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2016 Hop Optimal Irrigation Trial

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2016 HOP OPTIMAL IRRIGATION TRIAL

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Hops reportedly use about 610 to 715 mm (24 to 28 inches) of water per year (Evans 2003). Rainfall can contribute to this total, however, due to climatic variability, it is important that hops are irrigated regularly to combat moisture stress. Moisture deficit during the hop growing season has been shown to cause reductions in hop cone yield (Hnilickova et al. 2009). Irrigation systems can help to alleviate some of the potential drought stress, but timing of water application is just as important as the amount of water hops are receiving. Hops require the majority of their water in the critical period between training and flowering for optimal vegetative growth. The hop yard is irrigated through a well-fed drip irrigation system, which delivers 3000 gal ac^{-1} each week, beginning in late May. Over the 14-week irrigation period, this equates to 1.54 inches of water, or 0.11 inches each week, which is well below the 23.5 inches required, adjusting for potential evapotranspiration. The goal of this project was to evaluate differences in yield, insect pests, and disease presence between plants at the Borderview Research Farm that were watered at the optimal level, and plants that were irrigated at the level sustained by the on-farm well.

MATERIALS AND METHODS

The replicated research plots were located at Borderview Research Farm in Alburgh, VT on a Benson rocky silt loam. The experimental design was randomized throughout the variety trial. Replicates were split between two varieties: Cascade and Nugget. Each plot was split into plants that received supplemental irrigation to meet hop water requirements and control plants that did not.

All plants received a weekly water baseline of 3000 gal ac^{-1} through a drip line with emitters. Plants were scouted on a weekly basis for insect pests and symptoms of downy mildew, and they received fertilizer through fertigation and two side-dress applications. Other than additional watering, all plants were treated in the same manner.

The hop yard was irrigated weekly in July and August at a rate of 3000 gallons of water per acre. Detailed information as well as a parts and cost list for the drip irrigation system can be found at **www.uvm.edu/extension/cropsoil/hops**. Fertigation (fertilizing through the irrigation system) was used to apply fertilizer more efficiently. Starting in late May, the hops received 4 lbs ac^{-1} of nitrogen (N) through the irrigation system on a weekly basis until side shoots were observed. At each fertigation application, 25 lbs of Chilean nitrate organic fertilizer (16-0-0) was added to the irrigation lines. The fertilizer was distributed evenly through 3000 gallons of water using a Dosatron unit. In addition to the fertigation, hops were side-dressed twice during the season. In mid-May, 150 lbs ac^{-1} of Pro Gro (5-3-4) and 50 lbs ac^{-1} of Chilean Nitrate were applied to the plants. 100 lbs N ac^{-1} was applied on 21-Jun using a combination of Pro Gro and Chilean Nitrate. Total N application (including fertigation) for the season was 143.5 lbs ac^{-1}. All fertilizers were OMRI-approved for use in organic systems.

Supplemental water for plants in this trial was distributed using 5 gallon buckets. The total amount of water needed during the growing season is 23.5 inches, adjusting for evapotranspiration, over the 5 month growing season. The 3000 gal ac^{-1} applied using dripping irrigation equates to 0.11 inches of water each week. Each week, the amount of moisture from the previous 7 days was calculated by adding the rainfall and 0.11 inches irrigated and then subtracted from the optimal 1.175 inches per plant per week to determine the supplementation amount. With the current irrigation rate at Borderview Research Farm, it needed to rain 1.065 inches per week to achieve the optimal water quantity without supplementation. Table 1 outlines the calculation of total weekly rainfall and supplemental water per plant. In total, plants with supplemental irrigation received 5.15 inches of water more than plants that just received rainfall and drip irrigation. This equates to 140,455 gal ac^{-1} more just during this 9-week-trial period.

Table 1. Total baseline water amount and supplemental irrigation, Alburgh, VT, 2016.

