Organic Hop Variety Trial
Final Report

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UNIVERSITY OF VERMONT EXTENSION
CULTIVATING HEALTHY COMMUNITIES

INTRODUCTION

Hops production has increased steadily throughout the Northeast over the past 6 years. While hops were historically grown in the Northeast, they have not been commercially produced in this region for over a hundred years. With this large gap in regional production knowledge, we have a great need for region-specific, science-based research on this re-emerging crop. The vast majority of hop production in the United States occurs in the arid Pacific Northwest on a very large scale. In the Northeast, the average hop yard is well under 10 acres and the humid climate provides challenges not addressed by existing hops research. Knowledge is needed on how best to produce hops on a small-scale in our region. With this in mind, in August of 2010, the UVM Extension Northwest Crops and Soils Program initiated an organic hops variety evaluation program at Borderview Research Farm in Alburgh, Vermont. Since then, UVM Extension has been evaluating 22 publicly available hop varieties and 2 experimental varieties. The goal of these efforts is to find hop varieties that demonstrate disease and pest resistance, high yields, and desirable characteristics to brewers in our region. The UVM hop variety trial was initiated in 2010 and completed with a final harvest in 2016. This seven year trial helped us learn whether we could grow hops in the Northeast. The results and observations from each of the years the variety trial was conducted can be found online on the UVM Extension Northwest Crops and Soils Hops web page: www.uvm.edu/extension/cropsoil/hops. This document provides a summary of the knowledge gained in growing hops over the duration of this study.

THE UVM HOP YARD

The variety trial was located at Borderview Research Farm in Alburgh, VT (Figure 1) on a Benson rocky silt loam soil. The hop yard was certified organic by Vermont Organic Farmers (VOF), LLC. The experimental design was a randomized complete block with three replicates; treatments were 22 publicly available varieties and two experimental varieties. Each plot consisted of five consecutive hills that were distanced 7 feet apart. The row spacing of the hop yard is configured differently than a standard v-trellis to accommodate for the experimental design. There is a row of hops on either side of each row of poles. Pole rows are spaced 20 feet apart. The drive-row is 10 feet.

The hop yard was constructed in the spring of 2010 using 20' x 6" larch, tamarack, and cedar posts, with a finished height of 16 feet. Aircraft cable (5/16") was used for trellis wires. A complete list of materials and videos on the construction of the UVM Extension hop yard can be found at **www.uvm.edu/extension/cropsoil/hops**.

Figure 1: Map of Vermont showing Borderview Research Farm in the top left.

Each year we installed two strings of coir (coconut fiber) per hill, and trained three to four of the strongest bines per string. In general, we trained during a 7-10 day period on the 3rd or 4th week of May. A history of training dates at the UVM hop yard is shown in Table 1.

Table 1: Training dates from 2013-2016, Alburgh, VT.

Year	Date
2013	20-May to 27-May
2014	19-May to 30-May
2015	20-May to 26-May
2016	24-May to 25-May

While temperatures for most of the Vermont season are not much lower than in the traditional growing area of the Yakima Valley in Washington, early spring temperatures in Washington are much warmer. Figure 2 shows this difference by following degree days throughout the season. In our region, cooler weather during the spring months means that hops are slower to emerge and hence trained later than hops growing in the Yakima Valley (Figure 2). Hops switch their energy from upward vegetative growth to reproductive growth near the summer solstice, June 21. While another crop could simply be harvested a week later if it emerged a week late in the spring, hops stick to their schedule. More time for upward growth in the spring will leave the plants with more capacity for cone production when they switch from vegetative to reproductive growth in late June, so our goal in the Northeast is to train plants as early as possible.

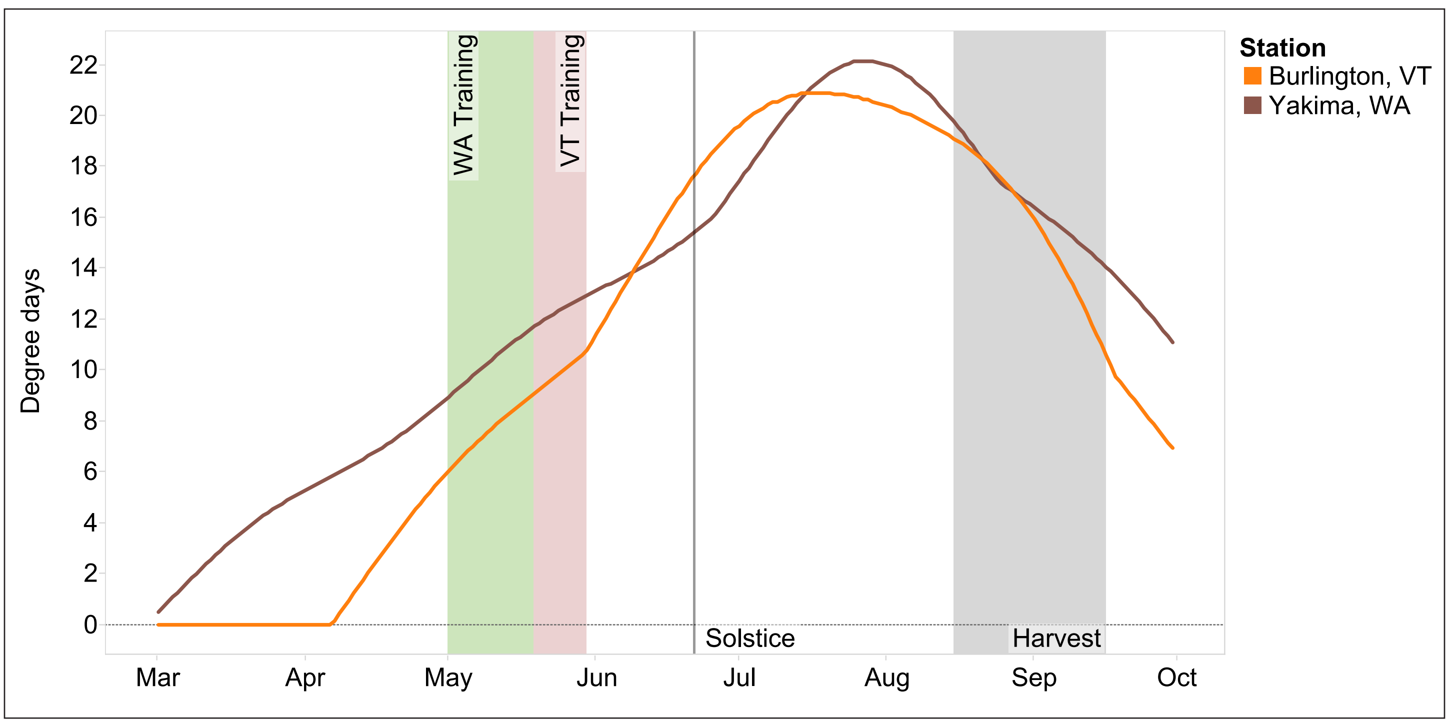

Figure 2: Average degree days 50°-95° F, gereral time period for training and harvest in Washington and Vermont.

PRECIPITATION

We know that hops require a lot of water for optimal growth. Evans (2003) reported that hops use 24 to 28 inches of water per year. Water needs of the hop plant are greatest when the plant is growing rapidly in the 10-week stretch between mid-May and late July. The UVM hop yard has a drip irrigation system that is limited to 3900 gallons of water per acre (0.14 inches) per week. Because of that, the hops must rely on mostly natural precipitation. Figure 3 shows cumulative rain in inches by season. Note that on the last day of July, marked by the reference line in Figure 3, 2013 and 2014 had accumulated significantly higher rainfall than the other years.

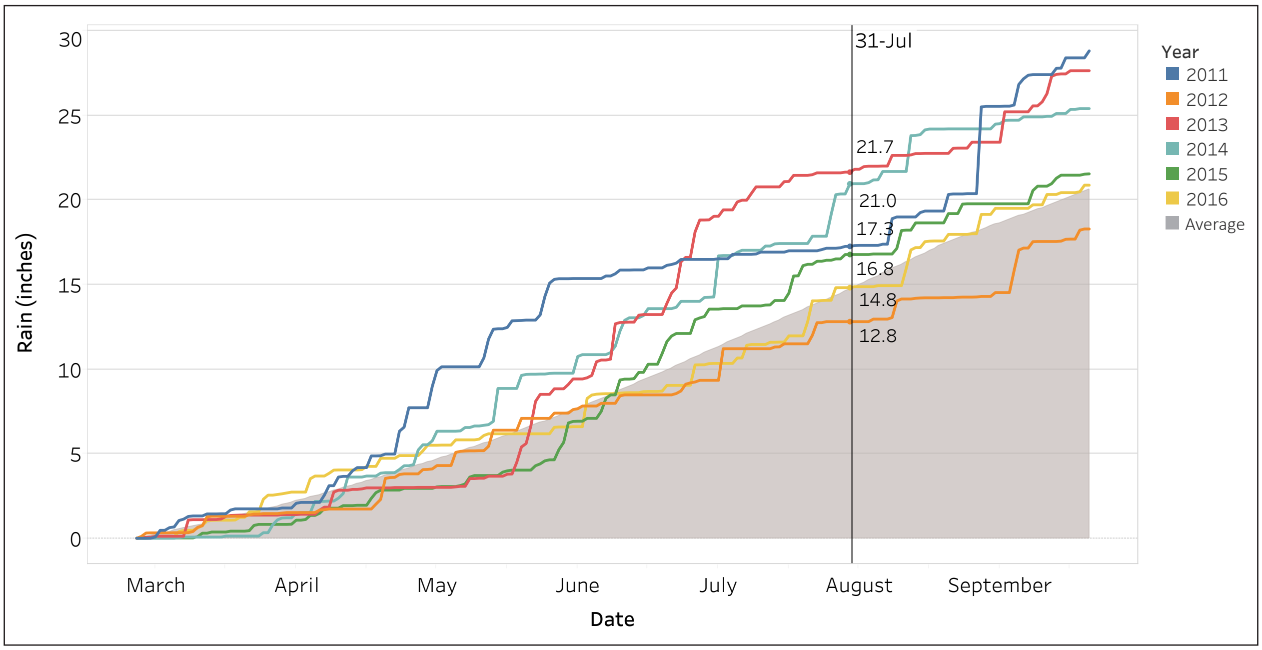

Figure 3: Cumulative rain in inches by year. Chazy, New York, 2011-2016.

TEMPERATURE

In general more degree days should result in faster plant growth and development. Extreme highs above 95° F can have a negative effect on hop plants. The best year for average yield in the UVM hop yard, 2014, was the coolest, and the two hottest years had the lowest yields. It is worth noting that one of those years, 2011, was limited by a number of other factors including disease and extreme spring weather. In a cooler year, it is likely the plants did not require as much water and may not have experienced as much stress as they did in hot years when moisture was also limiting. Four out of six years were above average in degree days.

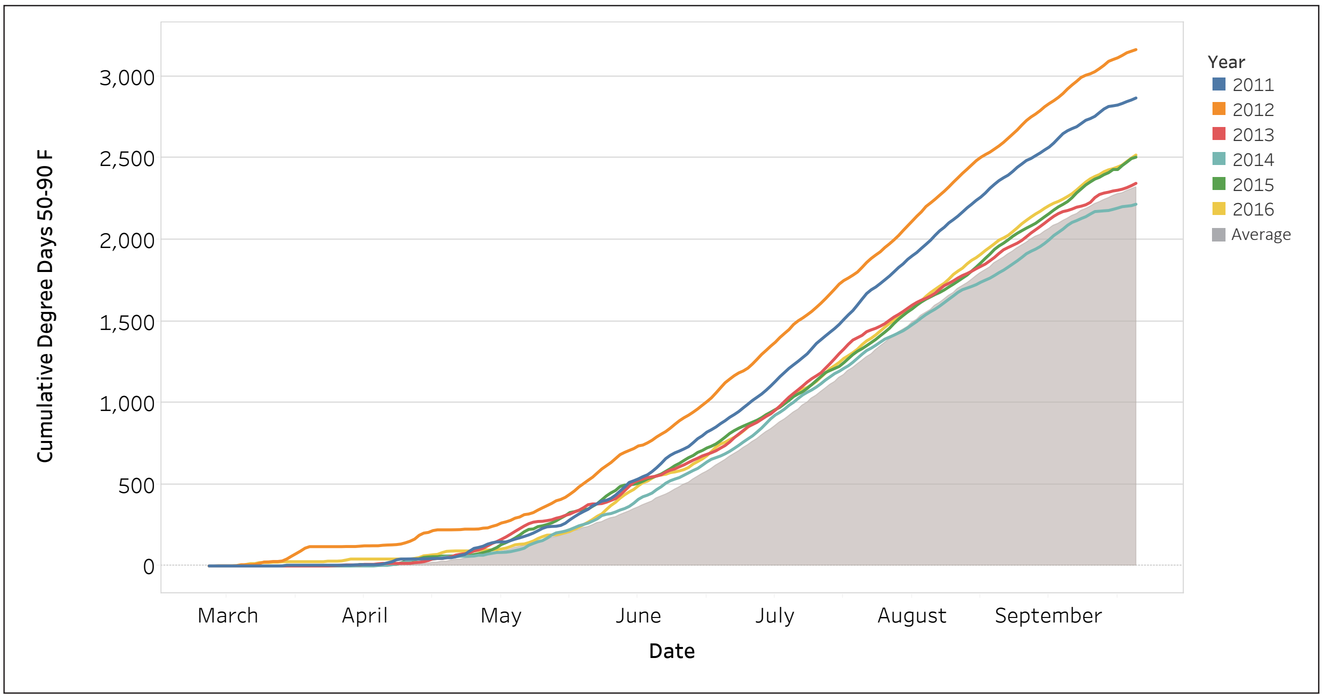

Figure 4: Cumulative degree days 50°-90° F by year. Chazy, New York, 2011-2016.

