government but may include Actinovate (*Streptomyces lydicus*), Organocide (sesame oil, refined fish oil), Sonata (*Bacillus pumilus*), Serenade Opti (*Bacillus subtilis*), Buran (garlic powder) and Tivano (citric acid, lactic acid). Each product will be applied a maximum of 5 times in rotation with Copper 53W starting in late May. An appropriate PHI for each product will be observed. Products will be applied to the foliage using a motorized backpack sprayer or small airblast sprayer. A DM susceptible cultivar will be grown and inoculated with DM in 2016 and again in 2017 before treatment applications commence. Disease incidence and severity will be assessed weekly during the growing season. Yield will be recorded and cones will be assessed for DM and other cone diseases.

2.3 Evaluating differences in susceptibility of downy mildew (DM) in hop cultivars

Six sites were monitored for downy mildew incidence in 2016. These included the Simcoe Research Station and commercial hop farms near Caledon, Collingwood, Meaford, Tavistock, and Windham. Farms will be identified using a randomly assigned number for confidentiality purposes. A total of 25 different hop cultivars were evaluated. A list of assessment dates and cultivars for each site can be found in Table 1.1. The cultivars assessed at the Simcoe Research were planted in 2013 as part of a replicated and randomized cultivar trial. Cultivars were arranged in a randomized complete block design with four replications. Hops at all sites were managed according to typical commercial practices, including application of fungicides for downy mildew control. At the Simcoe Research Station, the percentage of plants with basal spikes, aerial spikes and foliar lesions and severity of the foliar lesions was recorded on each assessment date. The severity of foliar lesions was assessed using a rating scale of 0-10, where: 0=no disease, 1=1-10% leaf area diseased, 2=11-20%, 3=21-30% .... 9= 81-90%, 10=dead leaf. At the Simcoe Research Station, foliar symptoms of powdery mildew was assessed on 8 June. Cone diseases were assessed at the Simcoe Research Station and the five grower sites by assigning a rating based on the amount of 'browning' on the cones. The cones were then examined and specific pathogens isolated using microscopy. At harvest, 100 cones from each cultivar were rated for the severity of cone diseases using a scale of 0-5 with: 0= no disease, 1= <10% of bracts with brown lesions, 2= 11-25%, 3= 26-49%, 4= 50-79%, 5= > 80%. Disease severity ratings were used to calculate the Disease Severity Index using the equation:

$$\text{DSI}= \frac{[(\text{class no.})(\text{ no.of leaves in each class})]}{(\text{total no. leaves per sample})(\text{n0.classes}-1)} \text{ x100}$$

At the other sites the percentage of plants with symptoms of downy mildew (basal/aerial spikes or foliar lesions) were recorded. Data from the Simcoe Research Station were analyzed using the General Linear Model procedure of SAS ver. 9.2. Means were separated using Fishers Protected LSD test at P = 0.05.

2.4 Test downy mildew (DM) from Ontario hop yards for resistance to metalaxyl-M and fosetyl-AL fungicides.

This objective was scheduled to be completed in 2016, but not enough inoculum could be collected due to the low incidence of downy mildew. This work will be conducted in 2017-2018. The prevalence of metalaxyl and fosetyl-Al resistance/insensitivity among Ontario isolates of P. humuli will be determined using a fungicide sensitivity assay. A total of 50 basal spikes from conventional hop yards (where metalaxyl has been applied) and one organic hop yard (where metalaxyl has not been applied) will be collected. Zoosporagia released from the basal spikes will be used to inoculate hop leaf disks of a DM susceptible cultivar. Prior to inoculation, leaf disks will be placed in petri plates containing water agar media amended with 25 µg/ml of metalaxyl or fosetyl-Al. After 7-11 days, leaf disks will be examined using a stereomicroscope and the incidence of sporulation will be recorded. An isolate will be considered insensitive to the fungicide if the incidence of sporulation on fungicide amended media is 50% or more of the sporulation on non-amended media. An effective dose assay will also be done to determine the concentration of fungicide that effectively reduces the incidence of sporulation to 50% of the untreated control. Zoosporangia from 5 basal spikes will be used to inoculate leaf disks as described above. Media will be amended with 0, 1, 10, 50 and 100 µg/ml of fungicide. The incidence of sporulation at each dosage will be determined and the effective dose will be calculated.

3.0 Results and Discussion

Only results from objectives 1) and 3) are available at this time (please see the Materials and Methods section for details). We expect to have preliminary results for objective 4) after 2017 and objective 2) after 2018.

3.1 Evaluating differences in susceptibility of downy mildew in hop cultivars

Overall, the incidence and severity of hop downy mildew was low in 2016, likely due to above average temperatures in June-Aug and below average rainfall from May-Aug (Table 1.2). At the commercial hop yards, incidence was low-moderate in May and decreased over the growing season. Disease incidence varied among cultivars and sites. Incidence was higher at the organic sites in May-July, but values decreased to zero in Aug. At the commercial sites, no cultivar stood out as being consistently more tolerant, partly due to the overall low incidence of downy mildew but also to variability from site to site. This is likely related to differences in source of the original plant material and management practices at each site. At farm 1, downy mildew was most severe in Fuggle, followed by Magnum, Chinook, Hallertau, Cascade and Centennial (Table 1.3). At farm 2, downy mildew was only found in Cascade, while at farm 3, only Centennial showed symptoms. At farm 4, low levels of disease were found in Centennial and Rakau. At farm 5, all cultivars were equally infected.