Week	Total rainfall inches	Total water applied inches plant^{-1}	Supplementation amount inches plant^{-1}	Supplementation amount gal ac^{-1}
20-Jun	0.36	0.47	0.60	16,364
27-Jun	1.36	1.47	0.00	0.00
4-Jul	0.43	0.54	0.53	14,455
11-Jul	0.08	0.19	0.88	24,000
18-Jul	1.10	1.21	0.00	0.00
25-Jul	0.09	0.20	0.87	23,727
1-Aug	0.14	0.25	0.82	22,364
8-Aug	0.45	0.56	0.51	13,909
15-Aug	0.02	0.13	0.94	25,636
Total	4.03	5.02	5.15	140,455

Total water applied includes total rainfall and drip irrigation for the week.

This season, we calculated the number of days that had ideal downy mildew conditions using a Pacific Northwest forecasting model based on temperature and humidity, (Gent et al. 2010) (Figure 1). The model was calculated using data from an on-farm weather station at the data collection site at Borderview Research Farm, Alburgh, VT. The humidity data was collected from a nearby weather station in Chazy, NY. We found that 28 of the 183 days between 1-Apr and 30-Sep exhibited conditions considered likely for downy mildew infection.

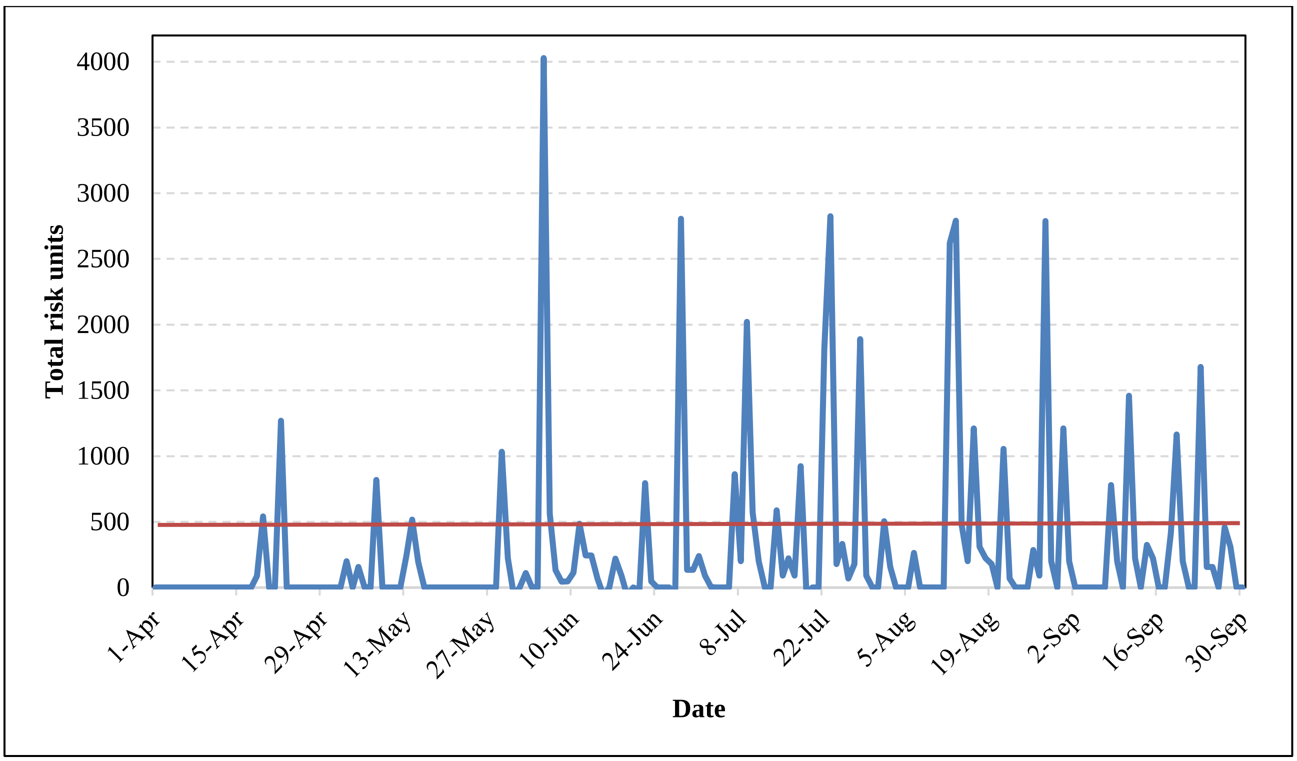

Figure 1. Number of risk units, (Gent et al. 2010), Alburgh, VT, 2016.
The red line at 500 risk units indicates an increased likelihood of downy mildew infection.

Predicting habitable conditions for downy mildew, using humidity and precipitation events, allowed us to determine optimal biofungicide application dates prior to periods of high infection risk. Given the climatic conditions of 2016, spray dates occurred weekly throughout most of the growing season. Table 2 shows fungicide application dates for the 2016 season.

Fungicides used were Champ WG, Regalia, Milstop, Cease, and Trilogy. Champ WG (Nufarm Americas Inc., EPA Reg. No. 55146-1) is a copper hydroxide solution that is used as a preventative treatment for downy mildew (*Pseudoperonospora humuli*). It works by releasing copper ions, and disrupts the cellular proteins of the fungus. Regalia