DOWNY MILDEW

Downy mildew (*Pseudoperonospora humuli*) has been identified as the primary pathogen plaguing our northeastern hop yards. This disease causes reduced yield, poor hop quality, and can cause the plant to die in severe cases. Downy mildew was identified in the hop yard in June of 2011. In the spring of 2013, a majority of the hills were "scratched" as an early season preventative measure against downy mildew. Scratching is a practice initiated in the early spring when new growth has just emerged from the soil. Removal of this new growth through mechanical means helps to remove downy mildew inoculum that has overwintered in the crown. The first shoots have an irregular growth rate and are not the most desirable for producing hop cones later in the season. The top of the crown itself can be removed before new growth emerges to further eliminate overwintering downy mildew. This practice, which was implemented in the hop yard in 2014, is commonly referred to as "crowning." Crowning dates from 2013-2015 are shown in Table 2. We didn't crown the variety trial in 2016 due to equipment limitations, but we did continue crowning in a section of the hop yard that was set aside to study the effects of crowning. Results from the Crowning Trial in 2014, 2015, and 2016 are available through our website: **www.uvm.edu/extension/cropsoil/hops**.

Table 2: Crowning dates from 2013-2016, Alburgh, VT.

Year	Date
2013	19-Apr
2014	14-Apr
2015	1-May
2016	N/A

Fungicides were sprayed when the forecast predicted weather favorable to downy mildew (warm and moist). Figure 5 shows "risk units" according to an index created by Royle (Gent et al. 2010). A risk index of 500 or above is considered a likely downy mildew infection event. This chart shows that in every year, there are frequent periods above 500 risk units between early April and late September, but that each year has different patterns. There was a difference between years in the total number of days that risk units were above 500 (Figure 6).

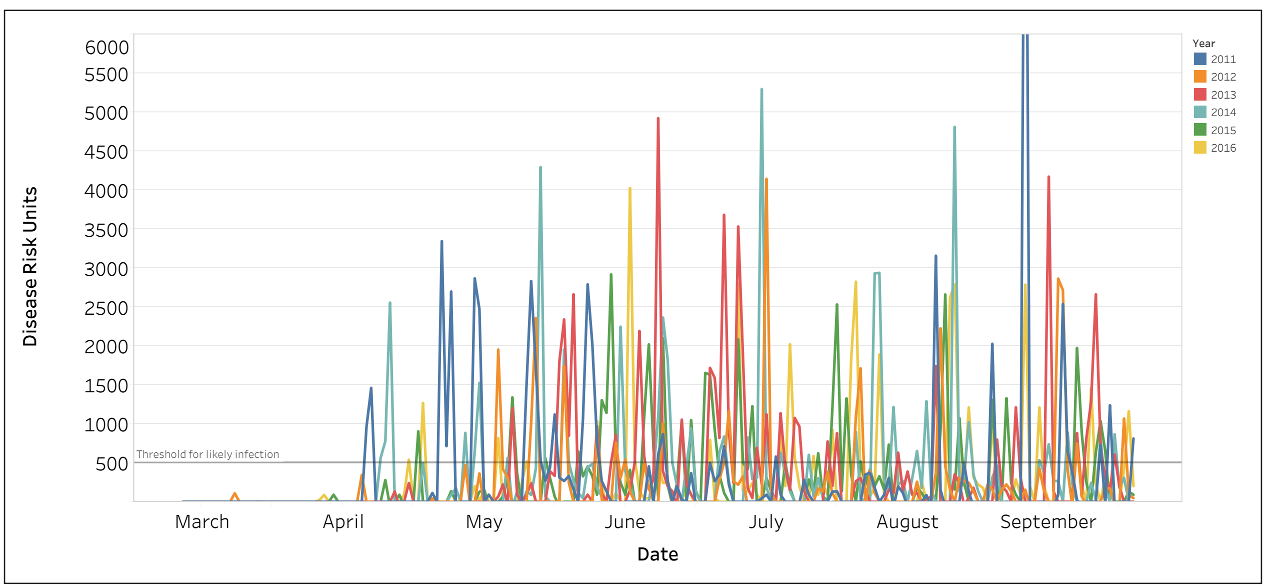

Figure 5: Number of "risk units" according to the disease risk index created by Royle (Gent et al. 2010), Chazy, New York, 2011-2016.

The 2013 and 2015 growing seasons had the most days with likely downy mildew infection (Figure 6). This also corresponds with high precipitation during 2013 and 2015.

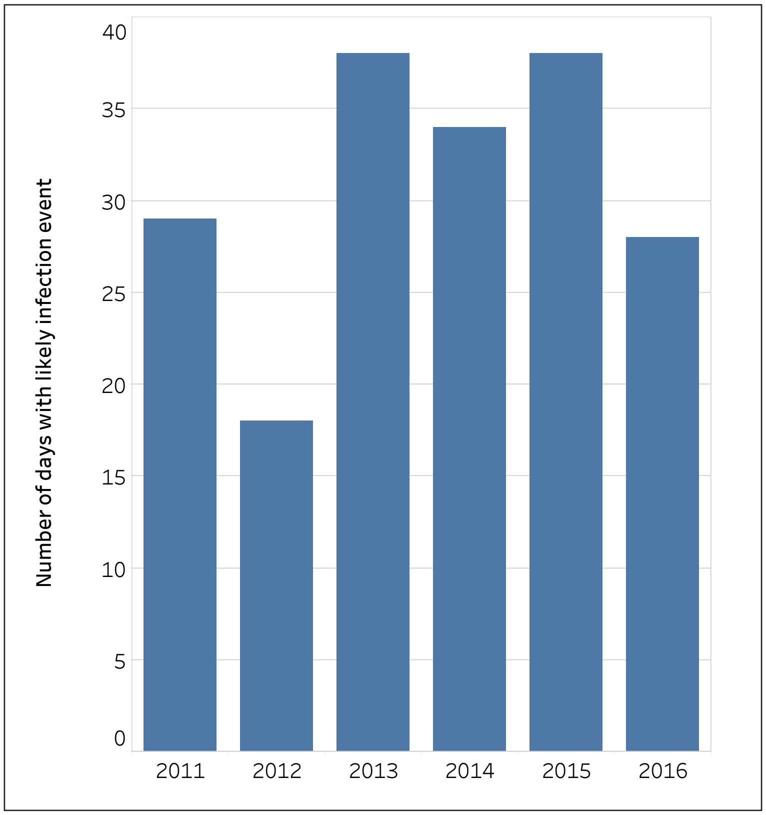

Figure 6: Number of days with a likely downy mildew infection event according to the disease risk index created by Royle (Gent et al. 2010). Compared by year. Alburgh, VT, 2011-2016.

Champ WG (Nufarm Americas Inc, EPA Reg. No. 55146-1) and Regalia (Marrone Bio Innovations, EPA Reg. No. 84059-3) were the primary fungicides to control downy mildew. Champ WG is 77% copper hydroxide and works as a control measure against downy mildew in hops. Champ is preventative, meaning that it protects the plant from further infection but does not kill the disease if it is already on the plant. How does this work? When copper hydroxide is mixed with water, it releases copper ions, which disrupt the cellular proteins of the fungus. Regalia is a broad spectrum bio-fungicide that works by stimulating the plant's natural defenses.

All fungicides applied were OMRI-approved for use in organic systems and were applied at rates specified by their labels using a Rear's Manufacturing Nifty Series 50-gallon stainless steel tank utility sprayer with PTO-driven mechanical agitation, a 3-point hitch, and a Green Garde® JD9-CT spray gun. In 2015 and 2016, additional biofungicides were evaluated for efficacy in controlling downy mildew. The full reports are available on our website: **http://www.uvm.edu/extension/cropsoil/wp-content/uploads/2016-Hop-Biofungicide-Trial.pdf**.

WEEDS

Weed control methods were studied over the course of the variety trial project to determine the best tools to manage weeds in an organic hop yard. We tested various methods including mulch, hand weeding, mechanical control, and herbicide. The primary weeds in the hop yard were quackgrass (*Elytrigia repens*), creeping Charlie (*Glechoma hederacea*), foxtail (*Setaria glauca*), and dandelion (*Taraxacum officinale*). The drive row contained predominantly perennial grasses and was mowed and weed-whacked periodically throughout each of the growing seasons.

Early in the variety trial project, in-row hand weeding and mechanical control followed by an application of hardwood mulch were the main weed control methods. Beginning in 2014, a weed control study was implemented to determine the efficiency, efficacy, and cost effectiveness of four weeding treatments alternative to hand weeding: steam weeding, mini-tiller, mulch, and herbicide.

Steam weeding was performed using a Steam Jenny hot water pressure washer; the primary method of terminating weeds with the Steam Jenny was heat. An Organic OMRI-approved herbicide, Avenger (Cutting Edge Formulations, Inc., EPA Reg. No. 82052-1), was used as a spot treatment for weeds and can be used on all weeds. It works by removing the plant cuticle, making the plant unable to adequately regulate moisture. It is most effective on annual weeds, and multiple applications may be required to kill well-established perennial weeds. Mechanical control was achieved using a Honda FG 110 mini-tiller, which was used to scratch the surface of the soil enough to remove weeds, but not deep enough to disturb the main root system of the hop plant. The mulch used was comprised of partially composted, assorted hardwood chips. Mulch was applied early enough to smother young weeds and prevent the germination of new weeds. Mulch was applied 6 inches thick and spread 3-4 feet wide.

Plots treated with herbicide and mulch weed control methods had higher yields and lower weed biomass than plots in the tilled and steamed treatments in 2014. This data remained consistent in 2015, with the herbicide, mulch, and tilling treatments performing higher than the steam treatments. Across the two years of the weed control study, it is clear the steam treatment consistently underperformed in comparison to the other treatments. Proper steam weeding equipment that reaches a higher temperature could help make this treatment more effective.

It is important to consider all treatment strategies before making a decision about weed control, as there are limitations to each method tested. These weed control methods would work best on annual weed and weeds in early stages of development, and it is important that treatments are used before weeds reach their reproductive stage, as this will have the greatest effect on weed seed bank reduction. The most effective weed control will likely be obtained through a combination of treatments and include multiple treatments over the growing season and into the fall, when weeds are most vulnerable. Strategizing timing and type of weed control method is key to a successful treatment plan.

When considering weed treatment strategies, it is important to consider how effective the treatment is, how often treatment needs to be reapplied, and the costs associated with labor, supplies, and equipment. In addition to cost, it is important to compare the estimated duration of effectiveness of each weed treatment and how many uses or applications will be needed throughout the season. Table 3 shows a summary of these variables.

Table 3: Cost and effectiveness considerations for weed treatments.

Weed Control Method	Estimated Duration of Effectiveness	Labor ($15/hr)	Equipment Cost	Pros	Cons
Hand Weeding	3-4 Weeks	80hrs ($1,200)	$50 gloves, hand tools	Consistent, relatively long-lasting	Very time consuming
Steam Weeding	2-3 Weeks	8hrs ($120)	$5,000 steam weeder	Fast	Equipment is very expensive
Mini-Tiller	2-3 Weeks	10hrs ($150)	$300 mini-tiller	Relatively fast	Can harm hop plants if not careful
Mulch	3-4 Weeks	8hrs ($120)	$1,600 100 yds mulch	Very effective	Expensive
Herbicide	2-3 Weeks	2hrs ($30)	$300 5gal/acre Avenger (OG), $400 for 5gal/acre Scythe (conventional)	Works well on broadleaves. Fast.	Not effective on perennial grasses

ARTHROPODS

In all years, arthropod scouting started in early June. Three leaves per hill and two hills per plot were scouted for insect pests and disease weekly in June, July, and August. Potato leafhoppers (*Empoasca fabae Harris*), two-spotted spider mites (*Tetranychus urticae Koch*), and aphids (*Aphis spp.*) were identified in the hop yard. Beneficial arthropods were also scouted and recorded.

From these scouting activities we are able to identify seasonal patterns of the three major pests in the hop yard and the beneficial Spider-mite Destroyer (*Stethorus punctillum*). Figure 7 shows average number of Two-spotted Spider mites (TSSM), Potato Leafhoppers (PLH), Hop Aphids (HA) and Spider-mite Destroyer (SMD), which prey on TSSM, by date. Notice that PLH commonly peak in late June, TSSM commonly peak in the hot, dry periods of July and early August, and the HA commonly peak right around harvest time when the weather begins to get cooler. The SMD population follows the TSSM population with a bit of a delay (Figure 7).