Disease incidence was higher in the replicated cultivar trial at the Simcoe Research Station compared to the commercial sites. However, incidence of downy mildew also decreased over the growing season. The percent of plants with basal spikes and the number of basal spikes per plant was highest in Bertwell, followed by Centennial, Crystal, Zeus, Chinook, Northern Brewer and Sterling (Table 1.4). No downy mildew basal spikes were found in Galena, Hallertauer or

Cascade. Incidence of aerial spikes was highest in Centennial, followed by Bertwell, Crystal, Zeus, Sterling, Hallertauer and Norther Brewer (Table 1.5). Foliar lesions were sporadic with Bertwell and Centennial the most severely infected, followed by Zeus, Crystal, Chinook, Galena and Cascade (Table 1.6). Overall, downy mildew was severe in Bertwell, Centennial and Crystal, moderate in Zeus, Chinook and Norther Brewer and low-zero in Sterling, Galena, Hallertauer and Cascade.

Powdery mildew was observed at the Simcoe Research Station. The incidence of foliar lesions was highest in Bertwell and Cascade, followed by Centennial, Hallertauer, Chinook, Galena, Sterling, Northern Brewer and Zeus (Table 1.7). Powdery mildew fungicides were applied after the initial appearance of symptoms, so disease severity was low. Disease incidence decreased over the growing season and did not impact cone quality at harvest.

Cone diseases were widespread but severity was moderate in 2016 at the Simcoe Research Station. All cultivars were affected, but the percent of infected cones was highest in Sterling and Zeus, followed by Northern Brewer, Centennial, Hallertauer, Galena, Bertwell, Cascade, Chinook and Crystal (Table 1.8). The percent of infected cones and disease severity at the grower sites also varied among the cultivars (Table 1.9). The percent of infected cones ranged from 0 to 100% but disease severity was low to moderate. Severity of cone diseases was highest for Centennial and Fuggle, followed Newport, Mt Hood, Chinook, Cascade, Glacier, Willamette and Hallertauer. Disease severity was very low for all remaining cultivars. Only Rakau was free of cone disease symptoms. *Alternaria* sp. was the only pathogen isolated from the cones in 2016.

3.2 Validation of an existing downy mildew forecasting model

The downy mildew forecasting model indicated a total of nine 'infection events' at the Simcoe Research Station, five events at farm 1, fifteen events at farm 4 and nine events at farm 5 (Figs. 2.1-2.4). However, the incidence of downy mildew decreased steadily during the growing season and no new infection or sporulation was observed at any of the monitoring sites except at the Simcoe Research Station in early June. This could be due to the application of fungicides to control downy mildew, but disease incidence decreased even in unsprayed plots at the Simcoe Research Station. The model used in this study was developed in England and incorporates a minimum temperature below which infection is not likely to occur but does not include a maximum temperature. Conditions where downy mildew infection can occur have been reported as 8-23°C and a wet period of 3-6 h for shoot infection and 15-29°C with a wet period of 1.5-2 h for leaf infection. Leaf infection can occur at temperatures as low as 5°C during wet periods of

24 h or longer (Mehaffe et al. 2009). Average air temperature was above normal in June, July and August in 2016 (Table 1.2) and there were a total of 24 days during this period where the maximum air temperature was over 29°C. It is possible that a maximum temperature may be need to be incorporated in the model to accurately reflect downy mildew infection in our climate.

Another weakness of this model is that it is reactive rather than predictive. Data from the previous 48 hrs are used in the model, and if an infection event occurred, it is too late for protective fungicides to be applied. In order for this model to be useful to growers, forecasted weather data will need to be used to predict when infection periods might occur. This work will continue in 2018 and 2019.

4.0 Acknowledgements

We would like to thank the OMAFRA/UofG Research Program for providing the funding for this project. The financial support of the Ontario Hop Growers Association is also greatly appreciated. We also appreciate the participation of our grower cooperators who allow us to have access to their hop yards. Melanie Filotas, IPM Specialist for Specialty Crops, OMAFRA graciously provided assistance with scouting, insect identification and scout training. The authors are grateful for her participation. Our work would not be possible without the help of our summer students and farm crew at the Simcoe Research Station.

5.0 Literature cited

Mahaffee, W., B. Engelhard, D.H. Gent, & G.G. Grove. 2009. Downy Mildew. In W. Mahaffee, S. J. Pethybridge, & D. H. Gent (Eds.), Compendium of Hop Diseases and Pests (pp. 18-22). St. Paul, Minnesota: The American Phytopathological Society.

Royle, D. J. 1973. Quantitative relationships between infection by the hop downy mildew pathogen, Pseudoperonospora humuli, and weather and inoculum factors. Ann. Appl. Biol. 73:19-30.

