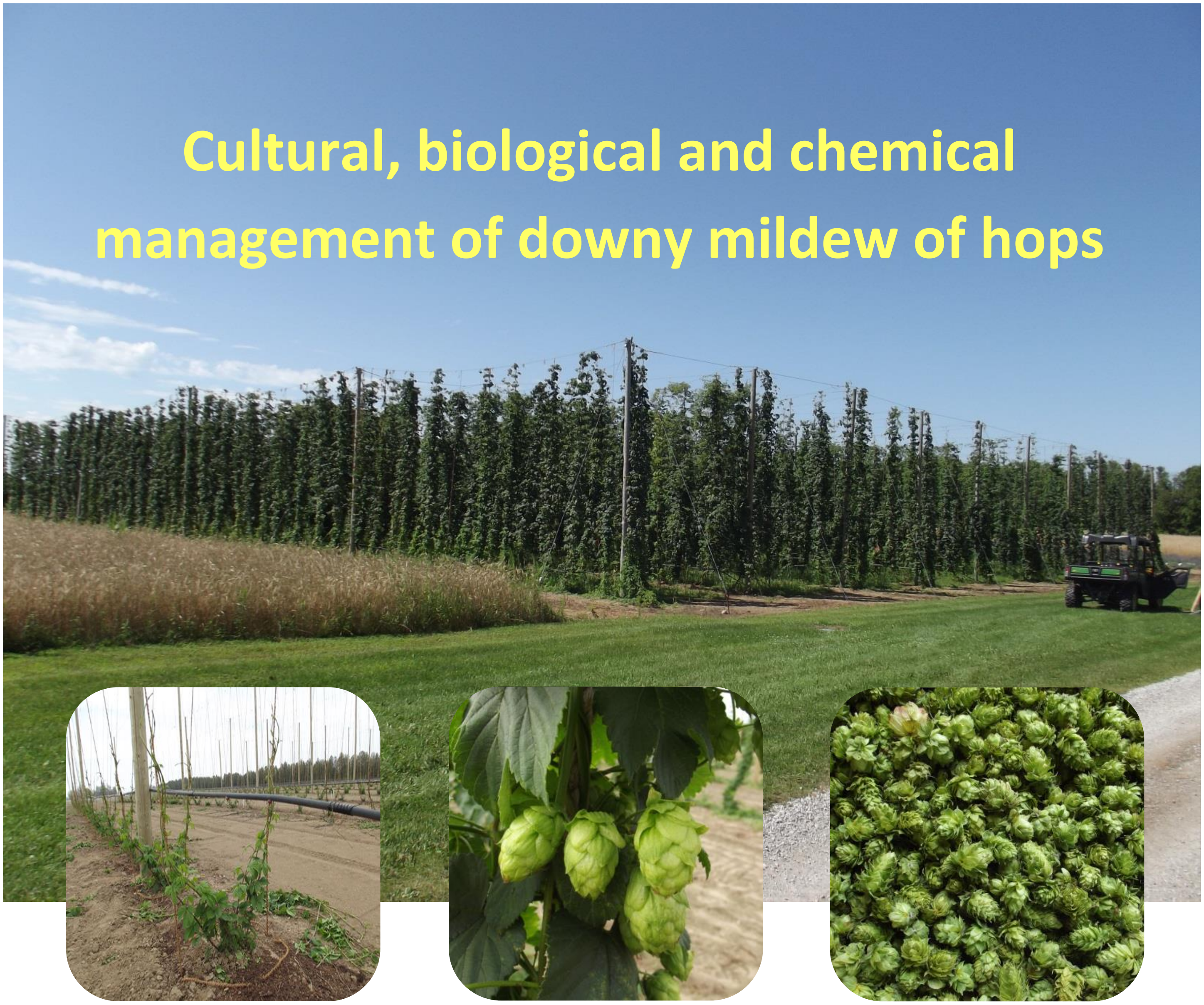
Cultural, biological and chemical management of downy mildew of hops



Annual report for the OMAFRA-UofG Research Program
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Ontario

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Annual report – OMAFRA-UofG Research Program

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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 Canada, the only organic fungicides registered for control of hop downy mildew are Serenade Opti, Copper 53W and Regalia Maxx. Serenade Opti and Regalia Maxx only provide suppression of the disease and limitations in the number of allowed applications of Copper 53W make it difficult for organic growers to achieve season long control. 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 2.