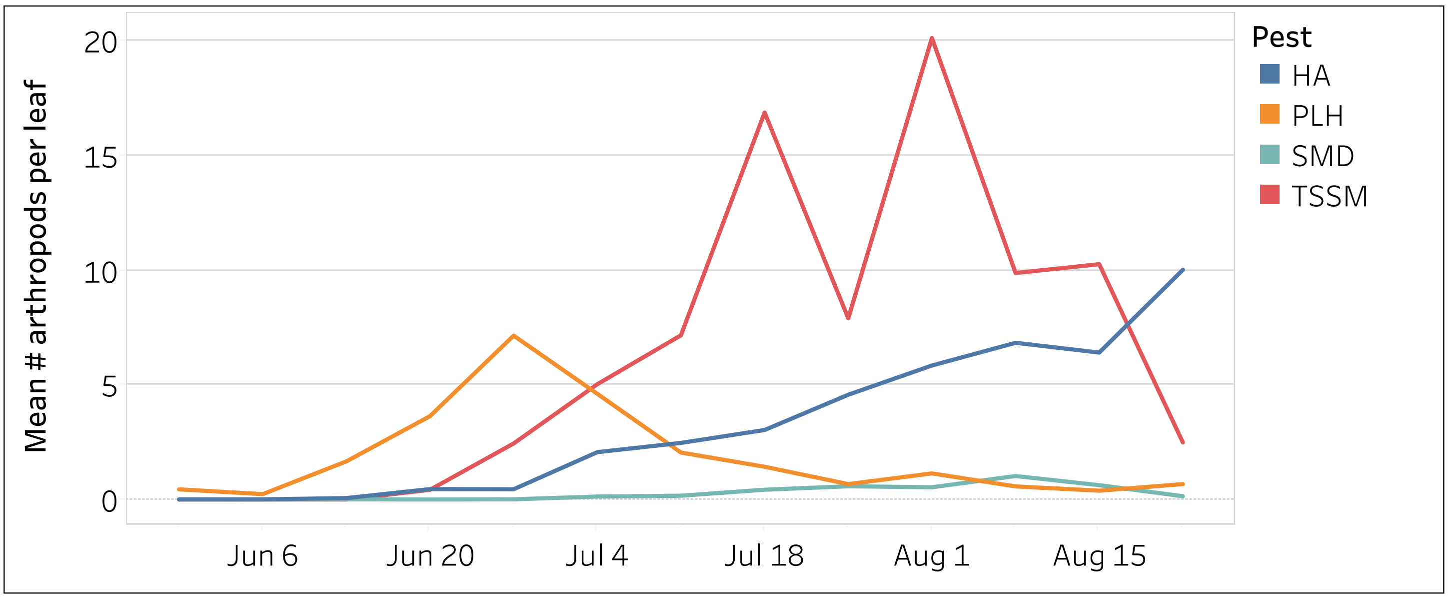

Figure 7: Average number of Two-spotted spider-mites (TSSM), Potato Leafhoppers (PLH), and Hop Aphids found per leaf by date, 2011-2016, Alburgh, VT.

Figure 8 shows average number of TSSM, PLH and HA by year. Notice that the different pests respond differently by year. In general, a hot, dry year like 2012 or 2016 favors the TSSM. PLH often have a better year immediately following a warm winter like we that experienced in 2015/2016. PLH blow in to Vermont from their winter habitat in southern states. The warmer the winter, the further north PLH are able to stay for the winter, which means they will have a shorter journey to Vermont in the spring. Although aphids have not been a significant problem in the UVM hopyard they have tended to become problematic in cooler, moist weather.

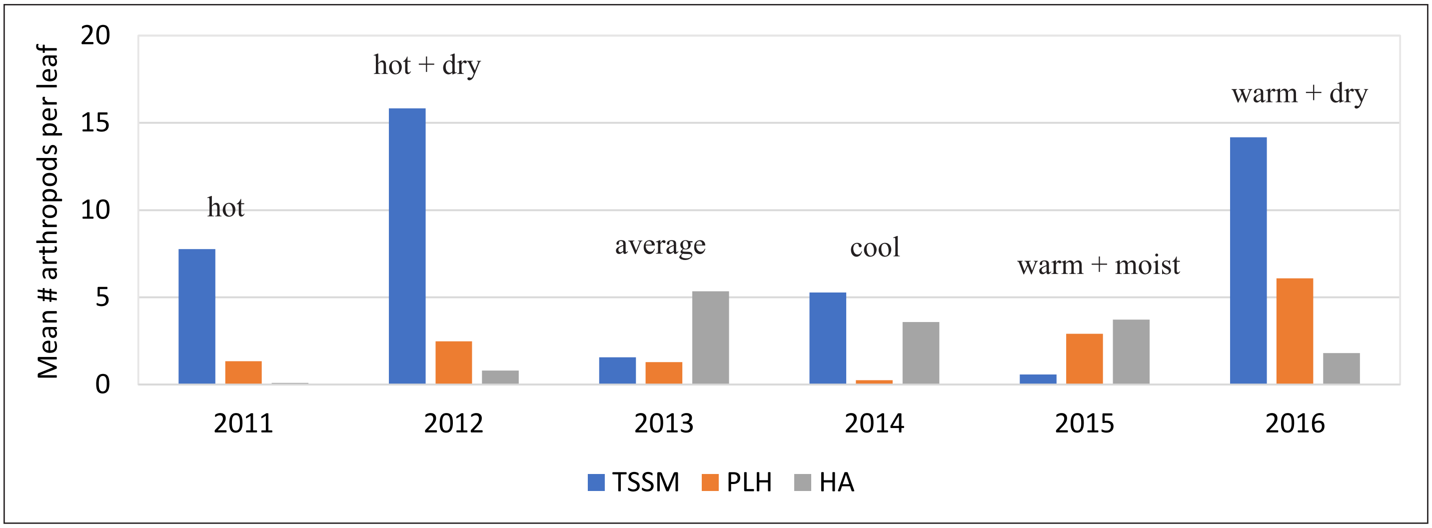

Figure 8: Number of Two-spotted spider-mites (TSSM), Potato Leafhoppers (PLH), and Hop Aphids (HA) found per leaf by variety, 2011-2016, Alburgh, VT.

Economic thresholds for potato leafhoppers in hops have not been created, but with an in-depth literature review, it was determined that two leafhoppers per leaf may be economically damaging to hops. A fact sheet on potato leafhoppers in hops can be found at: **http://www.uvm.edu/extension/cropsoil/wp-content/uploads/PLH-2014-Factsheet.pdf**.

Economic thresholds for two-spotted spider mites (TSSM) have been suggested in the Pacific Northwest to be 1-2 spider mites per leaf in June or 5-10 per leaf in July, based on a study done by Strong and Croft in 1995. A fact sheet from Cornell Cooperative Extension on TSSM can be found here: **http://nehopalliance.org/wp-content/uploads/2011/08/Article-Two-Spotted-Spider-Mite.pdf**.

Of late, some question has arisen on whether these TSSM thresholds are accurate (Weihrauch, 2005). It is important to note that spraying to control pests also eliminates many beneficial arthropods that help keep pest populations in check. Always consider carefully whether pesticide application is necessary before spraying. 2016 was the first year since 2012 that insecticides were used in the UVM hop yard. The product used in 2016, Trilogy (EPA Reg. No. 70051-2), is a fairly benign product made from neem oil.

IRRIGATION

The hop yard was irrigated weekly in June, July and August at a rate of 3900 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**.

It is reported that hops 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. Hops can be drought tolerant, but this is reliant on adequate subsoil moisture at the root zone provided by snow melt. 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 preceding the 2016 growing season, the subsoil moisture was also a major limitation to sustained growth. As spring snow melt contributed very little to subsurface moisture, hop plants were unlikely to maintain high yields and cone quality without supplemental irrigation. Moisture deficit during the hop growing season has been shown to cause reductions in hop cone yield (Hnilickova et al. 2009). Irrigation amount, as well as timing, is key to high yields, good cone quality, and overall plant health.

The amount of irrigation has varied each year the variety trial has been in place, the lowest rate, 3000 gal ac^{-1} was used in 2011 and 2016, 3900 gal ac^{-1} was used in 2014 and 2015, and 6000 gal ac^{-1} was used in 2013. 3000 gal ac^{-1} only equates to 0.11 inches each week, hops are, on average, irrigated for 12 weeks between training and harvest, leaving them far below the optimal water level. Limited by the well at the UVM hop yard, we are unable to irrigate at the desired amount. In 2016, we started a trial to quantify the pest, yield, and quality differences between plants with adequate water and the normal irrigation conditions for the UVM hop yard. More detailed results from this trial can be found in "2016 Hop Optimal Irrigation Trial" which is available on our website: www.uvm.edu/extension/cropsoil.

Table 4 shows the total rainfall, amount of water from irrigation, and the amount of water needed to reach plant requirements from the 2016 growing season. This trial was only representative of the second half of the growing season and supplementation amounts were calculated by distributing water needs equally throughout the season. However, as hops require the majority of their water prior to summer solstice, this distribution would change if the trial was started earlier in the season.

Table 4: Water through rainfall, irrigation, and supplementation, Alburgh, VT, 2016.

Week	Total rainfall	Water from irrigation	Supplementation required
	inches	inches	inches
20-Jun	0.36	0.11	0.60
27-Jun	1.36	0.11	-0.30 (surplus)
4-Jul	0.43	0.11	0.53
11-Jul	0.08	0.11	0.88
18-Jul	1.10	0.11	-0.04 (surplus)
25-Jul	0.09	0.11	0.87
1-Aug	0.14	0.11	0.82
8-Aug	0.45	0.11	0.51
15-Aug	0.02	0.11	0.94
Total	4.03	0.99	5.15

FERTILITY

Hops are considered "heavy feeders," meaning they require a lot of nutrients. Split applications of volatile nutrients such as nitrogen (N) are highly recommended, particularly on lighter soils. Slow release amendments such as manures, composts, and various meals (blood, alfalfa, oilseed, etc.) will release plant available N (PAN) over time, but only under the right conditions. Hop N needs are greatest in the month of June and into early July when the plant is growing quickly (Figure 9). Split applications should be timed for early spring at training, and again in early- to mid-June.

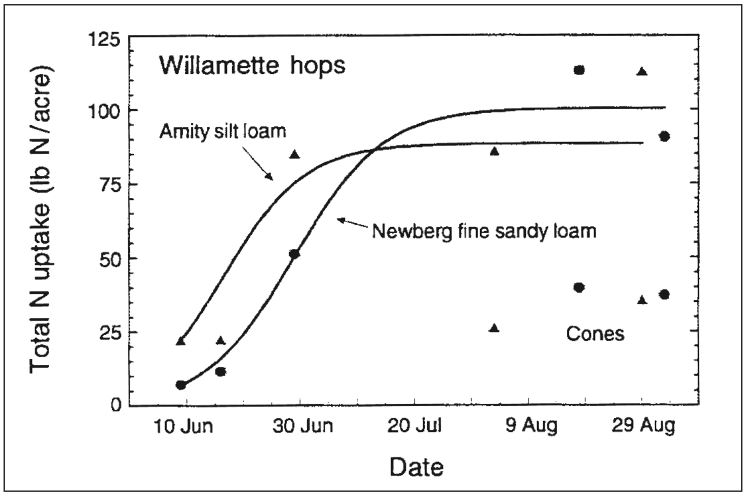

Figure 9: Rate of nitrogen uptake over time, Gingrich et al. 2000.

Fertigation (fertilizing through the irrigation system) was used to apply fertilizer more efficiently in the UVM hop yard starting in 2014. Beginning in early June, the hops received 3-5 lbs ac^{-1} of nitrogen (N) through the irrigation system on a weekly basis until side shoots were observed. At each fertigation application, 18-25 lbs ac^{-1} of sodium nitrate (16% N) were applied. The fertilizer was distributed evenly through 3000 gallons of water using a Dosatron unit.

In addition to the fertigation, a granular source of N was applied by hand in late May and again in late June. Sodium nitrate (16-0-0), Pro Gro (5-3-4), and Pro Booster (10-0-0) were used to supply granular N to the hops. Pro Gro and Pro Booster are made from a mix of vegetable protein meals, animal protein meals, and natural nitrate of soda and were from North Country Organics. Total N application (including fertigation) for each season is shown in Table 5. Fertility was only applied to the 3-foot row that the hops are planted in, and per-acre calculation for fertilizer was based on the square footage of those rows, excluding the 12-foot drive rows in between. All fertilizers were OMRI-approved for use in USDA approved organic systems.

During the 2014 growing season the highest yields were obtained even though low rates of N fertilizer were applied. It was our assumption that yields could be further boosted if additional N fertilizer was applied to the hop plants. In 2015 and 2016 we significantly increased application rates of plant-available N (Table 5).

Table 5: Total season nitrogen application from 2011-2016, Alburgh, VT.

Year	Broadcast	Fertigation	Total
	lbs	lbs	lbs
2011	80	-	80
2012	75	-	75
2013	135	-	135
2014	96	9	105
2015	150	15	165
2016	200	35	235

Higher N applications did not necessarily result in higher yield. Research and tradition still suggest that 120-200 lbs per acre of N is ideal, but these data indicate that hop yield differences observed from year to year were not always a result of inadequate fertility. Figure 10, Figure 11, and Figure 12 show percent N, phosphorous (P), and potassium (K) by variety across 3 years (2014, 2015, and 2016). While some varieties had adequate P and K, all varieties were deficcient in N on average. Ideally, the hop plant will contain about 3% N, 0.5% P, and 2% K.