Royle, D. J. 1979. Prediction of hop downy mildew to rationalize fungicide use. Rep. Dep. Hop Res. Wye Coll. 1978:49-57.

Table 1.1. Assessment dates and cultivars evaluated at each hop downy mildew monitoring site in 2016.

Site	Cultivars assessed	Assessment dates
Simcoe Research Station	Cascade, Hallertauer, Sterling, Northern Brewer, Zeus, Crystal, Chinook, Galena, Centennial, Bertwell	30 May, 8, 15, 23, 30 June 11, 27 July 3, 9, 15 Aug
Farm 1	Chinook, Centennial, Magnum, Fuggle, Hallertau, Cascade	18 May, 29 June, 22 July, 24 Aug
Farm 2	Cascade, Chinook, Willamette, Wild Turkey, Nugget, Mt. Hood, Hallertau, Perle, Sterling, Vojvodina, Santiam, Crystal, Centennial, Galena, Magnum, US Golding, Fuggle, East Kent Golding	18 May, 29 June, 22 July, 24 Aug
Farm 3	Centennial, Cascade, Willamette, Chinook, Columbus	31 May, 24 June, 29 July, 25 Aug
Farm 4	Hallertauer, Newport, Centennial, Cascade, Rakau, Glacier, Heritage	25 May, 26 June, 29 July, 17 Aug
Farm 5	Willamette, Mt. Hood, Cascade, Fuggle, Nugget	31 May, 26 June, 25 July, 23 Aug

Table 1.2. Air temperature and precipitation for May-August 2016 and 10 year climate averages, Simcoe Research Station, Simcoe ON.

Month	Average Temperature (°C)		Total Precipitation (mm)	
	2016	10 yr average	2016	10 yr average
May	14.7	14.5	39	70
June	20.1	19.6	34	83
July	23.6	21.8	47	82
August	24.0	20.9	26	86

Table 1.3. Disease incidence of hop downy mildew in five commercial yards in Ontario in May to August 2016.

Hop Farm	Farm-Type	Cultivar	Disease incidence (%) assessed at different dates			
			18 May	29 June	22 July	24 Aug
1	Organic	Chinook	7-10	<5	0	0
		Centennial	1 or less	5	0.5 or less	0
		Magnum	10	2	0.5 or less	0
		Fuggle	20	1	0.5 or less	0
		Hallertau	1	<1	0	0
		Cascade	1	1	0	0
Hop Farm	Farm-Type	Cultivar	Disease incidence (%) assessed at different dates			
			18 May	29 June	22 July	24 Aug
2	Conventional	Cascade	5-8	0	0	0
		Chinook	0	0	0	0
		Willamette	0	0	0	0
		Wild Turkey	0	0	0	0
		Mt hood	0	0	0	0
		Perle	0	0	0	0
		Hallertau	0	0	0	0
		Vojvodina	0	0	0	0
		Santiam	0	0	0	0
		Crystal	0	0	0	0
		Centennial	0	0	0	0
		Galena	0	0	0	0
		US Golding	0	0	0	0
		Fuggle	0	0	0	0
		East Kent Golding	0	0	0	0
		Magnum	0	0	0	0
Hop Farm	Farm-Type	Cultivar	Disease incidence (% age) assessed at different dates			
			31 May	24 June	29 July	25 Aug
3	Conventional	Centennial	1	0	0	0
		Cascade	0	0	0	0
		Willamette	0	0	0	0
		Chinook	0	0	0	0
		Columbus	0	0	0	0
Hop Farm	Farm-Type	Cultivar	Disease incidence (%) assessed at different dates			
			25 May	26 June	29 July	17 Aug
4	Conventional	Hallertau	0	0	0	0
		New Port	0	0	0	0
		Centennial	0	1	0	0
		Cascade	0	0	0	0
		Rakau	1	0	0	0
		Glacier	0	0	0	0
		Heritage	0	0	0	0
Hop Farm	Farm-Type	Cultivar	Disease incidence (% age) assessed at different dates			
			31 May	27 June	25 July	23 Aug
5	Organic	Willamette	<5	0	0	0
		Mt Hood	<5	0	0	0
		Cascade	<5	0	0	0
		Fuggle	<5	0	0	0
		Nugget	<5	<1	0	0

Table 1.4. Percent of plants with downy mildew basal spikes and number of basal spikes per plant of ten hop cultivars grown at the Simcoe Research Station, Simcoe ON, 2016.