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 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. Weather monitoring equipment (HOBO brand, Hoskins Scientific) were installed in early May. 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) were ordered from a propagator in New York State but were not received in time to plant in 2017. Planting occurred on 17, 18 May 2018 and treatments will be applied in 2018 and 2019. Treatments will consist of an unsprayed check, an organic commercial standard (Serenade OPTI), a conventional commercial standard (Torrent 400SC) and a maximum of 8 additional biological/organic or conventional 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), Timorex Gold (Tea tree oil), Buran (garlic powder), Tivano (citric acid, lactic acid), Phostrol (Mono- and dibasic sodium, potassium, and ammonium phosphites), Cueva (copper octanoate), OxiDate 2.0 (hydrogen peroxide, peroxyacetic acid). Each product will be applied according to the label starting in late June 2018 and late May 2019. An appropriate PHI for each product will be observed. Products will be applied to the foliage using a motorized backpack sprayer or small plot sprayer. Plants will be inoculated with DM in 2019 before treatment applications commence. Disease incidence and severity will be assessed weekly until harvest. 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

Three sites were monitored for downy mildew incidence in 2017. These included commercial hop farms near Caledon, Meaford, and Tavistock. Farms will be identified in this report using a randomly assigned number for confidentiality purposes. A total of 12 different hop cultivars were evaluated. A list of assessment dates and cultivars for each site can be found in Table 3.2. Hops at all sites were managed according to typical commercial practices, including removal of basal spikes and application of fungicides for downy mildew control. The percentage of plants with symptoms of downy mildew (basal/aerial spikes, foliar lesions) were recorded. 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:

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

The cones were also examined and specific pathogens isolated using microscopy.

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. Preliminary work was conducted in 2017 and will be continued in 2018. The prevalence of metalaxyl resistance/insensitivity among Ontario isolates of *P. humuli* was determined using a fungicide sensitivity assay. A total of 9 basal spikes from conventional hop yards (where metalaxyl has been applied) and one spike from an organic hop yard (where metalaxyl has not been applied) was collected. Sporangia from the basal spikes was used to inoculate hop leaf disks of a DM susceptible cultivar. Prior to inoculation, leaf disks were placed in petri plates containing water agar media amended with or without 50 and 100 µg/ml of metalaxyl. After 7-11 days, leaf disks were examined using a stereomicroscope and the incidence of sporulation was recorded. An isolate was considered insensitive to the fungicide if the incidence of sporulation on fungicide amended media was 50% or more of the sporulation on non-amended media. The sensitivity of *P. humuli* isolates for forsetyl-al was not tested in 2017 and will be done in 2018.

3.0 Results and Discussion

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

3.1 Validation of an existing downy mildew forecasting model

The downy mildew forecasting model indicated a total of 31 ‘infection events’ at farm 1, 24 events at farm 2 and 26 events at farm 3 (Figs. 3.1-3.3). Disease severity was very high in 2017 due to frequent rain events at each site. The model used in this study was developed in England

and appeared to accurately predict infection events during the growing season in 2017, which was cooler and wetter than 2016 (Table 3.1). Averaged over cultivar, disease incidence at farm 1, an organic hop yard, peaked at 20% infected in early July and then decreased, due to diligent implementation of management practices such as fungicide applications and removal of basal spikes. Disease incidence at farm 2, a conventionally managed hop yard, remained low throughout the season, peaking at 2% in early June and decreasing during the growing season. At farm 3, an organic hop yard, disease incidence was very high, reaching 100% by the end of July.

