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NORTHWEST CROPS & SOILS PROGRAM

2013 Organic Hop Variety Trial: Results from Year Three

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UNIVERSITY OF VERMONT EXTENSION
CULTIVATING HEALTHY COMMUNITIES

2013 ORGANIC HOP VARIETY TRIAL: RESULTS FROM YEAR THREE

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Great interest has been kindled in producing hops in the Northeast. While hops were historically grown in the Northeast, they have not been commercially produced in this region for over a hundred years. With this loss of regional production knowledge, and the advancements of cropping science and the development of new varieties over the last few decades, a great need has been identified for region-specific science-based research on this reemerging crop. Additionally, the vast majority of hops production in the United States occurs in the arid Pacific Northwest on a very large scale, which is very different from hops production in the humid Northeast where the average hopyard is well under 10 acres. Knowledge is needed on how to produce hops on a small-scale in our climate. With this in mind, in August of 2010, UVM Extension initiated an organic hops variety trial at Borderview Research Farm in Alburgh, VT. The UVM Extension hopyard is trialing 22 publicly-available hop varieties, and 3 additional varieties from Dr. John Henning's breeding program in Oregon. The goals of these efforts are to find hop varieties that not only grow well in the Northeast and demonstrate disease and pest resistance in combination with high yields, but also present desirable characteristics to brewers. Hops are a perennial crop, and most varieties do not reach peak production until year three. The results and observations from the first and second year hopyard can be found on the UVM Extension Northwest Crops and Soils website: www.uvm.edu/extension/cropsoil/hops. ***The following are the results from the third year of production.***

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

Four-foot wide hop beds were tilled with a moldboard plow, tilled again with a 3-point hitch, 4' rotary tiller, and then planted with two vegetative hop cuttings per hill on 4-Aug 2010. Hills were distanced 7' apart, and rows were spaced at 10'. Each plot consisted of five consecutive hills.

Scratching was initiated for the first time this year (3rd year of production). Crowning or scratching is a practice initiated in the early spring when new growth has just emerged from the soil (Figure 1). The first shoots have an irregular growth rate and are not the most desirable for producing hop cones later in the season. Removal of this new growth and the top portion of the crown through mechanical means help to remove downy mildew inoculum that has overwintered in the crown. Scratching was completed using a DR trimmer with a saw-blade head, on 19-Apr 2013.

Figure1: Scratching

Hand-weeding was the primary weed control method. However, this season we also experimented with organic herbicides including Matratec (Brandt Consolidated Inc, 25(b) EPA Exempt), active ingredient clove oil, and Avenger (Cutting Edge Formulations Inc, EPA Reg. No. 82052-3) active ingredient citrus oil
Table 1). Efficacy of steam weeding was also evaluated twice during the season. In the case of both organic herbicides and steam weeding, weed control was only adequate for small annual broadleaf and grass species. Perennial grasses such as quackgrass were not controlled by these strategies. Similarly, weeds with 8 or more inches of growth were not killed through either means of control.

As the weeds were brought under control, rows were trained with two strings of coir (coconut fiber) per hill, with three to four of the strongest bines trained per string. Bines were trained between 20-May and 27-May 2013.

On 28-May 2013, Pro-Gro ® 5-3-4 and Probooster® 10-0-0 were applied to provide 75 lbs plant available N, 45 lbs P, and 60 lbs K ac^{-1}. Boron was applied at a rate of 2 lbs ac^{-1} and zinc at a rate of 5 lbs ac^{-1}. On 18-Jun Chilean Nitrate was applied to provide 60 lbs of plant available N. All fertilizers were OMRI-approved for use in organic systems, and were applied at rates recommended in the Pacific Northwest (Gingrich et al., 2000).

In early June, three leaves per hill and two hills per plot were scouted for insect pests and disease. The hopyard was scouted weekly in June, July, and August. In August, another three leaves per plot were scouted at the top of a plant, in order to compare pest populations on different sections of the plant. Potato leafhoppers (*Empoasca fabae*) (Figure 2), two-spotted spider mites (*Tetranychus urticae* Koch) (Figure 5), and aphids (*Aphis spp.)* were identified in the hopyard. Economic thresholds for potato leafhoppers in hops have not been documented, but with an in-depth literature review, it was determined that two leafhoppers per leaf maybe economically damaging to the hops (Figure 2).