Cultivar	30 May	8 June		15 June		23 June		30 June		11 July		27 July	
	% infected	% infected	no. per plant	% infected	no. per plant	% infected	no. per plant	% infected	no. per plant	% infected	no. per plant	% infected	no. per plant
Bertwell	65 a	65 a[1]	4.2 ns[2]	60 a	2.9 a	55 a	4.0 a	35 ns	1.8 ns	20 a	0.4 ns	0 ns	0 ns
Centennial	20 bc	50 ab	1.3	20 b	0.8 b	25 b	1.5 b	20	1.1	5 b	0.3	0	0
Crystal	35 b	45 ab	0.9	20 b	0.2 b	5 b	0.1 b	5	0.1	0 b	0.0	0	0
Zeus	15 bc	30 bc	0.3	10 b	0.1 b	5 b	0.2 b	0	0.0	0 b	0.0	0	0
Chinook	15 bc	13 c	0.2	8 b	0.1 b	0 b	0.0 b	0	0.0	0 b	0.0	0	0
N. Brewer	10 bc	10 c	0.1	5 b	0.1 b	10 b	0.1 b	0	0.0	0 b	0.0	0	0
Sterling	5 c	10 c	0.0	5 b	0.1 b	0 b	0.0 b	0	0.0	0 b	0.0	0	0
Galena	0 c	0 c	0.0	0 b	0.0 b	0 b	0.0 b	0	0.0	0 b	0.0	0	0
Hallertauer	0 c	0 c	0.0	0 b	0.0 b	0 b	0.0 b	0	0.0	0 b	0.0	0	0
Cascade	0 c	0 c	0.0	0 b	0.0 b	0 b	0.0 b	0	0.0	0 b	0.0	0	0

[1] Numbers in a column followed by a different letter were significantly different at $P = 0.05$, Fisher's Protected LSD.

[2] ns indicates no significant differences were found among the treatments at $P = 0.05$.

Table 1.5. Percent of plants with downy mildew aerial spikes and number of aerial spikes per plant of ten hop cultivars grown at the Simcoe Research Station, Simcoe ON, 2016.

Cultivar	8 June		15 June		23 June		30 June		11 July		27 July	
	% infected	no. per plant	% infected	no. per plant	% infected	no. per plant	% infected	no. per plant	% infected	no. per plant	% infected	no. per plant
Centennial	45 a[1]	0.9 ns[2]	40 a	0.8 ns	25 ns	0.6 ns	20 a	0.4 ns	10 ns	0.1 ns	10 ns	0.2 ns
Bertwell	40 ab	0.6	40 a	0.5	25	0.4	30 a	0.4	20	0.2	0	0.0
Crystal	30 abc	0.4	35 ab	0.5	10	0.1	15 ab	0.2	10	0.1	5	0.1
Zeus	16 bcd	0.2	15 abc	0.2	0	0.0	0 b	0.0	0	0.0	0	0.0
Hallertauer	5 cd	0.1	5 c	0.1	0	0.0	0 b	0.0	0	0.0	0	0.0
Sterling	5 cd	0.1	10 c	0.1	5	0.1	0 b	0.0	0	0.0	0	0.0
Chinook	0 d	0.0	0 c	0.0	0	0.0	0 b	0.0	0	0.0	0	0.0
Galena	0 d	0.0	0 c	0.0	0	0.0	0 b	0.0	0	0.0	0	0.0
N. Brewer	0 d	0.0	5 c	0.1	5	0.1	0 b	0.0	5	0.1	0	0.0
Cascade	0 d	0.0	0 c	0.0	0	0.0	0 b	0.0	0	0.0	0	0.0

[1] Numbers in a column followed by a different letter were significantly different at $P = 0.05$, Fisher's Protected LSD.

[2] ns indicates no significant differences were found among the treatments at $P = 0.05$.

Table 1.6. Percent of plants with downy mildew foliar lesions and severity of foliar lesions of ten hop cultivars grown at the Simcoe Research Station, Simcoe ON, 2016.

Cultivar	8 June		15 June		23 June		30 June		11 July		27 July	
	% infected	DSI[1]	% infected[1]	DSI	% infected	DSI	% infected	DSI	% infected	DSI	% infected	DSI
Bertwell	40 a[2]	12.5 a	0 ns[3]	0 ns	30 ab	5.0 a	5 ns	0.5 ns	5 ns	0.5 ns	0 ns	0.0 ns
Centennial	15 b	5.0 b	0	0	40 a	4.0 ab	5	0.5	5	0.5	5	1.0
Crystal	15 b	2.0 b	0	0	20 abc	2.0 abc	0	0.0	5	0.5	0	0.0
Zeus	5 b	1.5 b	0	0	15 bc	2.0 abc	0	0.0	0	0.0	0	0.0
Chinook	0 b	0.0 b	0	0	13 bc	1.8 bc	0	0.0	0	0.0	0	0.0
N. Brewer	0 b	0.0 b	0	0	5 c	0.5 c	0	0.0	0	0.0	0	0.0
Sterling	0 b	0.0 b	0	0	0 c	0.0 c	0	0.0	0	0.0	0	0.0
Galena	0 b	0.0 b	0	0	0 c	0.0 c	10	1.0	0	0.0	0	0.0
Hallertauer	0 b	0.0 b	0	0	0 c	0.0 c	0	0.0	0	0.0	0	0.0
Cascade	0 b	0.0 b	0	0	5 c	0.5 c	0	0.0	0	0.0	0	0.0

[1] DSI = Disease Severity Index

[2] Numbers in a column followed by a different letter were significantly different at $P = 0.05$, Fisher's Protected LSD.

[3] ns indicates no significant differences were found among the treatments at $P = 0.05$.

Table 1.7. Incidence and severity of foliar powdery mildew symptoms in ten hop cultivars grown at the Simcoe Research Station, Simcoe ON, 2016.