Although the model predicted frequent sporulation events and reflected the high disease pressure observed in 2017, a 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 may need to be used to predict when infection periods might occur. This work will continue in 2018 and 2019.

3.2 Evaluating differences in susceptibility of downy mildew in hop cultivars

Overall, the incidence of hop downy mildew was high in 2017 compared to 2016, likely due to cooler temperatures in 2017 which were near or slightly below normal and above normal rainfall from May to August (Table 3.1). The exception was farm 2 where rainfall totals were slightly below normal.

Disease incidence varied among cultivars and sites. The disease incidence was high at the two organic sites (farm 1 and 3) compared to the conventional site (farm 2) that was scouted in 2017. At the organic sites the disease incidence was variable ranging from low 1.3% to as high as 80% in some cultivars in May. The incidence was high in June ranging from 2-43% which is higher than for the same month in 2016 (Table 3.2). Cultivars such as 'Centennial' at farm 1 and 'Cascade' and 'Fuggle' at farm 3, initially showed a low-moderate incidence in May-June but later in the season the incidence was 100% (Table 3.2). The only conventional farm scouted in 2017 had higher disease incidence compared to 2016 (Table 3.2) in May-June but incidence values decreased to zero for July-Aug.

No cultivar stood out as being consistently more tolerant, partly due to the differences in source of the original plant material and management practices at each site. At farm 1, downy mildew was most severe in 'Chinook', 'Centennial' followed by 'Cascade', 'Magnum', 'Fuggle' and 'Hallertau' (Table 3.2). At farm 2, downy mildew was high in 'Centennial' followed by 'Glacier', ‘Heritage’ and ‘Rakau’ while at farm 3, the disease incidence was high in ‘Mt Hood’ and ‘Fuggle’ followed by ‘Cascade’ and ‘Nugget’. At farm 2 cultivar ‘New Port’ did not show downy mildew symptoms in 2016 and in 2017, however it was difficult to conclude that this cultivar is ‘tolerant’ to downy mildew as it was not tested at multiple sites.

Cone diseases were widespread in all the commercial sites scouted in 2017. All cultivars were affected, and the percent of infected cones was highest in ‘Fuggle’, ‘Hallertau’ and ‘Mt Hood’ followed by ‘Chinook’, ‘Nugget’, ‘Cascade’, ‘Magnum’, ‘Glacier’ and ‘Centennial’. Percent infection was low in ‘New Port’ and ‘Rakau’ (Table 3.3). Disease severity was low to moderate in 2017. Severity of cone diseases was highest for ‘Chinook’, ‘Fuggle’ and ‘Hallertau’ and low for ‘New Port’ and ‘Rakau’. The infected cones were found heavily covered with *P. humuli* sporangia and spores of *Alternaria* sp.

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

In preliminary work, nine downy mildew infected spikes collected from a conventional hop yard and one spike from an organic hop yard was tested for metalaxyl sensitivity at 50 and 100 ug/ml (Fig 3.4). All spikes from the conventional yard were found resistant to metalaxyl at 50 ug/ml concentration and 8 of them were resistant at 100 ug/ml (Table 3.4). Spike no 9 was contaminated at 100 ug/ml, therefore the data for this concentration is not available. The only spike tested from an organic yard was found to be sensitive to the fungicide.

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.