Figure 2. Potato leafhoppers (above) and "hopper burn" caused by potato leafhoppers (below).

Figure 3. Downy mildew "flag shoot."

A fact sheet on potato leafhoppers (PLH) in hops can be found at: http://www.uvm.edu/extension/cropsoil/wp-content/uploads/Leaf_Hopper_Article.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).

Downy mildew (*Pseudoperonospora humuli*) was identified in the hopyard in June of 2011 (Figure 3). In the spring of 2013, a majority of the hills were “Scratched” as an early season preventative measure against downy mildew. Fungicides were sprayed when the forecast predicted downy-mildew-favorable weather (warm and moist) (Table 1). The fungicides used in the research yard in 2013 were Champ WG (Nufarm Americas Inc, EPA Reg. No. 55146-1), and Regalia (Marrone Bio Innovations, EPA Reg. No. 84059-3). Champ WG is 77% copper hydroxide and works as a control measure against downy mildew in hops. 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. All pesticides 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.

Table 1. 2013 Spray schedule in the organic hop variety trial, Alburgh, VT.

Date	Downy Mildew control Champ WG	Broad spectrum disease control Regalia	Organic herbicide Matratec	Organic herbicide Avenger
9-May	X	--	--	--
20-May	X	--	--	--
28-May	X	--	--	--
3-Jun	X	--	--	--
10-Jun	X	X	X	--
18-Jun	--	--	X	--
21-Jun	X	X	--	--
3-Jul	X	X	--	--
16-Jul	--	--	--	X

Figure 4. Hand harvesting hops.

The hopyard was irrigated weekly in July and August at a rate of 6000 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#irrigation.

Hop harvest was targeted for when cones were between 20 and 25% dry matter. At harvest, hop bines were cut in the field and brought to a secondary location to either be hand-picked (Figure 4) or run through our mobile harvester.

Harvest date for each variety can be found in Table 3. The number of living bines at the bottom of the coir were counted and recorded, as were bine height, and pre-pick bine weight. Bine height was measured but it should be noted that at least 3 ft of growth were left in the field. Sidearm length was measured on each string at 5’, 10’ and 12’, and averaged together. Picked hops were weighed on a per string or per plot basis, depending on method of harvest, 100-cone weights were recorded, and moisture was determined using a dehydrator. Hop cones were dried to 8% moisture, baled, vacuum sealed, and then placed in a freezer. Hop cones from each plot were sent to Alpha Analytics in Yakima, WA where they were analyzed for alpha and beta acids 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.

The data presented is of three replications. Hop brewing quality data is presented as varietal averages across the trial. The quality of each variety for hops was compared to industry standards.

Figure 5. Two-spotted spider mites.

Using an economic threshold of 1-2 adult TSSM leaf^{-1} in June, and 5-10 adult TSSM leaf^{-1} from mid-July through harvest, number of weeks above threshold was calculated; using a formula adapted from Costello (2007) a calculation for spider mites in vineyards.

Similarly for PLH, using an economic threshold of 2 PLH leaf^{-1}, the number of weeks above threshold was calculated. This calculation was determined using an extensive literature review.

Economic thresholds were also calculated for Aphids, using a threshold of 8-10 adult aphids leaf^{-1}, throughout the entire growing season.

Yields are presented at harvest moisture and at 8% moisture on a per hill and per acre basis. Per acre calculations were performed using the spacing in the UVM Extension hopyard of 70 ft^2 hill^{-1}, 622 hills ac^{-1}. Yields were analyzed using the PROC MIXED procedure in SAS using the Tukey-Kramer adjustment, which means that each variety was analyzed with a pairwise comparison (i.e. ‘Cluster’ statistically outperformed ‘Cascade’, Cascade statistically outperformed ‘Mt. Hood’, etc.). Pearson correlation coefficients (r) and probability levels for spider mite thresholds developed in the Pacific Northwest, brew values, and growth characteristics were performed across varieties. Pearson correlation coefficients (r) were also used to determine significance between these factors. Correlations were deemed significant at the p<0.10 level, and the Pearson correlation coefficient (r) was used to determine the degree of correlation, and whether it was a negative or positive correlation.