Cultivar	Percent infected (%)	Disease severity index[2]
Bertwell	90 a	18.0 a
Cascade	80 a	7.0 b
Centennial	25 b	2.5 b
Hallertauer	15 b	1.5 b
Chinook	10 b	1.0 b
Galena	10 b	3.0 b
Sterling	5 b	0.5 b
Northern Brewer	5 b	0.5 b
Crystal	0 b	0.0 b
Zeus	0 b	0.0 b

[1] Numbers in a column followed by a different letter were significantly different at *P* = 0.05, Fisher's Protected LSD.

[2] Ratings of powdery mildew severity were used to calculate the Disease Severity Index using the equation:

$$\text{DSI}= \frac{[(\text{class no.})(\text{ no.of leaves in each class})]}{(\text{total no. leaves per sample})(\text{n0.classes}-1)} \text{ x}100$$

Table 1.8. Incidence and severity of cone diseases in ten hop cultivars grown at the Simcoe Research Station, Simcoe ON, 2016.

Cultivar	Percent infected (%)	Disease severity index[2]
Sterling	100 a	47.3 a
Zeus	100 a	45.4 ab
Northern Brewer	97 a	35.9 abc
Centennial	88 ab	45.8 ab
Hallertauer	87 ab	41.7 ab
Galena	77 bc	36.8 abc
Bertwell	70 bcd	32.1 bc
Cascade	66 cd	25.3 cd
Chinook	55 de	25.4 cd
Crystal	41	14.2 d

[1] Numbers in a column followed by a different letter were significantly different at *P* = 0.05, Duncan's Multiple Range Test.

[2] Ratings of cone disease severity were used to calculate the Disease Severity Index using the equation:

$$\text{DSI}= \frac{[(\text{class no.})(\text{ no.of leaves in each class})]}{(\text{total no. leaves per sample})(\text{n0.classes}-1)} \text{ x}100$$

Table 1.9. Incidence and severity of cone diseases on various hop cultivars from five commercial hop yards in 2016.

Hop Farms	Cultivars	DSI[1]	Percent infected	Average DSI	Average percent infected
1	Cascade	12.8	45	17.6	47
2	Cascade	5.0	25		
3	Cascade	38.4	69		
4	Cascade	7.2	27		
5	Cascade	25.0	71		
1	Centennial	15.4	51	35.5	65
3	Centennial	35.8	56		
4	Centennial	55.4	89		
1	Chinook	27.4	100	18.4	59
2	Chinook	5.8	20		
3	Chinook	22.1	57		
2	Crystal	4.6	21	4.6	21
2	East Kent Golding	2.0	10	2.0	10
1	Fuggle	35.4	98	33.2	99
5	Fuggle	31.0	100		
2	Galena	6.0	30	6.0	6
4	Glacier	15.8	46	15.8	46
2	Hallertauer	13.2	58	13.2	58
1	Magnum	5.0	25	7.9	39
2	Magnum	10.8	54		
2	Mt Hood	6.0	30	24.3	61
5	Mt Hood	42.6	92		
4	Newport	25.2	59	25.2	59
2	Nugget	6.7	23	4.8	17
5	Nugget	2.9	11		
2	Perle	5.2	26	5.2	26
4	Rakau	0.0	0	0.0	0
2	Santiam	6.8	29	6.8	29
2	US Golding	4.6	16	4.6	16
2	Vojoudina	2.2	11	2.2	11
2	Wild Turkey	2.0	10	2.0	2
2	Willamette	6.5	27	15.6	49

[1] Ratings of cone disease severity were used to calculate the Disease Severity Index using the equation:

$$DSI= \frac{[(\text{class no.})(\text{ no.of leaves in each class})]}{(\text{total no. leaves per sample})(\text{n0.classes}-1)} \text{ x}100$$