5.0 Literature cited

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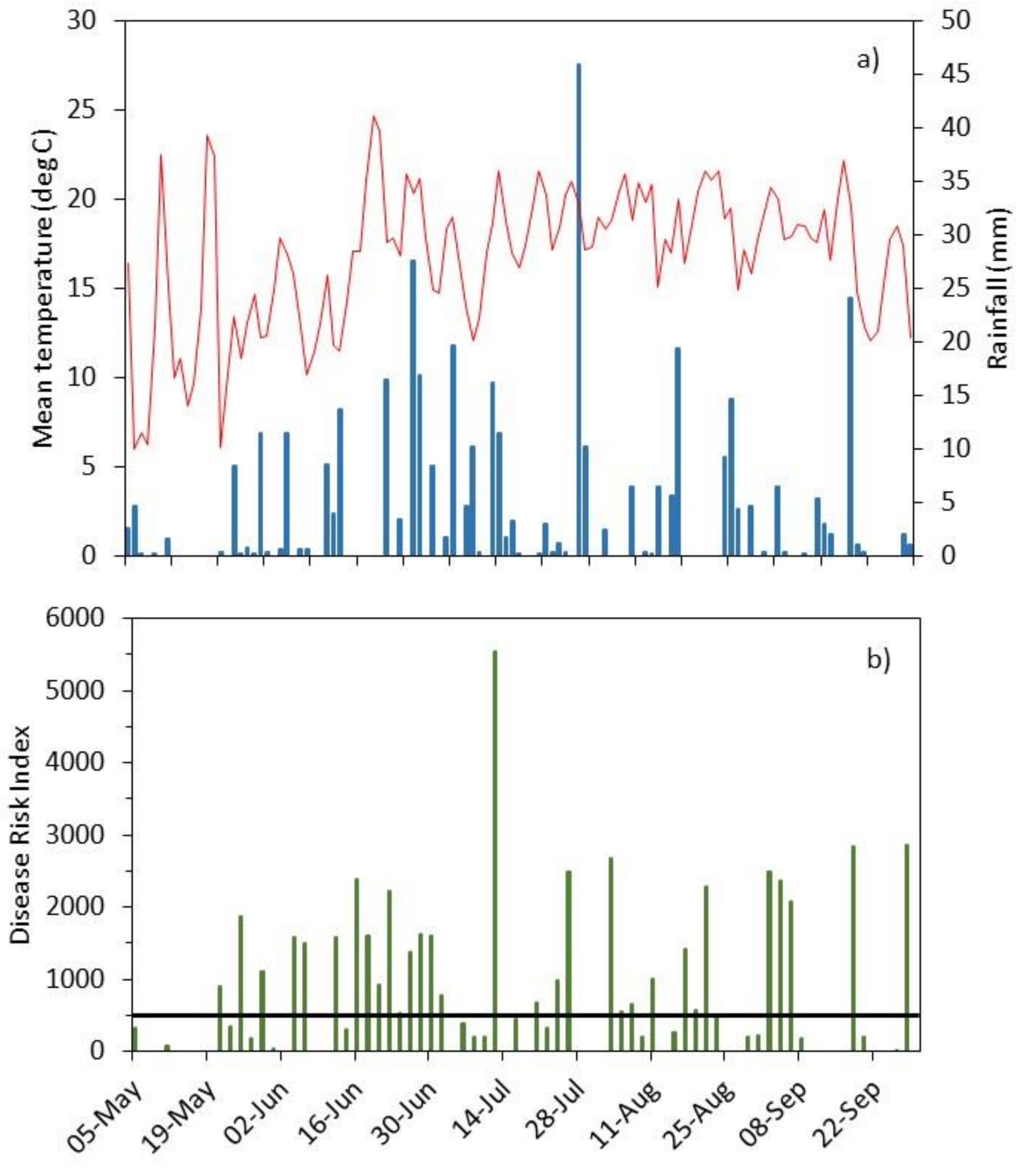

Figure 3.1. a) Mean temperature and rainfall; b) Disease Risk Index (DRI) at farm 1 from May to September 2017. The black bar on graph b) indicates the DRI threshold of 500 units when an infection event is predicted.