(Marrone Bio Innovations, EPA Reg. No. 84059-3) is a broad spectrum biofungicide that is active against soil borne and foliar pathogens. The active ingredient is extracted from giant knotweed (*Fallopia sachalinensis*) and works by stimulating the plant's natural defenses. Milstop (Bioworks Inc. EPA Reg. No. 70870-1-68539) is used as a preventative treatment for foliar diseases. It works by changing leaf surface pH and decreases the ability for fungal cell wall formation. Cease (Bioworks Inc. EPA Reg. No. 264-1155-68539) is used as a preventative treatment for foliar disease. Trilogy (Certis USA, LLC., EPA Reg. No. 70051-2) is a fungicide and miticide derived from neem oil. It acts a repellent and makes it difficult for fungi and insects to attack the plants.

Table 2. Fungicide application dates, Alburgh, VT, 2016.

Date	Treatment
3-Jun	Champ WG
5-Jul	Champ WG
12-Jul	Champ WG and Regalia
21-Jul	Milstop and Cease
1-Aug	Milstop and Trilogy
9-Aug	Champ WG and Trilogy

Throughout the season, all plants in this trial were scouted weekly for evidence of downy mildew through infected leaves and aerial spikes. Leaf scouting was performed by counting 10 leaves at random on the bottom 6 feet of each plant. Aerial spikes were quantified based on the total number per plant. All plants were also scouted for three major insect pests: potato leafhopper, aphid, and two-spotted spider mite. Three leaves per plant were scouted each week for these insect pests.

Hop harvest was targeted when cones were at 21-27% dry matter. At harvest, hop bines were cut in the field and were visually assessed for disease severity on a 1-5 scale, with 5 indicating the most severe infection. The plants were then brought to a secondary location to be run through our mobile harvester (Hopster5P, hopharvester.com). Picked hop cones were weighed on a per plot basis and moisture was determined using a dehydrator. 100 cones were separated from the plots and were assessed for incidence of disease by counting the number of diseased cones. Severity was assessed on a scale of 1-10, 10 being worst. A sample of wet cones was taken from each treatment and was brought to the UVM Plant Pathology lab to quantify disease presence. All hop cones were dried to 8% moisture, baled, vacuum sealed, and then placed in a freezer. Hop samples from each plot were analyzed for alpha acids, beta acids, and Hop Storage Index (HSI) by the Northwest Crops and Soils team.