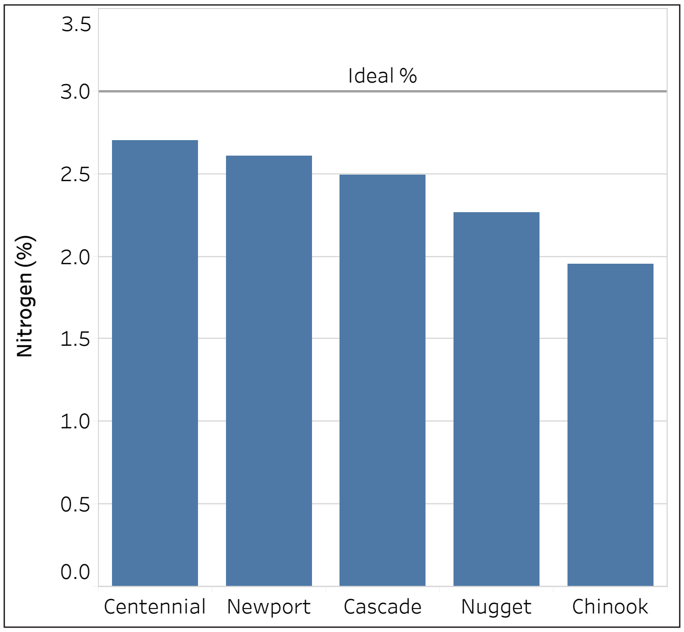

Figure 10: Total hop plant nitrogen concentration (%) for 5 varieties, 2014-2016, Alburgh, VT.

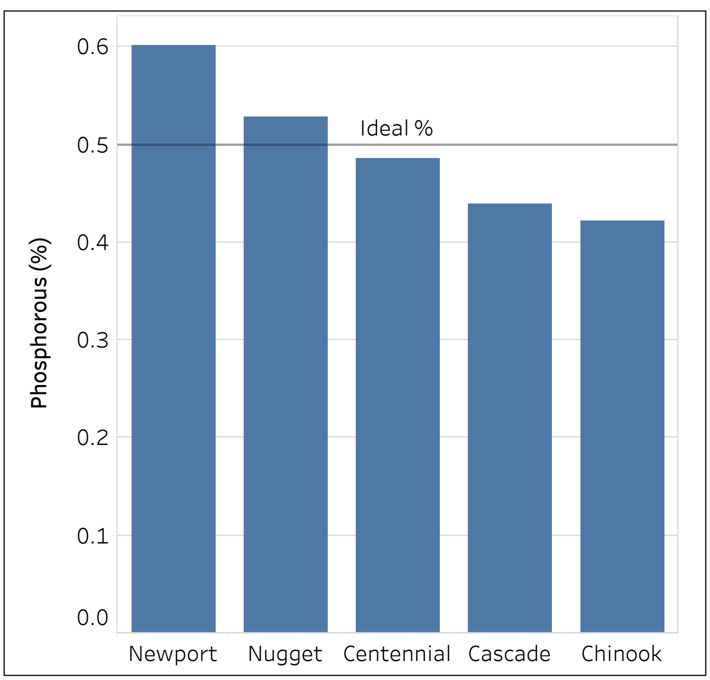

Figure 11: Total hop plant phosphorus concentration (%) for 5 varieties, 2014-2016, Alburgh, VT.

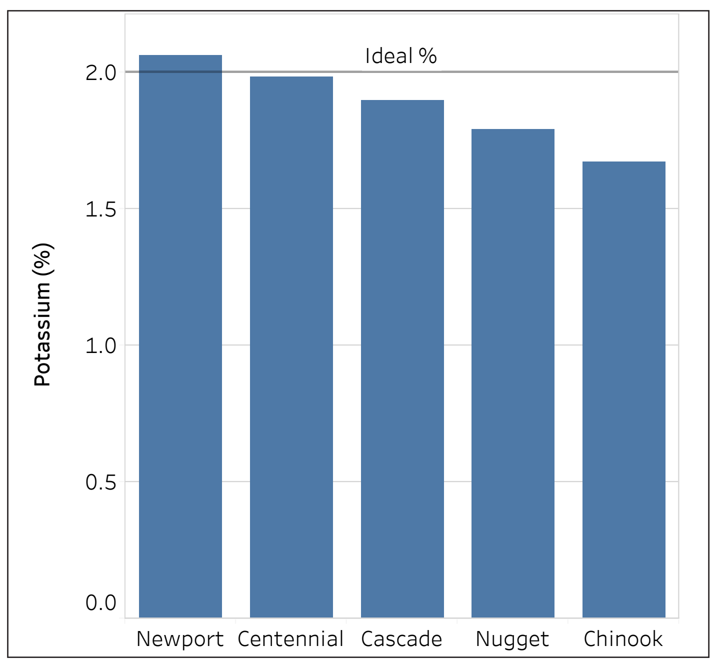

Figure 12: Total hop plant potassium concentration (%) for 5 varieties, 2014-2016, Alburgh, VT.

Adding biomass yield to the equation shows total nutrient removal for each plant. Figure 13 shows N removal in pounds per acre by variety and year for Newport, Nugget and Cascade. Interestingly, the highest nutrient levels (2015) did not correspond to the highest yields (2014). P and K levels by variety and year are shown in Figure 14and Figure 15 respectively. Only N data is shown from the 2014 year. The shaded area in each figure represents the ideal range for each nutrient. Ideally, hop plants will remove 80-150 pounds per acre of N, 20-30 pounds per acre of P, and 80-150 pounds per acre of K (Gingrich et al. 2000).

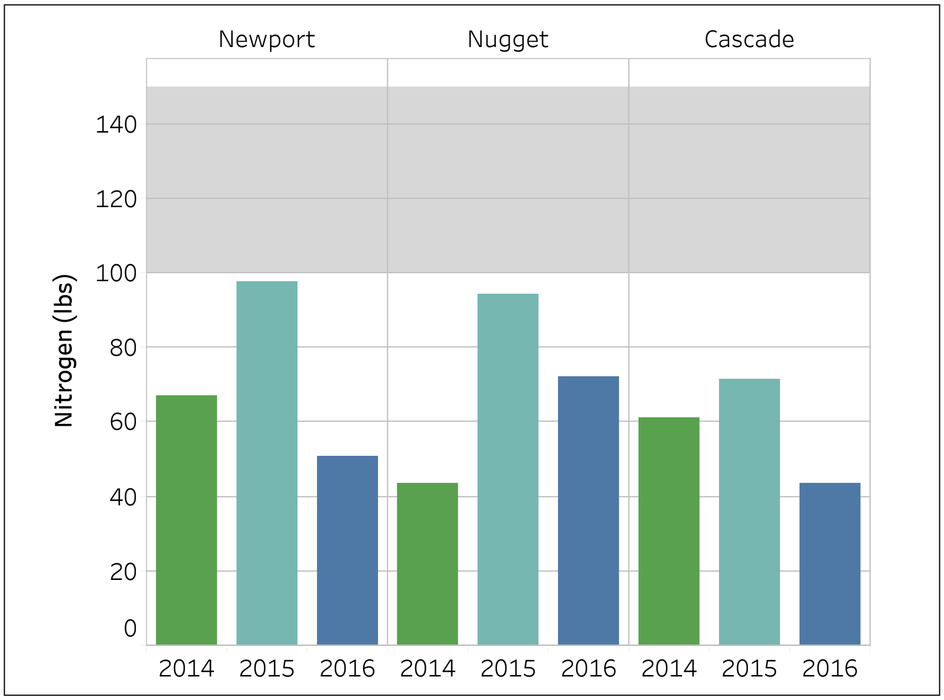

Figure 13: Nitrogen removal in pounds per acre by year and variety, 2014-2016, Alburgh, VT. The shaded area represents the ideal nitrogen range according to Gingrich et al. 2000.

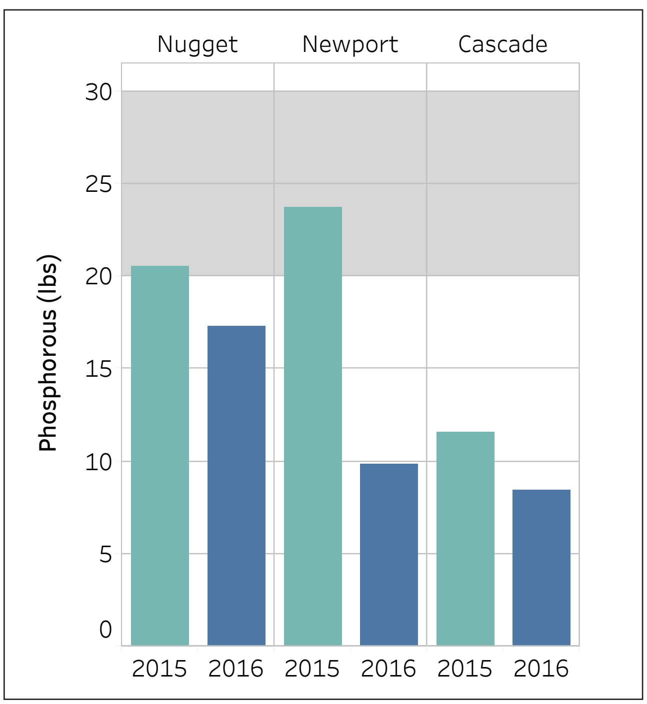

Figure 14: Phosphorous removal in pounds per acre by year and variety, 2015-2016, Alburgh, VT. The shaded area represents the ideal phosphorous range according to Gingrich et al. 2000.

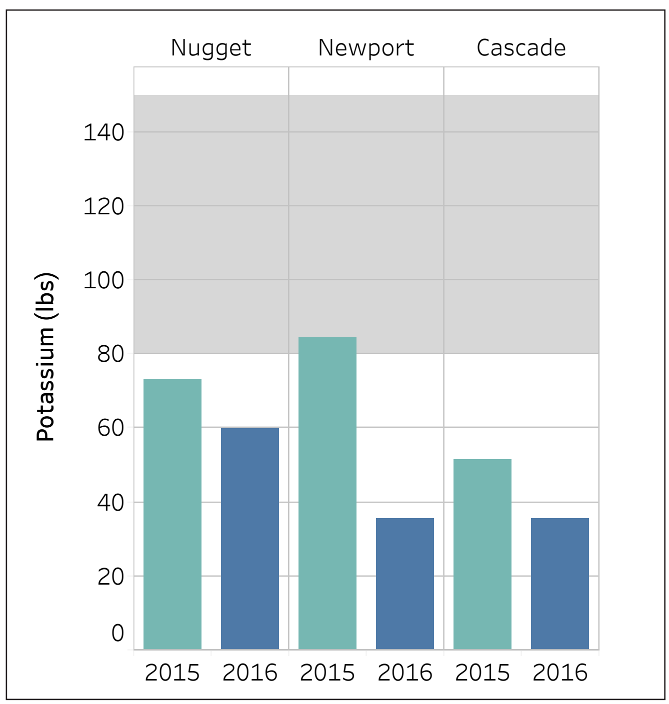

Figure 15: Potassium removal in pounds per acre by year and variety, 2015-2016, Alburgh, VT. The shaded area represents the ideal potassium range according to Gingrich et al. 2000.

VARIETY EVALUATION: YIELD AND QUALITY

Hop harvest was separated by variety and targeted for when cones reached 21-27% dry matter. In general, hop harvest timing in the Northeast occurs between mid-August and mid-September. At harvest, hop bines were cut in the field and brought to a secondary location to be run through a harvester. Yields for each variety represent the mean of 3 replicates. Harvest date for each variety is shown in Figure 16. Limitations in equipment availability and labor always make for some variation on harvest date. Table 7 shows harvest window by year.

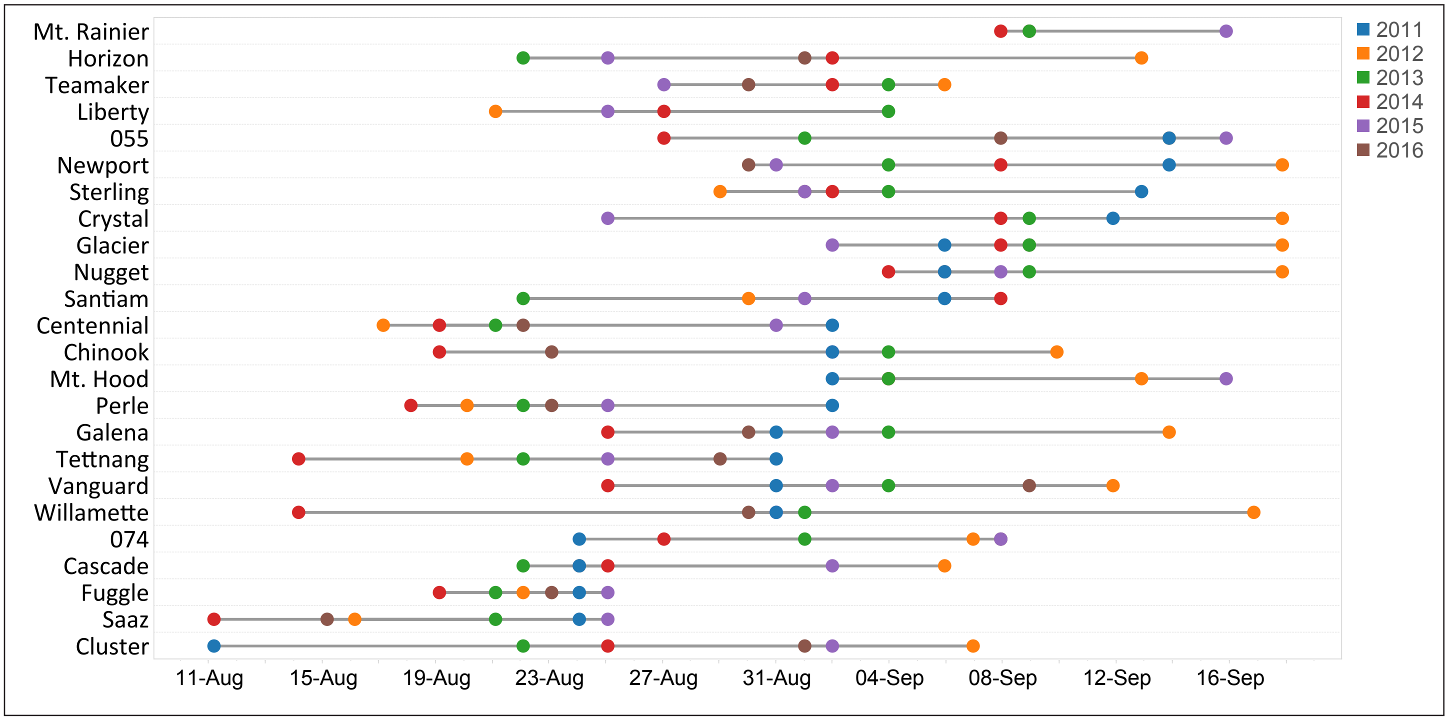

Figure 16: Harvest date by variety from 2011-2016, Alburgh, VT.