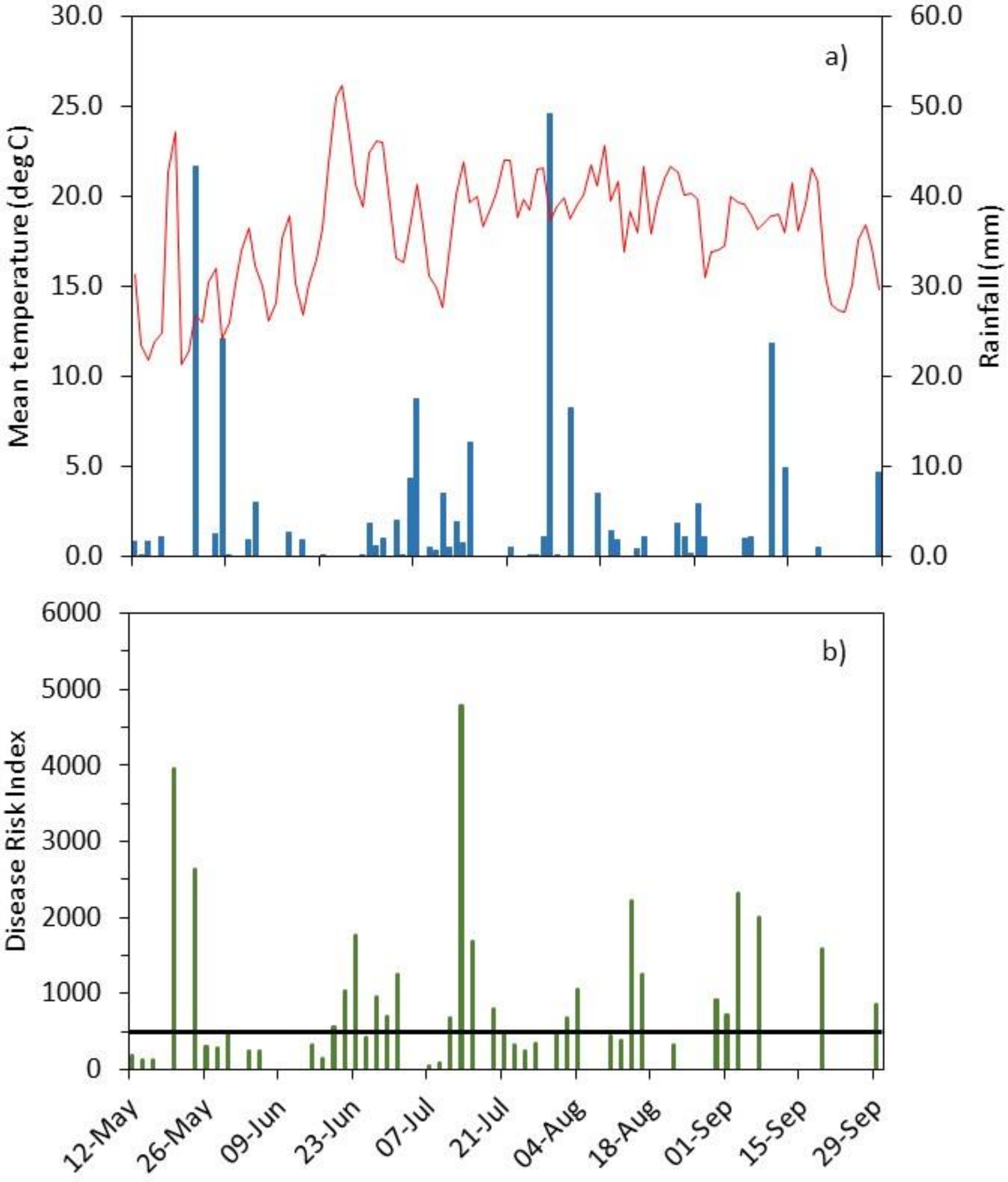

Figure 3.2. a) Mean temperature and rainfall; b) Disease Risk Index (DRI) at farm 2 from May to September 2017. The black bar on graph b) indicates the DRI threshold of 500 units when an infection event is predicted.