Yields are presented at 8% moisture on a per acre basis. Per acre calculations were performed using the spacing in the UVM Extension hop yard biofungicide trial section of 872 hills ac^{-1}. Yields were analyzed using the GLM procedure in SAS and brew values were analyzed using the PROC MIXED procedure in SAS with the Tukey-Kramer adjustment, which means that each cultivar was analyzed with a pairwise comparison (i.e. 'Cluster' statistically outperformed 'Cascade', 'Cascade' statistically outperformed 'Mt. Hood', etc.). Relationships between variables were analyzed using the GLM procedure.

RESULTS

Weather data was recorded with a Davis Instrument Vantage Pro2 weather station, equipped with a WeatherLink data logger at Borderview Research Farm in Alburgh, VT. Missing precipitation data from 17-Aug through 31-Oct was supplemented using data provided by the NOAA from Highgate, VT. March, May, August, and September had above average temperatures. Despite the lack of rain, June and July were close to the average temperature (Table 3). While March experienced more precipitation than usual, May through September was unusually dry, accumulating 7.27 inches less rain than in a usual year. Overall, there were an accumulated 2653 Growing Degree Days (GDDs) this season, approximately 284 more than the historical 30-year average.

Table 3. Temperature, precipitation, and growing degree days summary, Alburgh, VT, 2016.

Alburgh, VT	March	April	May	June	July	August	September
Average temperature (°F)	33.9	39.8	58.1	65.8	70.7	71.6	63.4
Departure from normal	2.90	-4.90	1.80	0.00	0.10	2.90	2.90
Precipitation (inches)	2.50	2.60	1.50	2.80	1.80	3.00	2.50
Departure from normal	0.29	-0.26	-1.92	-0.88	-2.37	-0.93	-1.17
Growing Degree Days (base 50°F)	32	59	340	481	640	663	438
Departure from normal	32	-16	74	7	1	82	104

Based on weather data from a Davis Instruments Vantage Pro2 with WeatherLink data logger. Historical averages are for 30 years of NOAA data (1981-2010) from Burlington, VT. Alburgh precipitation data from 8/17/16-10/31/16 was missing and was replaced by data provided by the NOAA for Highgate, VT.

There were no significant differences between treatments in terms of harvest quality characteristics (Table 4). Dry matter at harvest is targeted between 22% and 27%; the average harvest dry matter was 24.3%. The plots receiving supplemental irrigation yielded 578 lbs ac^{-1}, while the control plots yielded 682 lbs ac^{-1}; however these values were not statistically different from each other. The average incidence of cone disease was 37.3%. There was very little disease presence on the hop cones with an average rating of 1.08 out of 10.

Table 4. Impact of irrigation treatments on harvest parameters, Alburgh, VT, 2016.

Treatment	Harvest dry matter %	Yield at 8% moisture lbs ac^{-1}	Cone disease incidence %	Cone disease severity 0-10
Supplemental irrigation	25.0	578	41.5	1.19
Control	23.5	682	33.0	0.969
Trial mean	24.3	630	37.3	1.08
p-value (0.1)	0.296	0.309	0.708	0.792

Pest presence was recorded throughout the growing season (Table 5). While the plots with supplemental irrigation had fewer recorded pests than control plots, the difference between the two treatments was not significant. The average number of potato leafhoppers per plant was 5.5, the average number of two-spotted spider mites per plant was 5.3, and the average number of aphids per plant was 2.1. While the two-spotted spider mite populations was not highly significant between the two treatments (p-value = 0.113), there was a greater amount of fluctuation within the population on the control plots in comparison to the plants receiving supplemental irrigation (Figure 2).

Table 5: Impact of irrigation treatment on pest prevalence, Alburgh, VT, 2016.