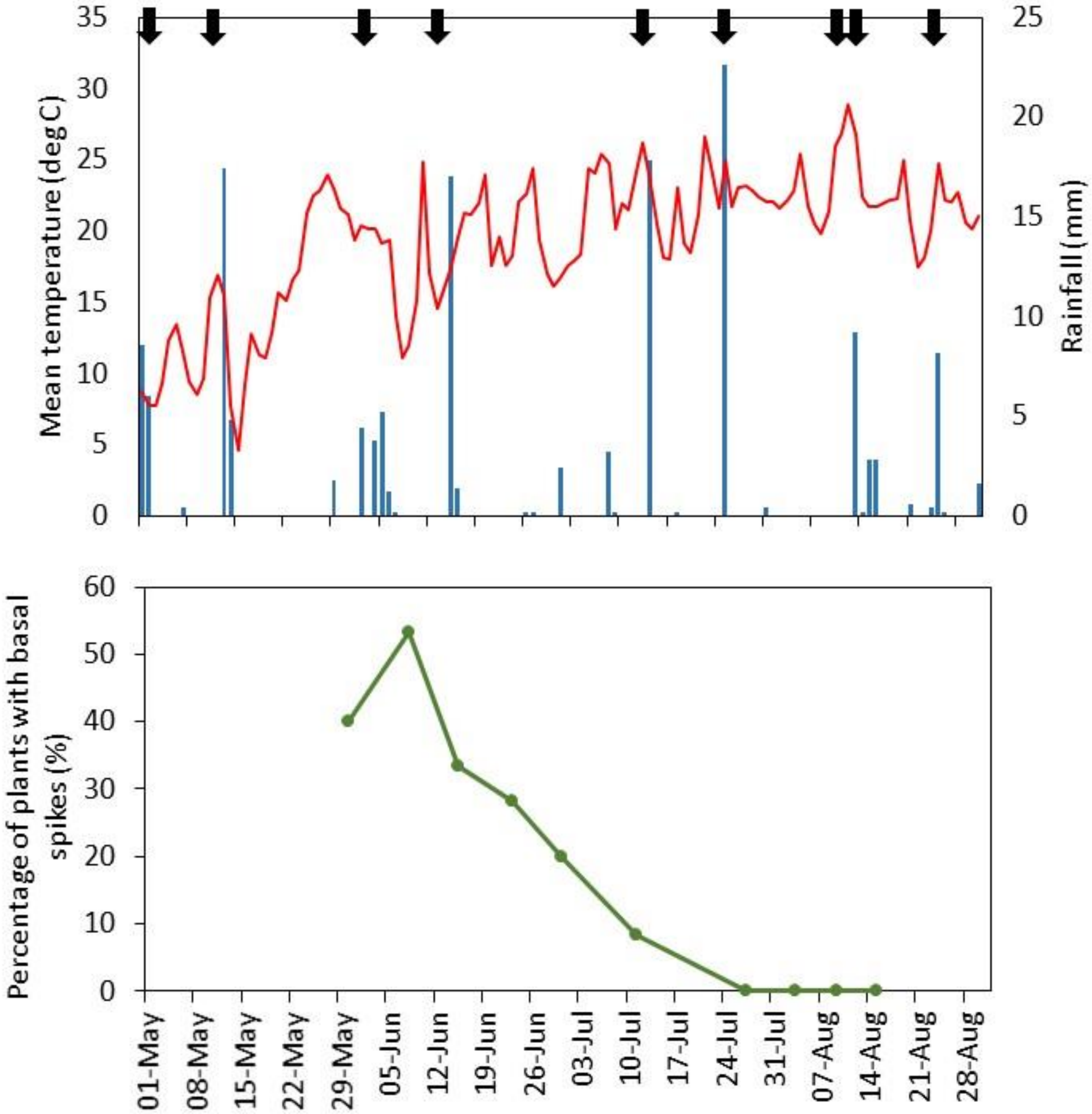

Figure 2.1. Mean temperature, rainfall and the percentage of plants with downy mildew basal spikes (average of Bertwell, Centennial and Crystal) at the Simcoe Research Station from May to August 2016. The black arrows at the top of the graph indicate periods when the DRI reached the 500 unit threshold indicating an infection event.