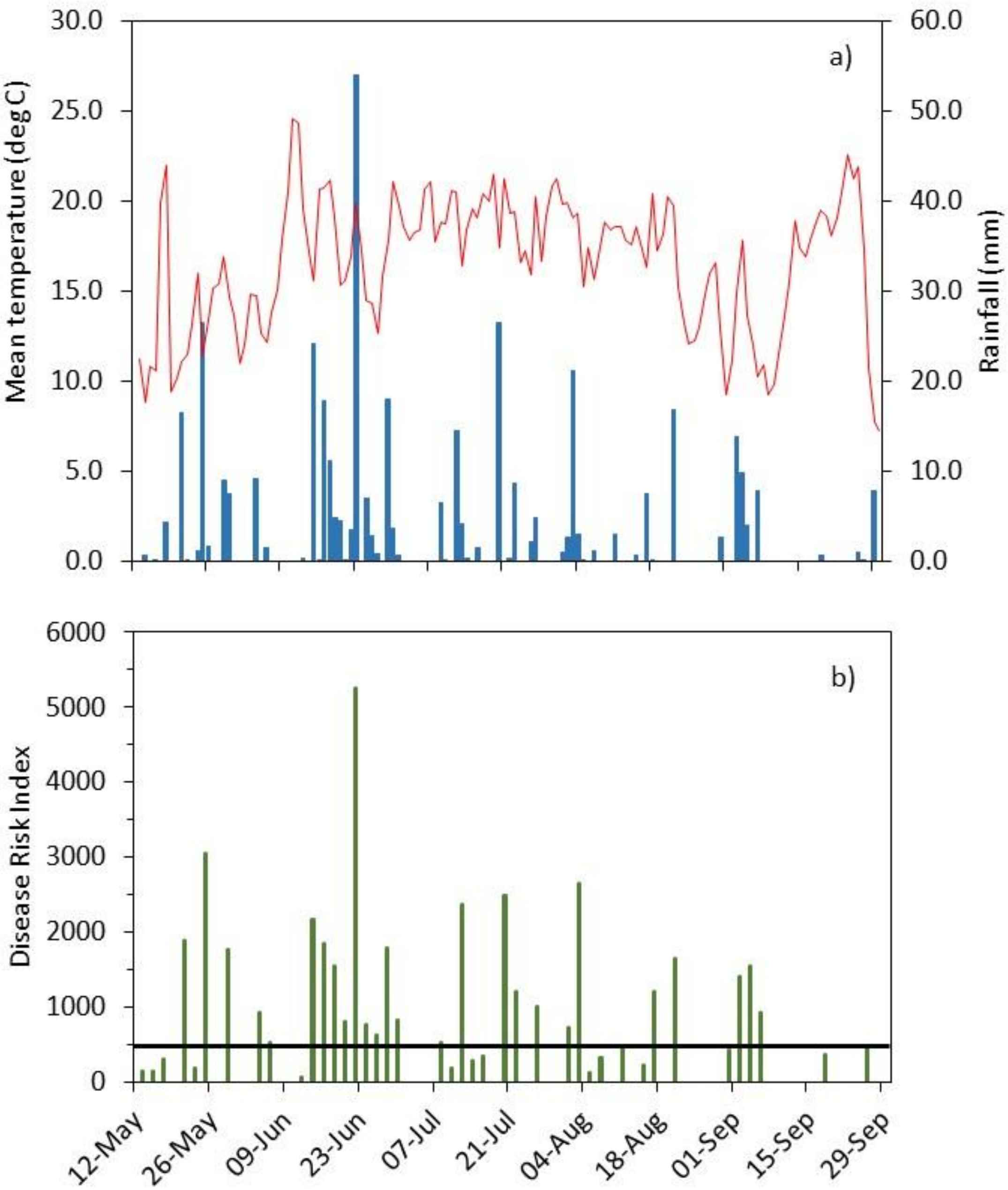

Figure 3.3. a) Mean temperature and rainfall; b) Disease Risk Index (DRI) at farm 3 from May to September 2017. The black bar on graph b) indicates the DRI threshold of 500 units when an infection event is predicted.

Table 3.1: Average air temperature and rainfall for summer 2016-2017.