Treatment	Potato leafhopper # plant^{-1}	Two-spotted spider mite # plant^{-1}	Aphid # plant^{-1}
Supplemental irrigation	5.04	4.08	2.02
Control	6.15	7.03	2.21
Trial mean	5.50	5.30	2.10
p-value (0.1)	0.993	0.113	0.687

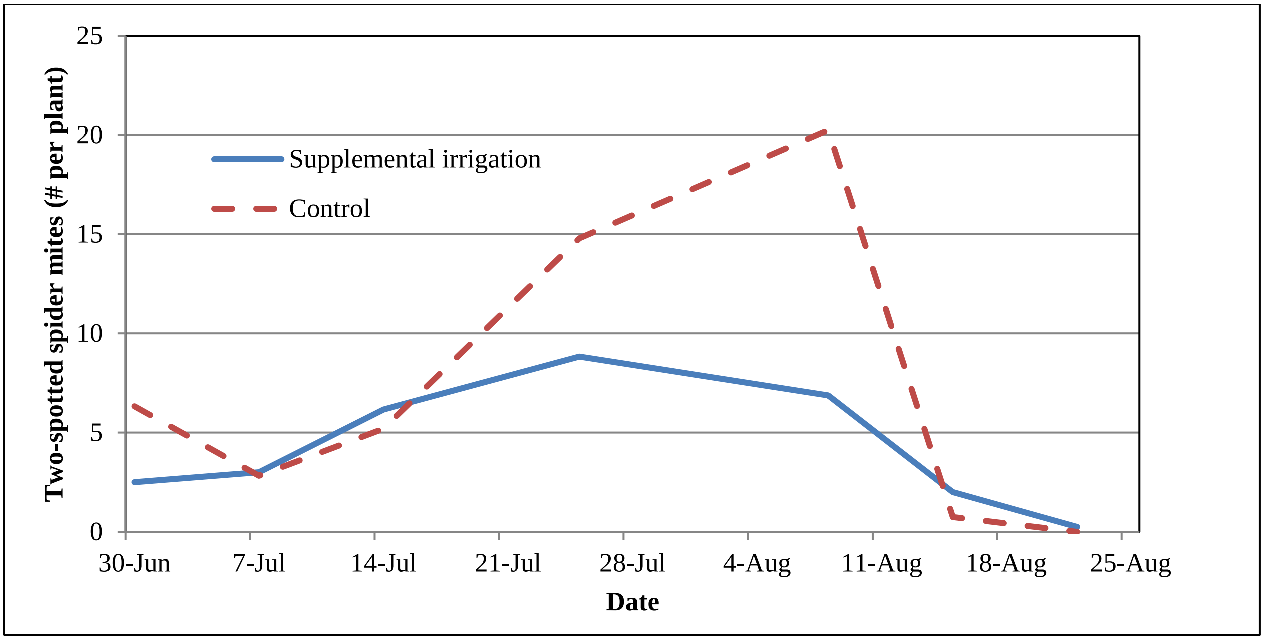

Figure 2: Average number of two-spotted spider mites by treatment each week, Alburgh, VT, 2016.

Downy mildew indicators were scouted throughout the growing season (Table 6). No leaf infection was found on either treatment in the trial. There were no statistically significant differences between treatments for aerial spike presence. Control plants had an average of 0.029 aerial spikes per plant and plants with supplemental irrigation had an average of 0.188 aerial spikes per plant.

Table 6: Impact of irrigation treatment on downy mildew indicators, Alburgh, VT, 2016.

Treatment	Aerial spikes # plant^{-1}	Infected leaves # plant^{-1}
Supplemental irrigation	0.188	0.00
Control	0.029	0.00
Trial mean	0.122	0.00
p-value (0.1)	0.246	-

Plant uptake of macronutrients was split between cones and bines, only bine nutrients were examined for this irrigation trial (Table 7). Bines are expected to contain 70-80% of plant nutrients, and total plants should contain approximately 3.00% nitrogen, 0.50% phosphorous, and 2.00% potassium. This means bines should contain around 2.10-2.40% nitrogen, 0.35-0.40% phosphorous, and 1.40-1.60% potassium. While the control plots contained overall higher amounts of nutrients, the results were not statistically different when compared to the irrigated plots. The bines tested in both treatments contained near optimum level of nutrients.