Table 7: Harvest window from 2012-2015, Alburgh, VT 2015.

Year	Date
2011	11-Aug to 14-Sep
2012	16-Aug to 18-Sep
2013	21-Aug to 9-Sep
2014	11-Aug to 5-Sep
2015	25-Aug to 16-Sep
2016	15-Aug to 9-Sep

Figure 17 shows harvest dry matter by variety for 2011-2016. Harvesting between 21% and 27% dry matter is recommended. Overall the hops in the UVM hop yard were harvested within the optimum dry matter range (Table 8). Murphy and Probasco (1996) have found that a 2% increase in dry matter can result in a 9% increase in production. Alpha acid content and essential oil levels are also affected by harvest timing. Total essential oils continue to develop well beyond normal harvest dates, whereas alpha acids degrade as harvest date is pushed back (Murphy and Probasco, 1996). In fact, Bailey et al (2009) found that late-harvested hops rated better in aroma quality, and beers brewed with late harvested hops were also rated better, described as more palate-full with a more pleasant bitterness, and more intense hop flavor and aroma. Table 8 shows average dry matter at harvest for each year of the variety trial.

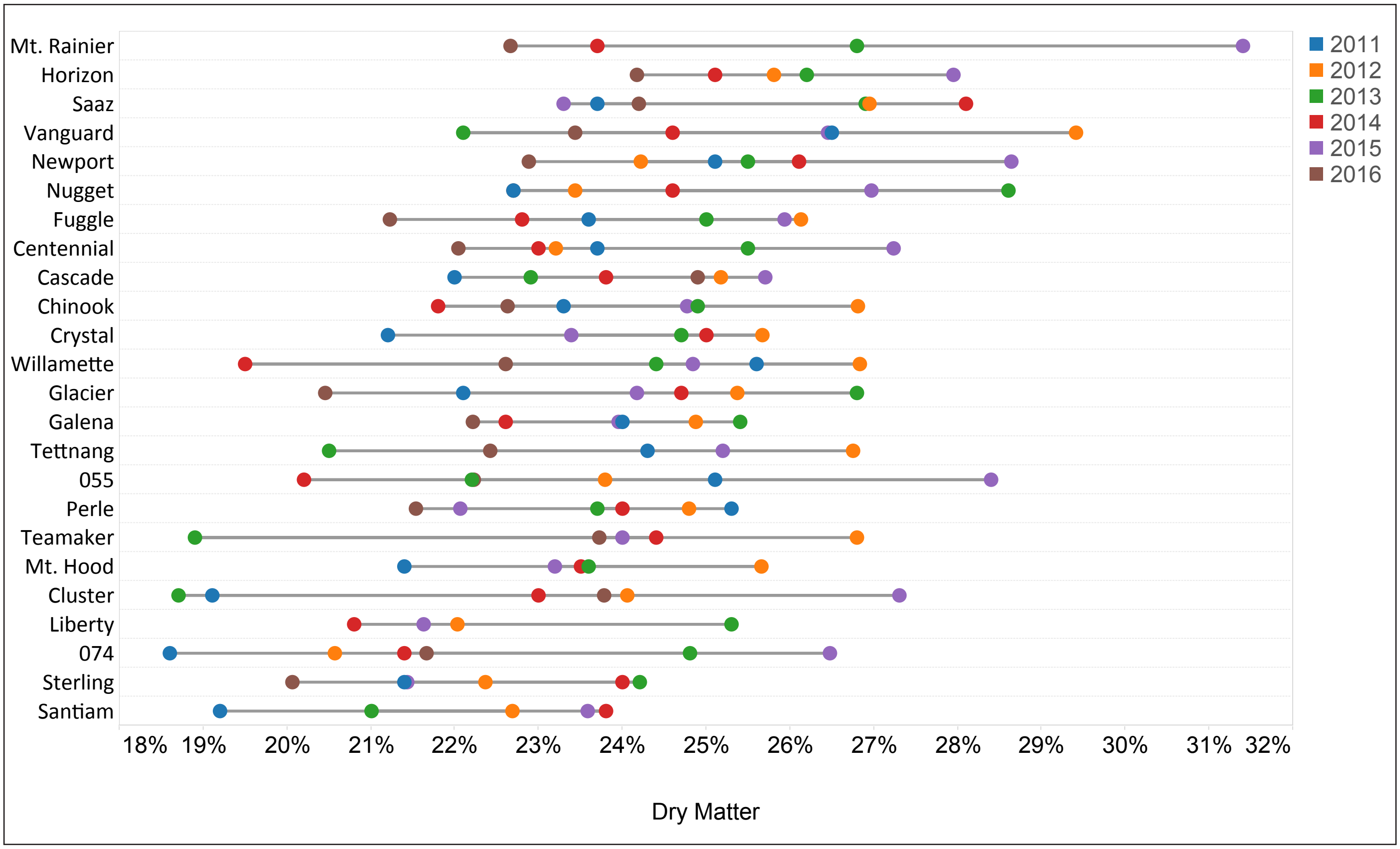

Figure 17: Harvest dry matter by variety from 2011-2016, Alburgh, VT.

Table 8: Average dry matter at harvest, Alburgh, VT 2011-2016.

Year	Average dry matter
	%
2011	22.9
2012	24.9
2013	24.1
2014	24.6
2015	25.3
2016	22.6

Picked hop cones were weighed on a per plot basis, 100-cone weights were recorded, and moisture was determined using a food dehydrator. Our hop moisture calculator is online at **http://www.uvm.edu/extension/agriculture/engineering/?Page=hopscalc.html**. Hop cones from all plots were dried to 8% moisture, baled, vacuum sealed, and then stored in a freezer. Hop cones from each plot were analyzed for alpha and beta acids in our lab using spectrophotometry as per the American Society of Brewing Chemists (ASBC) Method of Analysis entitled Hops 6a. Hop Storage Index (HSI) was also measured using the ASBC Method of Analysis detailed in Hops 12.

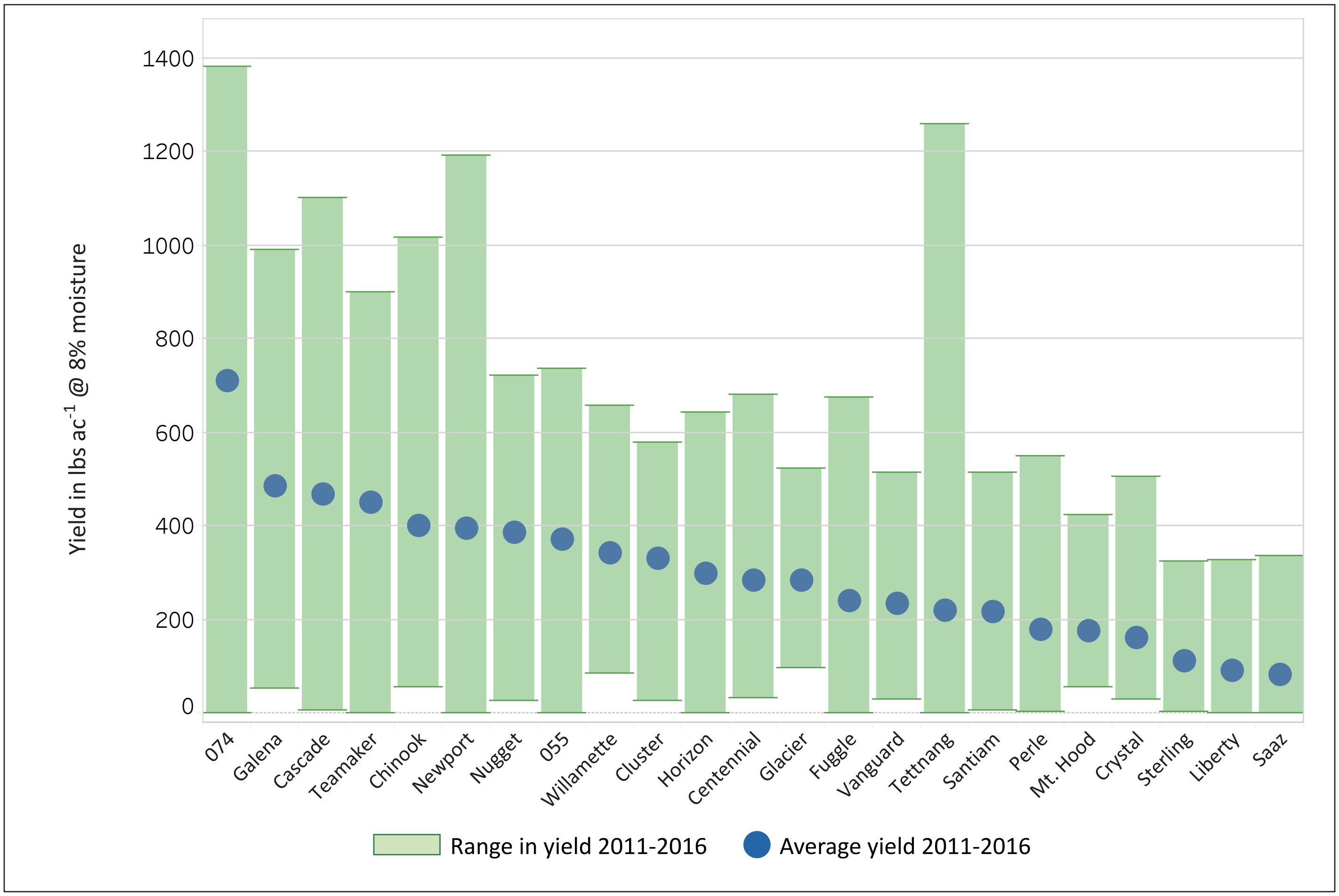

Figure 18: Minimum, maximum and average yields in the UVM hop yard, Alburgh, VT 2011-2016. Varieties are ordered from highest average yield (left) to lowest (right).

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 of 622 hills (1244 strings) per acre. Figure 18 shows the minimum, maximum, and average yields from the UVM hop yard over the past six seasons. There is a steep learning curve for growing hops. The low end of these ranges, mostly from the earlier years of the trial, illustrate that well. The high end, however, show that great yields are possible in this region. It has become clear that certain varieties consistently outperform the rest. Out of the seven varieties that had at least one plot yield above 800lbs per acre, six of those are also the top six varieties for average yield across all years (Figure 18). Table 9 shows minimum, maximum, and average yields for each variety across all six years of production.

Table 9: Range of yields by variety, Alburgh, VT 2011-2016.

Variety	Yield @ 8% moisture		
	Minimum	Average	Maximim
	lbs ac^{-1}	lbs ac^{-1}	lbs ac^{-1}
055	0	370	738
074	1	710	1,382
Cascade	6	468	1,103
Centennial	32	284	680
Chinook	56	401	1,016
Cluster	28	331	578
Crystal	29	160	504
Fuggle	2	240	674
Galena	52	484	990
Glacier	96	283	524
Horizon	0	298	643
Liberty	0	92	328
Mt. Hood	55	175	425
Newport	2	395	1,192
Nugget	26	385	722
Perle	4	178	550
Saaz	0	82	336
Santiam	5	217	516
Sterling	3	112	325
Teamaker	0	451	899
Tettnang	0	220	1,259
Vanguard	30	233	514
Willamette	86	342	658

Over the six years of this trial, hop quality and yield have been closely linked. When yield increased or decreased, so did percent alpha and beta acids. Figure 19 and Figure 20 show an average of alpha and beta acids across all varieties, respectively, by year.