Year	Month	Average Temperature (°C)	Total Rainfall (mm)
Farm 1			
2016	May	11.9	39.3
	June	17.2	48.6
	July	21.8	21.0
	August	22.5	15.1
2017	May	13.2	43.6
	June	16.8	163.6
	July	18.9	107.2
	August	17.6	79.0
Climate normals (1981-2010)[z]	May	11.5	82.7
	June	16.7	79.1
	July	19.8	72.1
	August	19.2	78.2
Farm 2			
2016	May	13.0	68.0
	June	17.4	39.7
	July	21.2	77.8
	August	21.3	101.3
2017	May	14.7	83.6
	June	18.7	57.1
	July	20.0	96.6
	August	18.0	62.3
Climate normals (1981-2010)[z]	May	12.7	91.4
	June	17.9	76.5
	July	20.2	102.1
	August	19.2	83.9
Farm 3			
2016	May	12.6	42.3
	June	14.7	30.6
	July	21.0	48.6
	August	21.2	90.4
2017	May	13.4	67.7
	June	16.9	163.7
	July	19.1	70.3
	August	17.0	60.1
Climate normals (1981-2010)[z]	May	11.7	86.6
	June	16.9	81.3
	July	19.4	80.8
	August	18.4	88.2

[z]Climate normals from closest Environment Canada weather station.

Table 3.2: Incidence of downy mildew at three commercial hop farms in 2016 and 2017.

Hop Farm	Farm-Type	Cultivar	Disease incidence (% infected) 2016				Disease incidence (% infected) 2017						
			18 May	29 June	22 July	24 Aug	11 May	06 June	21 June	05 July	20 July	10 Aug	22 Aug
1	Organic	Chinook	7-10	<5	0	0	70-80	26	2	0.3	0	0	0
		Centennial	1 or less	5	0.5 or less	0	5	11	39	100	8	0	0
		Magnum	10	2	0.5 or less	0	4	4	3	0	0	0	0
		Fuggle	20	1	0.5 or less	0	4	0	0	0	0	0	0
		Hellertau	1	<1	0	0	0.8	0	0	0	0	0	0
		Cascade	1	1	0	0	18	43	2	19	1	0	0
Hop Farm	Farm-Type	Cultivar	Disease incidence (% infected) 2016				Disease incidence (% infected) 2017						
			25 May	26 June	29 July	17 Aug	12 May	06 June	22 June	06 July	24 July	14 Aug	23 Aug
2	Conventional	Hallertaue	0	0	0	0	.	.	.	.	.	.	.
		New Port	0	0	0	0	0	0	0	0	0	0	0
		Centennial	0	1	0	0	0.7	14.5	0	0	0	0	0
		Cascade	0	0	0	0	0	0	0	0	0	0	0
		Rakau	1	0	0	0	0	2.5	3	0	0	0	0
		Glacier	0	0	0	0	0	5.5	1.8	0	0	0	0
		Heritage	0	0	0	0	0	5	0	0	0	0	0
Hop Farm	Farm-Type	Cultivar	Disease incidence (% infected) 2016				Disease incidence (% infected) 2017						
			31 May	27 June	25 July	23 Aug	12 May	06 June	22 June	06 July	24 July	14 Aug	23 Aug
5	Organic	Willamette	<5	0	0	0	0	.	.	.	.	.	.
		Mt Hood	<5	0	0	0	4	12.5	4	100	100	100	.
		Cascade	<5	0	0	0	2.4	5	6	2.6	0	14.3	13
		Fuggle	<5	0	0	0	0	4	0	100	100	100	.
		Nugget	<5	<1	0	0	1.3	0	3	20	3.9	24	16

Table 3.3. Incidence and severity of cone diseases at harvest on various hop cultivars from three commercial hop farms in 2017.