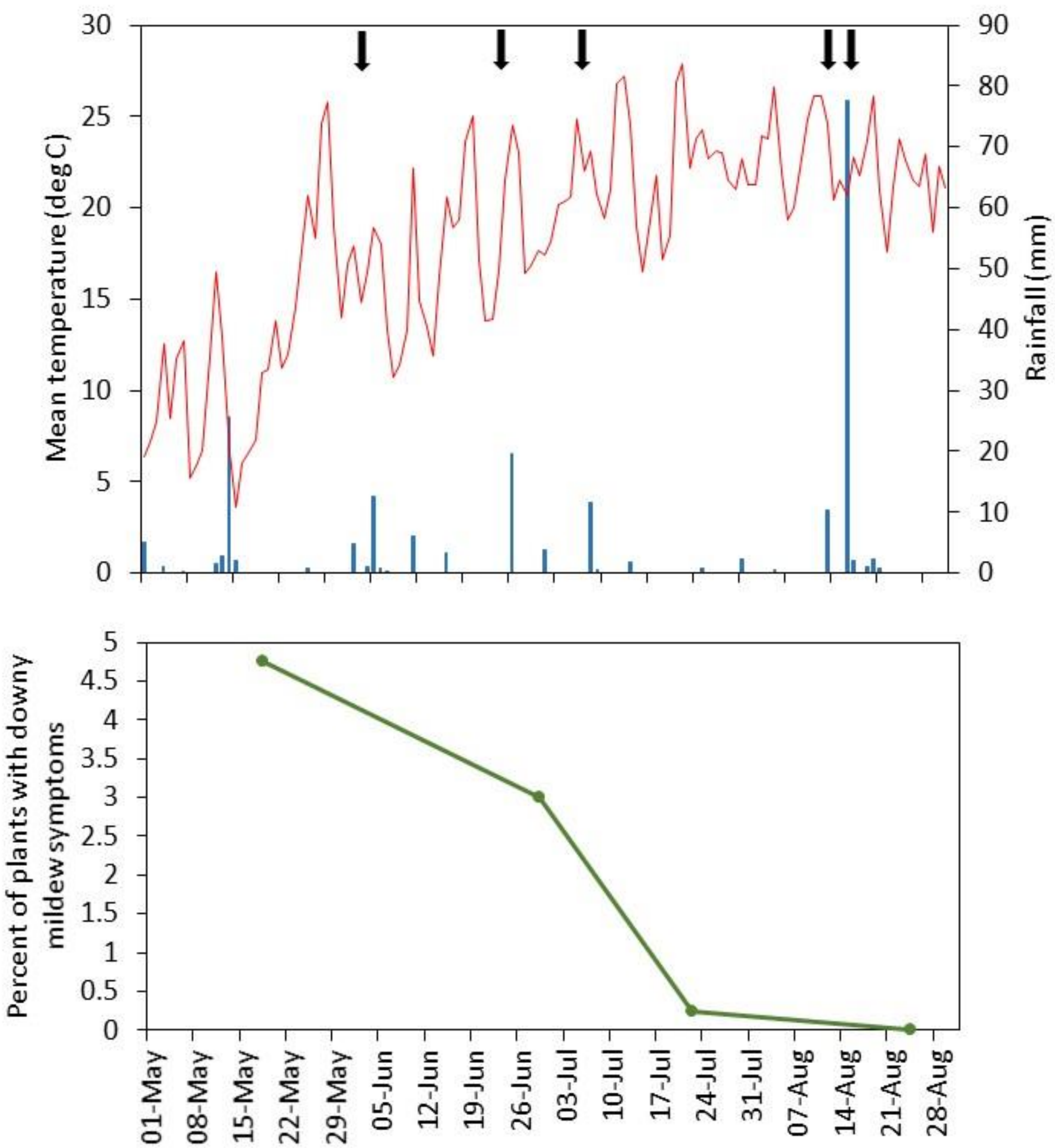

Figure 2.2. Mean temperature, rainfall at farm 1 from May to August 2016. Data from the Environment Canada weather station in Collingwood was used. The black arrows at the top of the graph indicate periods when the DRI reached the 500 unit threshold indicating an infection event.