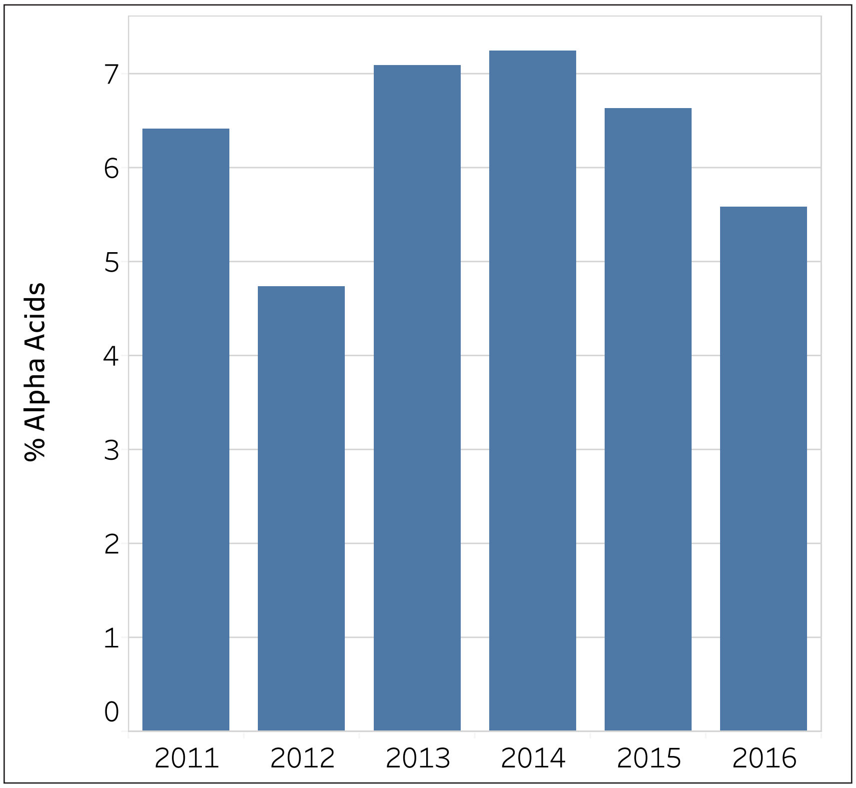

Figure 19: Percent alpha acids by year, Alburgh, VT 2011-2016. Average across all varieties.

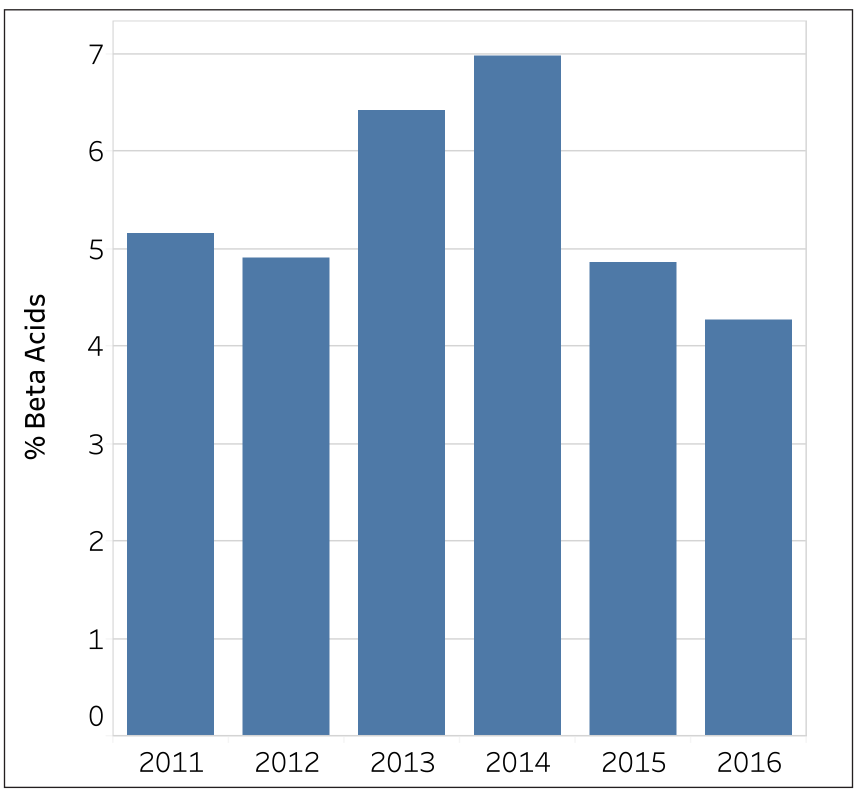

Figure 20: Percent beta acids by year, Alburgh, VT 2011-2016. Average across all varieties.

Figure 21 and Figure 22 compare the range in alpha and beta acids, respectively, to the industry standard range. Three varieties, Newport, Sterling, and Santiam had no overlap with alpha acid industry standards (Figure 21). This suggests that those varieties behave differently in the northeastern climate, or that they were lacking a specific input or environmental condition that they receive in the Pacific Northwest. In terms of beta acids, many varieties actually had higher levels than the industry standard in some years. Most dramatically, the lowest value for Cascade was just at the top end of the typical range (Figure 22). Many different factors influence acid content. Lewis and Thomas (1982) found that high temperatures during flower initiation in the end of May and early June can cause high alpha acid levels, as this is when resin glands are initiated.

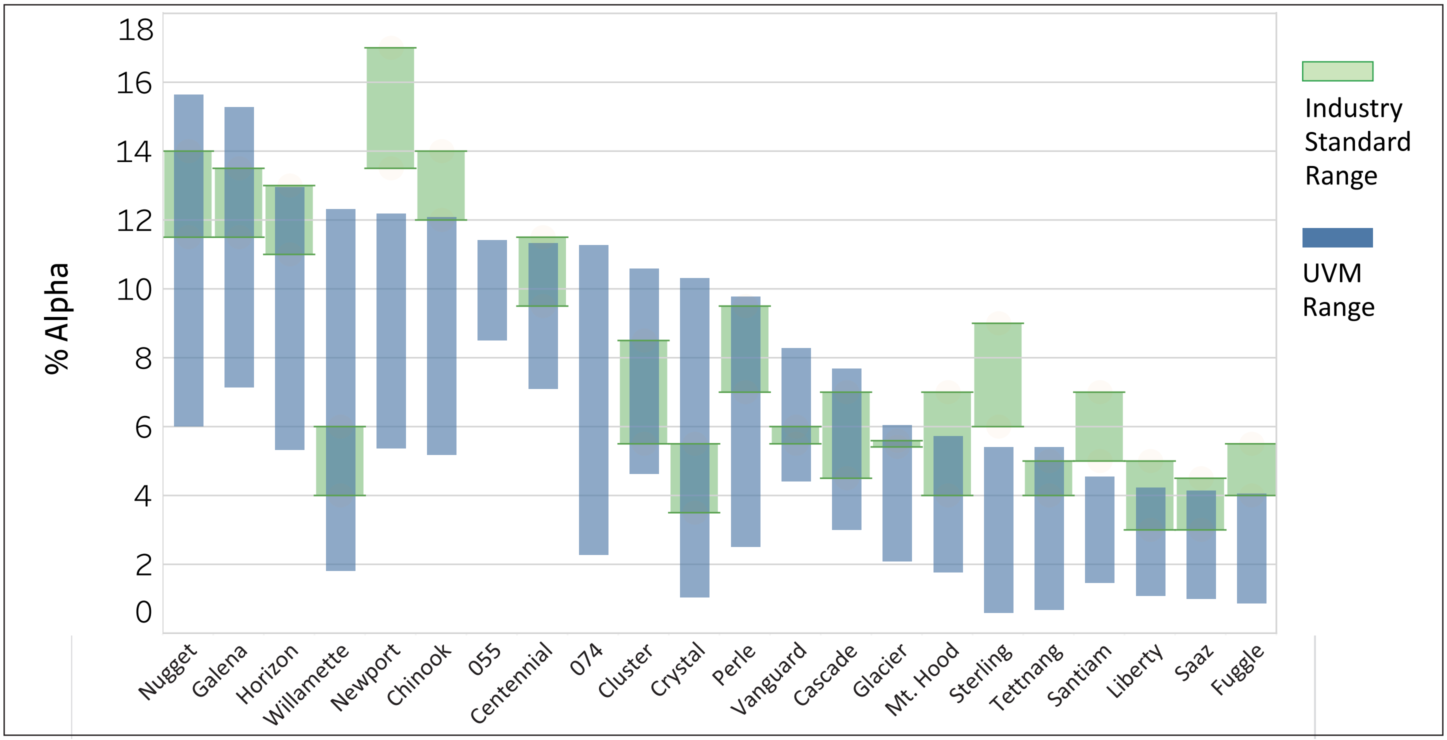

Figure 21: Range in alpha acids by variety, Alburgh, VT 2011-2016. Compared against industry standards published by USA Hops and Hopunion. 055 and 074 are experimental varieties and do not have an industry standard.

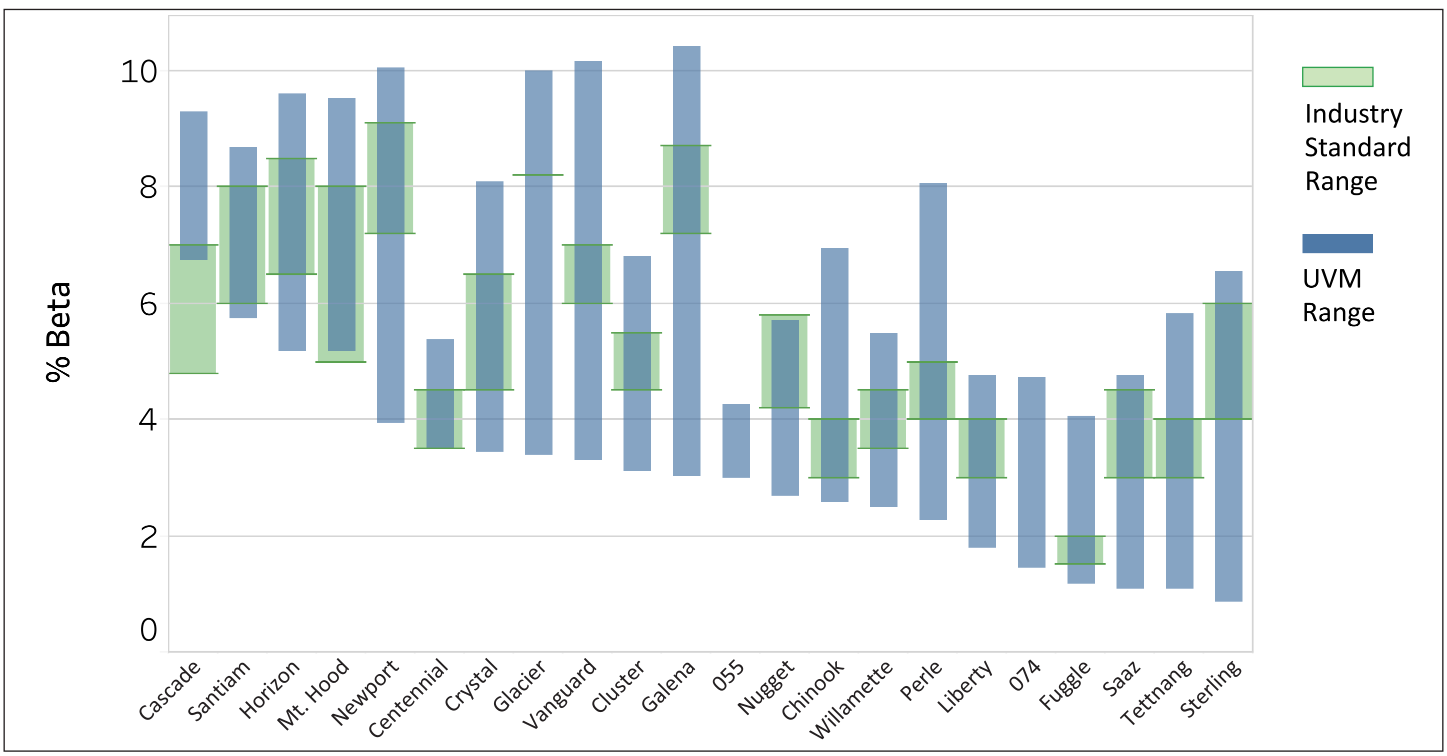

Figure 22: Range in beta acids by variety, Alburgh, VT 2011-2016. Compared against industry standards published by USA Hops and Hopunion. 055 and 074 are experimental varieties and do not have an industry standard.

VARIETY EVALUATION: PESTS

Figure 23 shows average TSSM and SMD per leaf by variety over all years. Liberty, Perle, Teamaker and Crystal were especially sucseptible to TSSM. In general SMD populations followed TSSM populations, although varieties such as Santiam seemed to be especially attractive to SMD.