Cultivar	Hop Farm	DSI[1]	Percent Infection	Average DSI	Average Percent infection	Organisms isolated
Cascade	1	34	92	27	77.6	*P. humuli*, *Alternaria* sp.
	2	11	45			*Alternaria* sp.
	3	37	96			*P. humuli*, *Alternaria* sp.
Centennial	1	62	88	34.5	59.5	*P. humuli*, *Alternaria* sp.
	2	7	31			*Alternaria* sp.
Chinook	1	45	79	45	79	*P. humuli*, *Alternaria* sp.
Fuggle	1	53	100	44	100	*P. humuli*, *Alternaria* sp.
	3	35	100			*P. humuli*, *Alternaria* sp.
Glacier	2	21	70	21	70	*P. humuli*, *Alternaria* sp.
Hallertau	1	41	98	41	98	*P. humuli*, *Alternaria* sp.
Magnum	1	20	75	20	75	*P. humuli*, *Alternaria* sp.
Mt Hood	3	38	98	38	98	*P. humuli*, *Alternaria* sp.
New Port	2	3	13	3	13	*Alternaria* sp.
Nugget	3	28	78	28	78	*P. humuli*
Rakau	2	4	20	4	20	*Alternaria* sp.

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

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

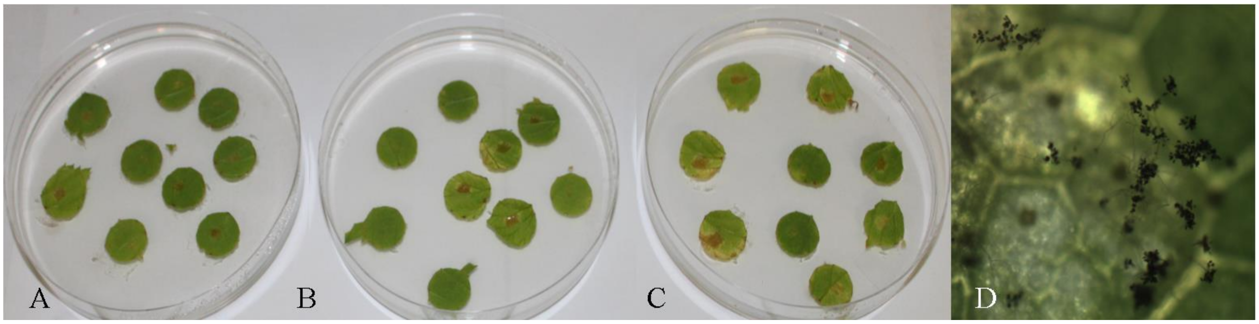

Fig 3.4: Testing sensitivity of metalaxyl fungicide on isolates of *P. humuli* collected in 2017. A = downy mildew lesions on non-amended media, B = downy mildew lesions on amended media with 50 ug/ml of fungicide, C = downy mildew lesions on amended media with 100 ug/ml of fungicide, D = microscopic view of sporulation of *P. humuli* at 50 ug/ml.

Table 3.4: Incidence of sporulation 7-11 days post-inoculation at two different Metalaxyl concentrations and non-treated control of various downy mildew samples (spikes) collected from a conventional and organic hop yard.

Location	Spike	Percentage of inoculation sites showing sporulation (%)			Incidence of sporulation compared to the control*[1]	
		Concentration of Metalaxyl			Concentration of Metalaxyl	
		0	50 ug/ml	100 ug/ml	50 ug/ml	100 ug/ml
Conventional	1	87.5	56.25	68.75	64.3	78.6
	2	52	56.5	34.8	108	66.6
	3	100	87.5	62.5	87.5	62.5
	4	50	25	30	50	60
	5	58	58	29.2	100	50
	6	56.5	43.4	30.4	76.9	53.8
	7	76.9	61.5	42.3	80	55
	8	53.8	30.8	26.9	57.1	50
	9	52	52	.*[2]	60	.*[2]
Organic	1	57.1	0	0	0	0

*[1] = Calculated by dividing the percentage of sporulation in the Metalaxyl amended media by the percentage of sporulation in the non-amended control and multiplying by 100. A sample is considered to be resistant/insensitive to metalaxyl if the percentage of inoculation sites on the metalaxyl amended media showing sporulation is 50% or more compared to the non-amended media.
*[2] = missing data