Table 7: Impact of irrigation treatments on bine nutrients, Alburgh, VT, 2016.

Treatment	Nitrogen % of DM	Phosphorous % of DM	Potassium % of DM
Supplemental irrigation	1.85	0.404	1.64
Control	2.03	0.443	1.79
Trial mean	1.94	0.424	1.72
p-value (0.1)	0.330	0.566	0.323

DM is dry matter.

Quality parameters for Cascade hops were tested at the University of Vermont Hop Analysis lab (Table 8). The ideal alpha acid content for Cascade ranges between 5.50 and 9.00%; both treatments fell below the industry standard with a trial mean of 4.81%. The industry standard for beta acid levels in Cascade ranged from 6.00 to 7.50%. Both treatments fell within this range. The hop storage index represents the degree of oxidation, and has an ideal value of 0.200. Both treatments fell above this value, but were not statistically significant from each other.

Table 8: Impact of irrigation treatments on Cascade quality parameters, Alburgh, VT, 2016.

Treatment	Alpha acid %	Beta acid %	Hop storage index
Supplemental irrigation	4.76	7.30	0.25
Control	4.93	7.06	0.243
Trial mean	4.81	7.22	0.250
p-value (0.1)	0.426	0.561	0.498

Quality parameters for Nugget hops were also tested (Table 9). Ideally, Nugget hops alpha acid values range between 13.5 and 16.0%, and beta acid values should be between 4.40 and 5.50%. Irrigation and control treatments were below the industry standard for both values. The average hop storage index was above the standard 0.200, with a trial average of 0.237.

Table 9: Impact of irrigation treatments on Nugget quality parameters, Alburgh, VT, 2016.

Treatment	Alpha acid %	Beta acid %	Hop storage index
Supplemental irrigation	11.0	4.27	0.235
Control	11.5	4.03	0.237
Trial mean	11.4	4.08	0.237
LSD (0.1)	0.925	0.130	0.967

DISCUSSION

This season, rainfall contributed very little to the total water requirements, and seven of the nine weeks included in this trial required supplemental irrigation. Evans (2003) notes that it is important to start the growing season with the root zone as full of water as possible, and given the mild and dry winter, the subsoil moisture was also a major limitation to sustained growth. Spring snow melt contributed very little to subsurface moisture, so hop plants were unlikely to maintain high yields and cone quality without supplemental irrigation. Interestingly, Nakawuka (2013) also showed that drought stress did not impact hop quality parameters.

In this study, irrigation did not impact yields. The most critical hop growth stages, which require an adequate soil water supply are early spring May, and from just prior to, and through the flowering period in early July (Evans, 2003). It was clear that our study that began in late June missed much of the critical hop growth stages and likely was why we did not see clear treatment differences in the irrigation treatments. Others have shown 75% reductions in yields when optimal moisture is not maintained throughout the entire hop growing season (Nakawuka, 2013). Irrigation amount, as well as timing, is key to high yields, good cone quality, and overall plant health.

This lack of water had implications for pest prevalence. While the irrigated and non-irrigated treatments did not have any statistically significant differences, there was much more fluctuation in two-spotted spider mite populations in the control group (Figure 2). Two-spotted spider mites thrive in hot, dry weather, and populations can quickly escalate out of control in the last summer months. Given the lack of rainfall throughout the growing season, especially during July and August, population spikes were to be expected. Reduction of dust through proper irrigation techniques or by spraying drive rows with water can help mitigate this risk. It is important to monitor key pests throughout the season to determine when to treat hop plants with miticides and other pesticides.

This trial will be continued during the 2017 growing season with some modifications to better confirm differences in irrigation treatments. Watering events will occur on a few days throughout the week rather than at one time. This may aid plants in utilizing the water more effectively and uptake nutrients more successfully. It is expected that irrigating plots at the optimal level will increase yields, resiliency to pests and disease, and nutrient removal from the soil.

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