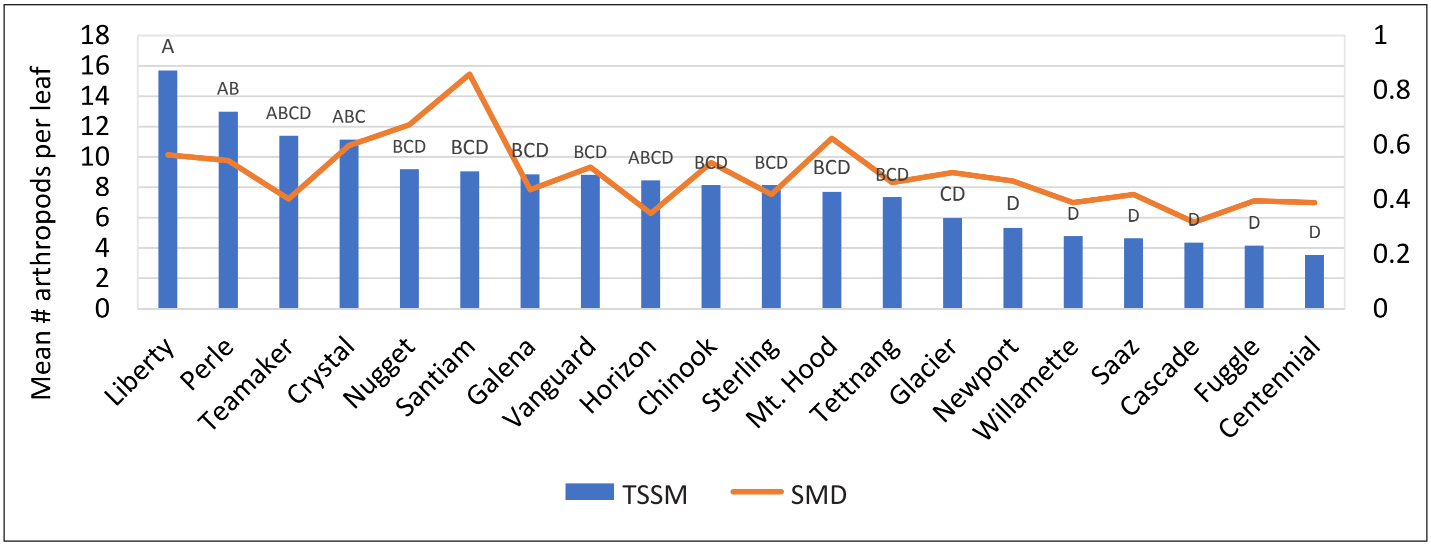

Figure 23: Number of Two-spotted spider-mites (TSSM), left axis, and Spider-mite Destroyers (SMD), right axis, number per leaf by variety, 2011-2016, Alburgh, VT.

Differences between varietal susceptibility to TSSM are well known, and have a genetic component. Research has indicated that there are differences in TSSM fecundity living on host plants of differing varieties, and that varieties have different susceptibilities to TSSM (Peters and Berry, 1980b). Peters and Berry (1980a) found that leaf characteristics such as hair and gland density affected TSSM oviposition rates, development rates, and sex ratios. Regev and Cone (1975) found that varieties vary in the susceptibility to TSSM based on their chemical differences, namely levels of farnesol.

Figure 24 shows average PLH per leaf by variety across all years. Mt. Hood, Liberty, Saaz, Newport, and Santiam were most susceptible to PLH damage. Centennial was consistently among the most resistant to TSSM and PLH.

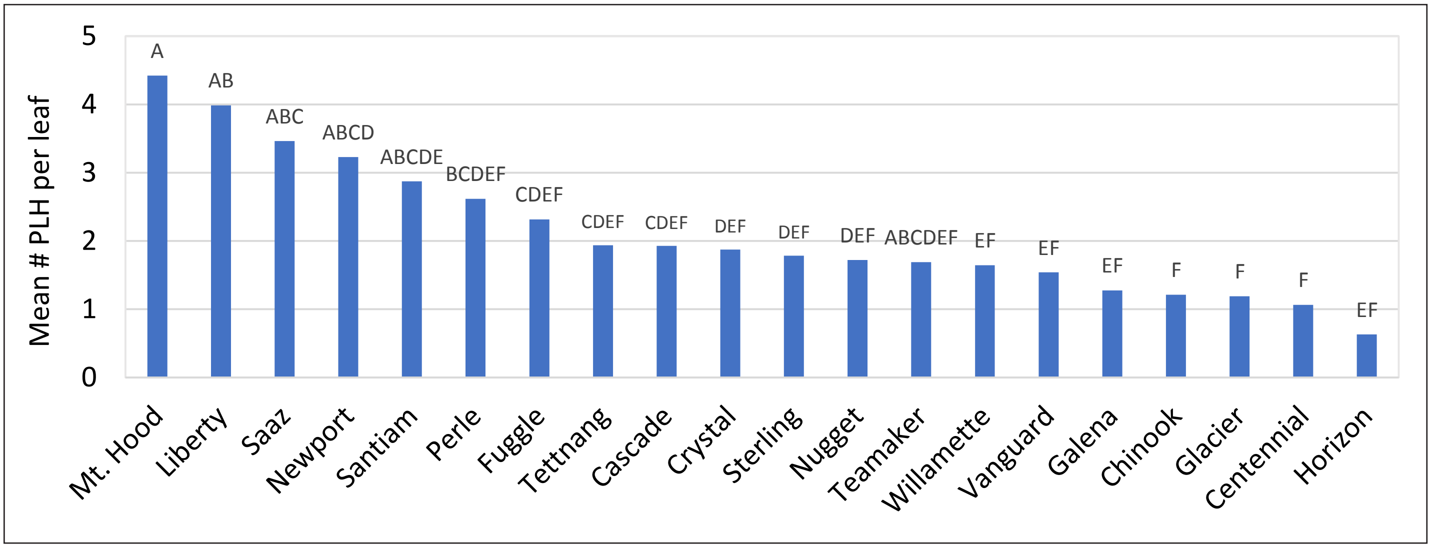

Figure 24: Number of Potato Leafhoppers (PLH) found per leaf by variety, 2011-2016, Alburgh, VT.

The fact that PLH may prefer certain hop varieties over others is a new discovery. Potato leafhoppers, native to the eastern United States, are not an economically problematic pest in the major hop growing regions of the world. However, the UVM Extension hop yard is located within a grass/alfalfa field where these pests already live. Leafhoppers pierce the leaf tissue and suck out water and nutrients. The saliva that is left behind by this action can block the leaf veins, preventing nutrients from reaching the tips of the leaf and causing leaf necrosis. In severe cases, this is referred to as "hopper burn."

At this time, it is unknown what draws leafhoppers to certain varieties or perhaps repels them from another. There are physical differences between hop leaves by variety, as demonstrated by research on TSSM (Peters and Berry, 1980a). These physical differences are known to provide resistance to PLH in alfalfa, potato and dry bean plants. Leafhopper-resistant alfalfa varieties have been developed and reduce the need for pesticide application. These resistant varieties have dense hairs that exude a chemical that deters leafhopper nymphs.

As hop production continues to grow in this region, PLH will likely remain a major pest problem. PLH resistant/tolerant hop varieties would reduce pesticide use if these varieties were grown by local farms.

Figure 25 shows average HA per leaf by variety across all years. Cascade had the lowest incidence, although numbers across all varieties were fairly low.

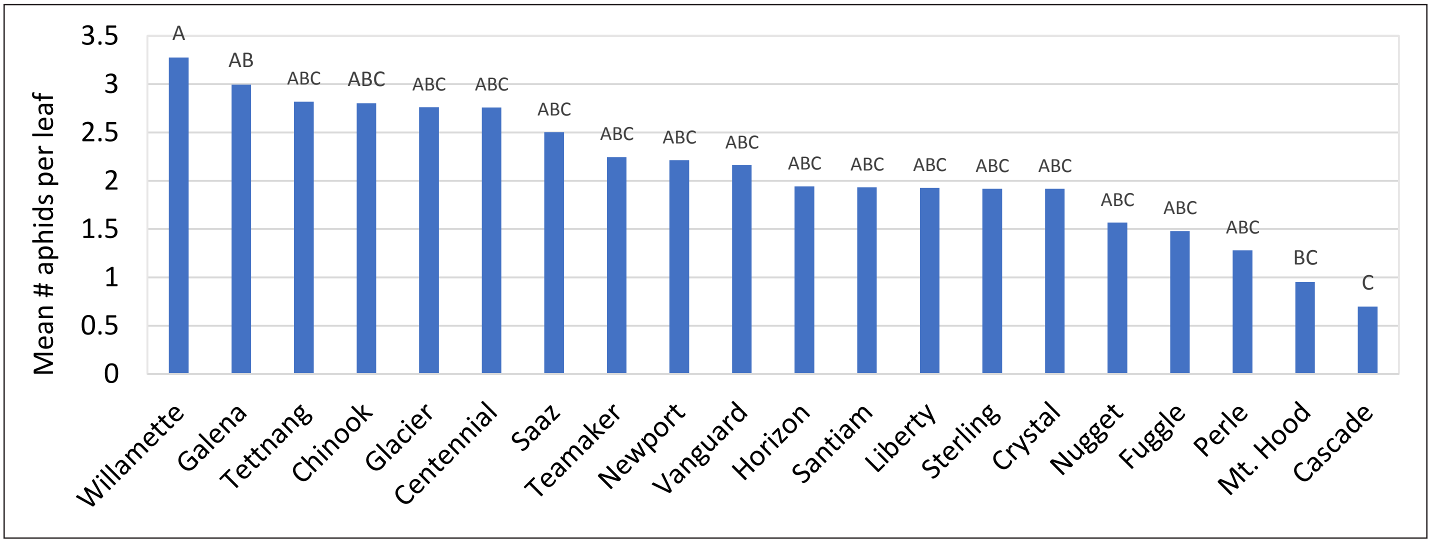

Figure 25: Number of Hop Aphids found per leaf by variety, 2011-2016, Alburgh, VT.

Research shows that certain hop varieties are more susceptible to aphids than others (Campbell 1983, Dorschner and Baird 1988, Weihrauch and Moreth 2005). Kralj et al. 1998 shows a relationship between high essential oil content and higher susceptibility to aphids, suggesting that the aphids feed on certain essential oils and are attracted to those plants with more available.

CONCLUSION

Figure 26 compares the range of yields in the UVM hop yard to the industry standard yield for each variety. As we have reported in previous years, there is a significant gap between our yields and those in the Pacific Northwest. This chart shows that we have the opportunity to greatly improve yields by discovering the sources of this gap. There would be benefit to developing varieties specifically developed to the temperate, cool climate in the Northeast. However, it is likely that a significant portion of the yield gap can be addressed by further understanding and improving fertility, irrigation, and IPM strategies for the region.

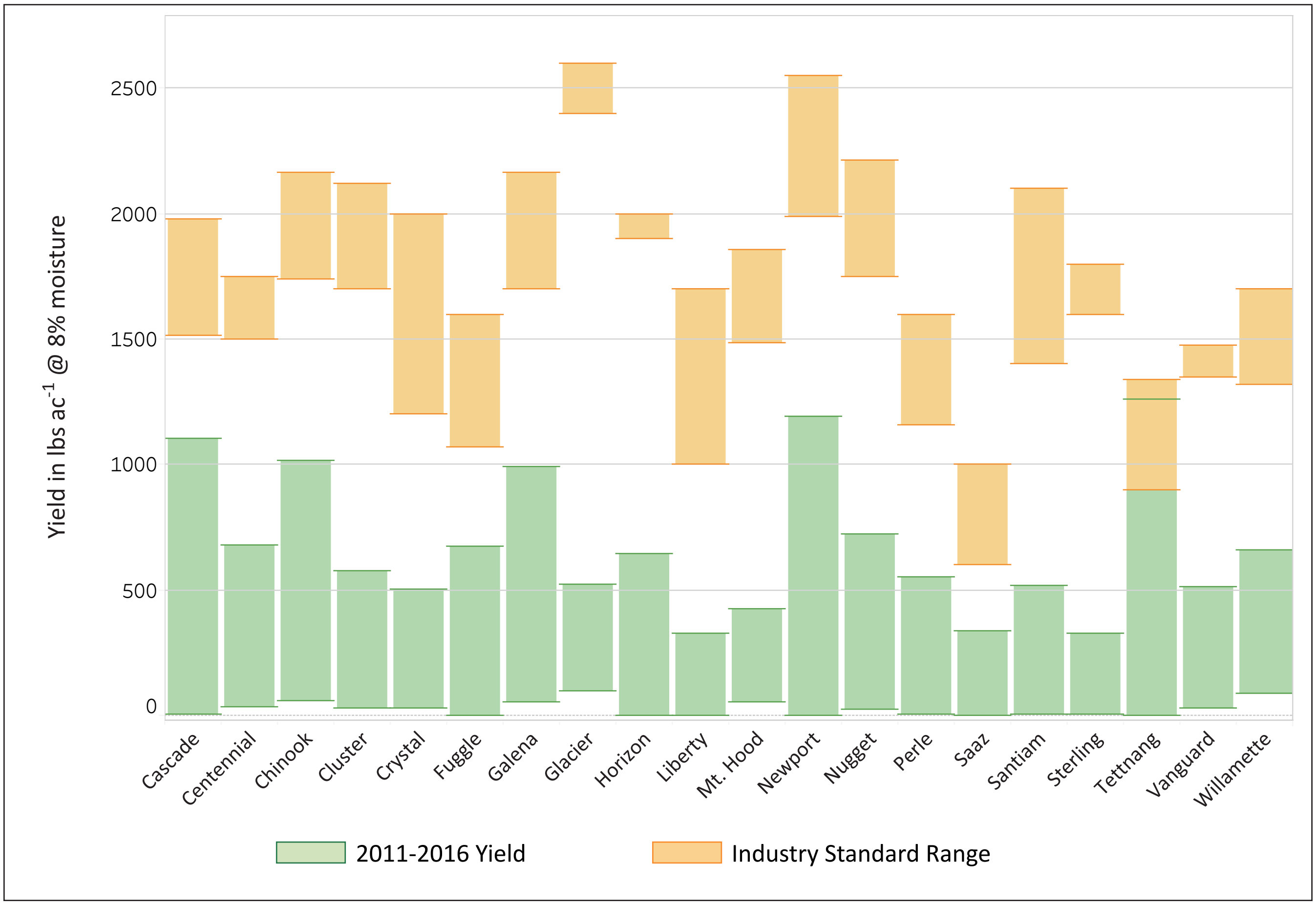

Figure 26: Range of yields in UVM hop yard compared against standard yields in the Pacific Northwest.