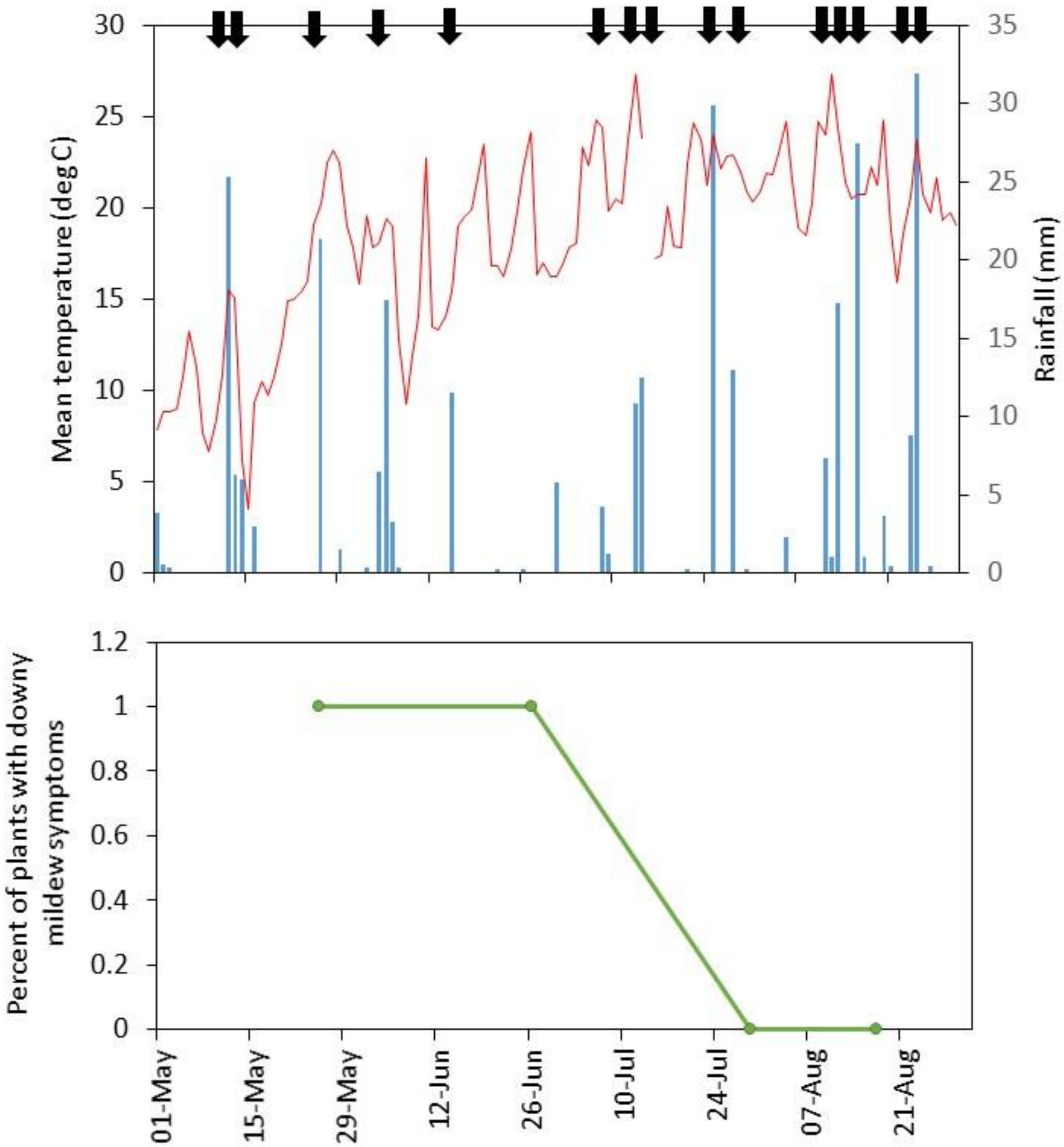

Figure 2.3. Mean temperature, rainfall at farm 4 from May to August 2016. Data from the Environment Canada weather station in Kitchener/Waterloo was used. The black arrows at the top of the graph indicate periods when the DRI reached the 500 unit threshold indicating an infection event.

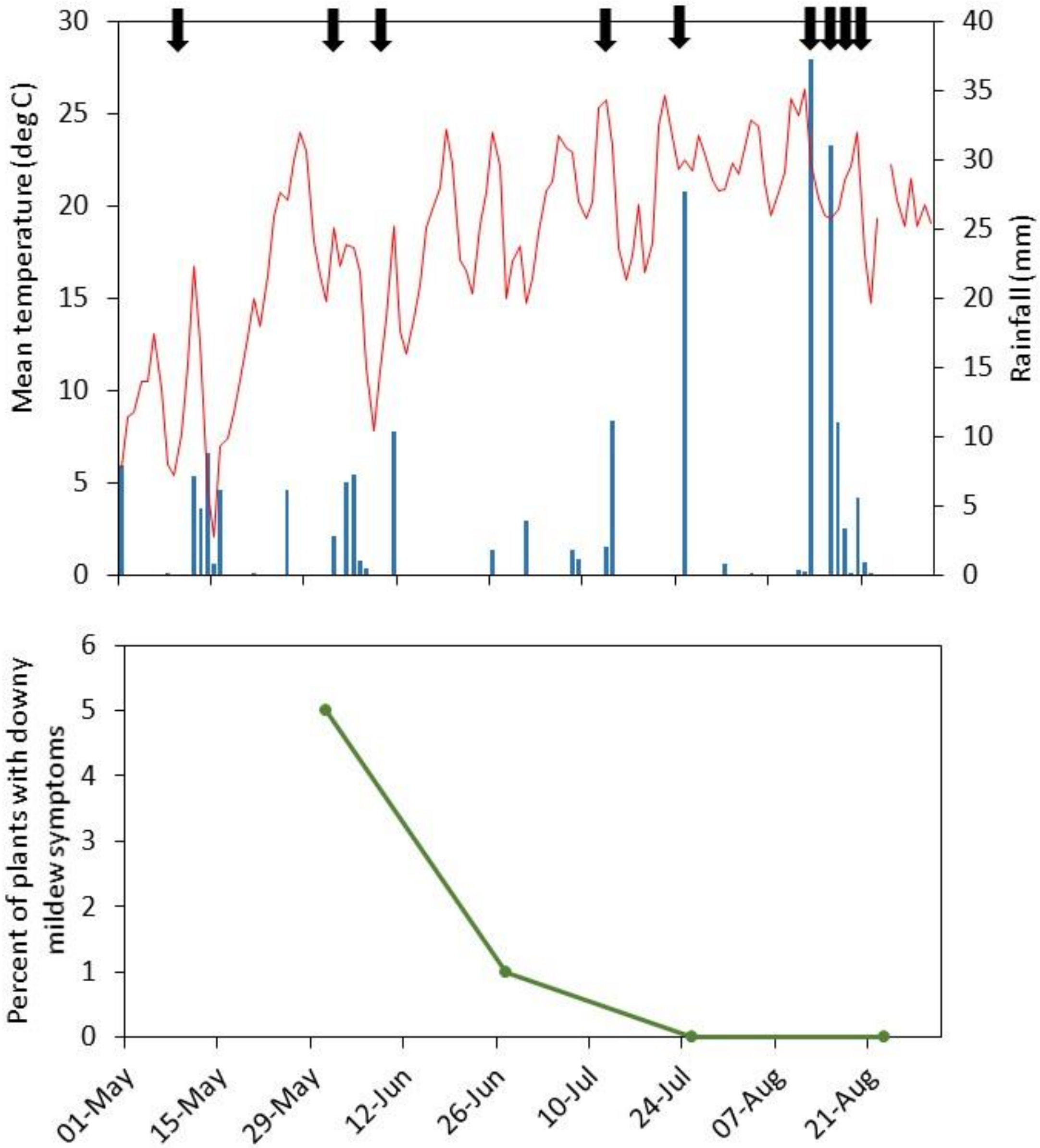

Figure 2.4. Mean temperature, rainfall at farm 5 from May to August 2016. Data from the Environment Canada weather station in Mono Centre was used. The black arrows at the top of the graph indicate periods when the DRI reached the 500 unit threshold indicating an infection event.