Table 10 evaluates varieties by yield as well as tolerance to arthropod damage and downy mildew infection. Varieties earned an “X” in the yield column if they were in the top ten for average yield. They received an “X” in the arthropod resistance column if their average TSSM per leaf was below 10 AND average PLH per leaf was below 2. Aphid levels were low enough for all varieties. They received an “X” in the downy mildew resistance column if they are known to be resistant according to the Hopunion variety manual: **https://drive.google.com/open?id=0B7aNkuU_q8iEQjJvUmttWGJ1R0k**. The varieties 055 and 074 are experimental varieties developed by Dr. John Henning at Oregon State University. Since they are new varieties, they are not included in the Hopunion variety manual, but received an “X” for downy mildew tolerance because they have demonstrated disease resistance in the UVM hop yard.

Seven varieties scored an “X” in each category: Cascade, Chinook, Galena, Nugget, Willamette, 055 and 074. These are the varieties that we recommend as best performers in the UVM variety trial. It is worth noting that Centennial is known to have lower yields than other varieties but is often grown anyway because of its popularity with brewers.

Table 10: Overall evaluation by variety, Alburgh, VT 2011-2016.

	Yield	Arthropod tolerance	Downy mildew tolerance	Total
Cascade	X	X	X	3
Chinook	X	X	X	3
Galena	X	X	X	3
Nugget	X	X	X	3
Willamette	X	X	X	3
055	X	X	X	3
074	X	X	X	3
Centennial		X	X	2
Cluster	X	X		2
Fuggle		X	X	2
Newport	X		X	2
Sterling		X	X	2
Teamaker	X		X	2
Tettnang		X	X	2
Vanguard		X	X	2
Glacier		X		1
Horizon		X		1
Liberty			X	1
Mt. Hood			X	1
Perle			X	1
Saaz			X	1
Santiam			X	1
Crystal				0

In addition to yield performance, it is also useful to look at plant health over time. While quantity and quality of cones is often a good indicator of plant health, it may not always correlate to long term success. Figure 27 shows the percent of original hills that died over the six-year lifetime of the UVM Extension hop yard, separated by variety. Hill failure can occur for many reasons. For example, one Cascade plot in our hop yard receives more shade than the rest of the yard. However, for varieties like Hallertau, Cluster, Mount Rainier and Tettnang that have had significant failure, it is likely that they are not well suited for our specific climate and/or pest pressure.

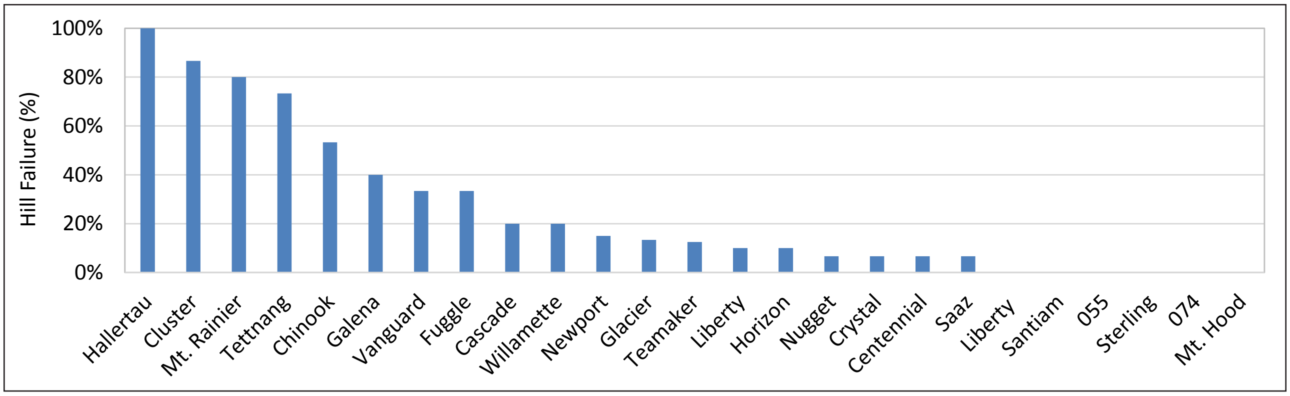

Figure 27: Percent hill failure by variety, Alburgh, VT 2010-2016.

While this trial is intended to compare varieties against each other, we can also learn from how they responded together to weather and management decisions. Figure 28 shows average yield across all varieties by year. Why was 2014 our best year? Despite having extremely low disease pressure, why was 2016 lower in yield? One useful way to look at this is by the “law of the limiting factor.” As an example, in Lake Champlain, all conditions were right for rapid blue-green algae growth except that there was too little phosphorous. As phosphorous began to accumulate in the lake from runoff, the algae exploded.

The hops are waiting to do the same thing, but any one factor in a given year has the power to hold them back. As we learn more about the hops, we can eliminate each factor. In the UVM hop yard, the most important limiting factor is likely irrigation. Especially hot, dry years like 2012 and 2016 exaggerate the effect, but it likely has an effect on all years. 2014, which was by far our best year, had moderate temperatures and adequate precipitation throughout the season (Figure 4). The cool temperatures allowed the plants to get away with less water use over the course of the season. Figure 28 shows some likely limits over the years. In 2013, lots of rain may have decreased nitrogen levels in the soil. While downy mildew pressure was high in 2015 (Figure 6), extreme cool June temperatures were also a major limiting factor in that year. It is important to remember that plant success relies on a variety of factors. For a more detailed summary of what we learned during each year of the variety trial, see blow:

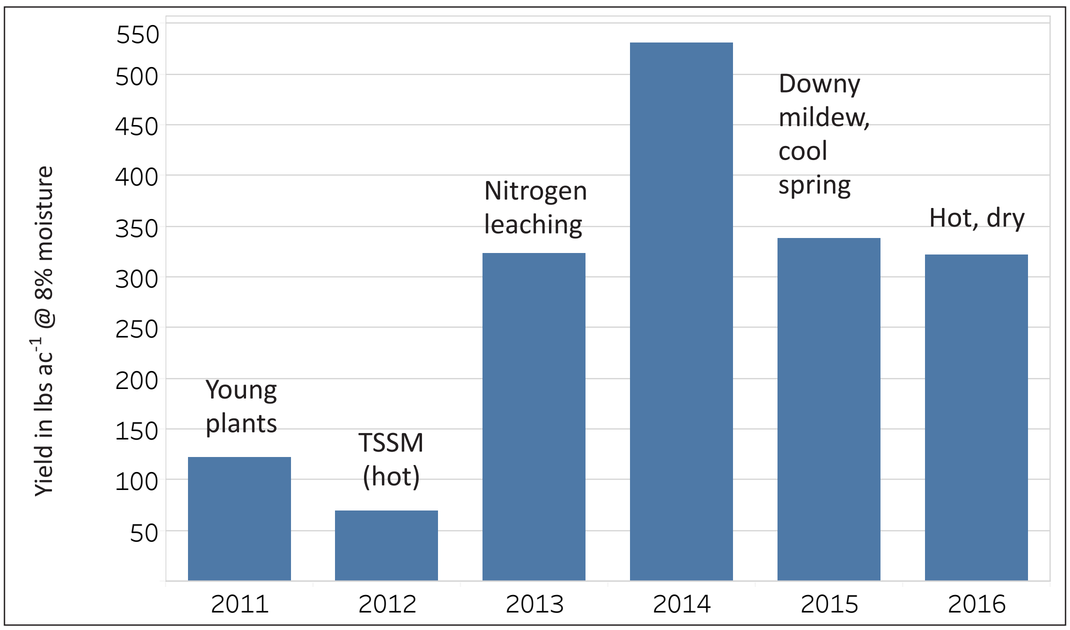

Figure 28: Average yield in the hop yard by year. This is an average of all varieties together. Alburgh, VT, 2011-2016.

2010-2011

The young hop plants used in the UVM research hop yard arrived in Vermont in August 2010. Three principal conditions led to decreased plant vigor: The plants arrived infested with two-spotted spider mites, suffered travel injury due to temperature variation in the refrigerated truck, and were planted in August, which was too late for weak plants to establish themselves and prepare for winter. Fall 2010 and spring 2011 were extremely wet, and soil saturation was a major issue. The increased water level and decreased oxygenation of the soil led to root rot and this in conjunction with high winds in the spring led to a high number of failed hills. Due to the sub-optimal experience prior to the 2011 growing season, supplemental plants were added to the hop yard to replace plants that did not survive. Harvest in 2011 was also affected by winds associated with hurricane Irene, side arms were ripped off the plants that had not been harvested at that point, which significantly decreased yields, and some plants were detached at the crown, which rendered them unharvestable. Plants that were harvested after the hurricane had increased cone browning and premature dry-down. The adverse growing conditions affected plant yield and health, and low yields in 2011 were attributed to the young age of the plants.

Lesson: Buy clean plants and make sure they have a safe ride to the farm.

2012

The second year of growth was very dry in comparison to 2011. There was minimal snow cover during the winter preceding 2012, which made the plant crowns more vulnerable to fluctuating temperatures and frost heaves. Like 2011, supplemental plants were also added in June 2012 to replace hills that had not survived. The 2012 growing season was characterized by hot, dry temperatures and inadequate moisture decreased plant photosynthetic abilities and left plants susceptible to two-spotted spider mites. Two-spotted spider mites, which thrive in hot, dry, dusty conditions, experienced a dramatic increase in population throughout the season, and likely contributed to low yields. Pyrethroids were sprayed to control pests. The use of pyrethroids led to diminished natural predator populations and secondary outbreaks of two-spotted spider mites followed the use of pesticides. Natural enemy populations are very important in managing pest populations at levels below economic threshold.

Lesson: Adequate irrigation is very important, scouting is critical and pesticides have secondary consequences; they must be used as a last resort.

2013

The 2013 growing season yielded better than the previous two years, but despite increased fertilization, the plants were still nitrogen deficient. Plants were sidedressed with nitrogen in June, and due to heavy rain, these nutrients had likely leached from the soil before the plants were able to utilize them. Overall pest pressures were low in 2013, and there were very few weeks above recommended thresholds.

Lesson: Rain can have an important effect on N fertility. Split applications and fertigation with rain events in mind will decrease this risk.

2014: The 2014 growing season was characterized by fairly average temperatures and above average precipitation, which caused vigorous plant growth. Plants flowered earlier in the season than average, which led to an earlier-than-usual harvest; it is suspected that low winter temperatures triggered this early flowering. 2014 yields were the highest in the six year variety trial experiment with eight varieties yielding above 500 lbs ac^{-1}.

Lesson: Increased water availability leads to better yields and moderate temperatures keep pest pressure low.

2015

In 2015, the hops were slow to reach the top of the trellis and this impacted overall plant yield. Low April temperatures and dry conditions contributed to low levels of hop growth at the beginning of the season. The hops did not regain any of the time they had lost in the spring during June, the primary growing month, due to high precipitation and cold temperatures. Hop growth was likely not aided by the aggressive crowning strategy that was implemented. The extremely wet 2015 season was characterized by an enormous increase in downy mildew presence in the hop yard. Downy mildew uses moisture as a breeding ground and uses rain splash as a vehicle for spore movement. Moisture remained in the dense hop yard vegetation and downy mildew was a rampant problem. Potato leafhopper populations were also higher than average, most likely due to the mild winter.

Although all these factors contributed to a decrease in plant yield in 2015, downy mildew was likely the primary cause.

Lesson: Spring temperatures have an important effect on hop growth, downy mildew is a significant challenge in the Northeast.

2016

2016 was extremely hot and dry and sub-optimal irrigation was likely the cause for low yields. Overall, disease and pest pressures were low, which alleviated some of the previous years' issues. Two-spotted spider mite populations were high, and the use of miticides were used to alleviate some of the pressure. The hop yard is irrigated from a well, which is a limiting factor in determining how much can be allocated to the hops versus other farm crops.

Lesson: Irrigation is critical to successful hop production.

OVERALL

After six years of the variety trial, it has become evident that there are many important factors regulating hop plant growth, and none can be neglected. Environmental conditions play a large part in plant success, and the temperature and precipitation variations through these six years each presented unique challenges in the forms of irrigation, nutrient management, and pest and disease pressure.

We have experienced different pest pressures than growers experience in the Pacific Northwest. Due to the overwhelming dry conditions of the Pacific Northwest, downy mildew is a minor pest there. Potato leafhoppers migrate from the southeastern United States each year, uniquely targeting hop yards in the eastern half of the country. Nitrogen management strategies have evolved to increase plant uptake, but still can be improved. Likewise, optimal irrigation has been tricky to achieve based on water availability, and new strategies may need to be implemented to increase yields and decrease the problems associated with water deficiency, such as two-spotted spider mites.

Pest management techniques have also provided a learning opportunity. In 2012, broad-spectrum pesticides were used liberally to manage pest populations, and this had negative implications on the natural enemy community. By increasing natural enemy habitat through the use of cover crops, pest populations can be managed in a more ecologically-friendly manner and reduce the risk of secondary outbreaks. Overall, yields have been variable and dependent on the environmental conditions present. There is a steep learning curve in determining the best strategies to manage all issues, but we have learned that a multi-faceted approach is the best way to manage pests, diseases, and nutrient deficiencies over the six years of this variety trial.

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