RESULTS

Using data from a Davis Instruments Vantage Pro2 weather station at Borderview Research Farm in Alburgh, VT, weather data was summarized for the months spanning from the 2012 harvest to 2013 harvest (

Table 2). The winter of 2012-2013 was fairly mild, adding to the total number of Growing Degree Days (GDD's). The 2013 growing season (March-September) experienced 5,424 GGD's, which were 74 more than the 30 year average (1981-2010 data). June 2013 saw near record rainfall in our area, with 5.5 more inches of precipitation than the 30 year average, while the rest of the summer experienced less precipitation than the 30 year average.

Table 2. Temperature, precipitation, and Growing Degree Day summary, Alburgh, VT.

Alburgh, VT	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13
Average temperature (°F)	71.1	60.8	52.4	36.7	28.7	20.6	21.9	32.1	43.6	59.1	64.0	71.7	67.7	59.3
Departure from normal	2.3	0.2	4.2	-1.5	2.8	1.8	0.4	1.0	-1.2	2.7	-1.8	1.1	-1.1	-1.3
Precipitation (inches)	2.92	5.36	4.13	0.68	3.49	0.60	1.08	1.04	2.12	4.79	9.23 ǂ	1.89	2.41	2.20
Departure from normal	-0.99	1.72	0.53	-2.44	1.12	-1.45	-0.68	-1.17	-0.70	1.34	5.54	-2.26	-1.50	-1.44
Growing Degree Days (base 32°F)	1241	896	652	144	535	47	21	89	348	848	967	1235	1112	825
Departure from normal	102	38	150	-40	535	47	21	89	-36	91	-47	37	-27	-33

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.
* November 2012 data are based on National Weather Service data from cooperative observation stations in South Hero, VT.
ǂ June 2013 precipitation data based on National Weather Service data from cooperative stations in South Hero, VT.

Harvest

Hop harvest is targeted for when the cones are 20 to 25% dry matter. Varieties Centennial, Fuggle, and Saaz were harvested first, based on observation and preliminary dry matter testing. The last harvested varieties were Crystal, Glacier, and Nugget. The hop harvest window was from mid-August to mid-September (Table 3).

Table 3. Organic hop variety trial harvest date and dry matter at harvest.

Variety	Harvest Date	Harvest dry matter (%)
Cascade	22-Aug	22.9
Centennial	21-Aug	25.5
Chinook	4-Sep	24.9
Cluster	22-Aug	18.7
Crystal	9-Sep	24.7
Fuggle	21-Aug	25.0
Galena	4-Sep	25.4
Glacier	9-Sep	26.8
Horizon	22-Aug	26.2
Liberty	4-Sep	25.3
Mt. Hood	4-Sep	23.6
Newport	4-Sep	25.5
Nugget	9-Sep	28.6
Perle	22-Aug	23.7
Saaz	21-Aug	26.9
Santiam	22-Aug	21.0
Sterling	4-Sep	24.2
Teamaker	4-Sep	18.9
Tettnang	22-Aug	20.5
Vanguard	4-Sep	22.1
Willamette	1-Sep	24.4
O55	1-Sep	22.2
O74	1-Sep	24.8

The variety Cluster was the tallest variety (15.8 ft), although not statistically different from Centennial, Glacier, Liberty, Newport, Nugget, Perle, Saaz, Santiam, Sterling, Vanguard, or Willamette (Table 4). Vanguard had the longest sidearms (62.0 cm), although Cluster, Newport, Tettnang, and Willamette were not statistically different.

Table 4. Bine height and sidearm length of hop varieties, 2013.

Variety	Bine height		Average sidearm length	
	ft		cm	
Cascade	12.0	bcdef	25.5	efg
Centennial	14.8	abc	33.1	cdefg
Chinook	11.2	cdef	38.1	bcdef
Cluster	**15.8**	a	55.3	ab
Crystal	9.40	f	13.4	g
Fuggle	12.0	bcdef	36.4	bcdef
Galena	10.0	def	35.8	bcdef
Glacier	15.5	ab	39.2	bcde
Liberty	14.2	abc	32.2	defg
Mt. Hood	9.40	ef	29.5	defg
Newport	14.9	abc	52.8	abc
Nugget	14.3	abc	35.2	cdef
Perle	13.5	abcd	28.3	defg
Saaz	13.3	abcd	19.2	fg
Santiam	13.7	abcd	35.2	cdef
Sterling	13.1	abcde	23.1	efg
Tettnang	8.60	f	42.8	abcde
Vanguard	14.2	abc	**62.0**	a
Willamette	15.2	ab	45.7	abcd
p-value		<0.0001		<0.0001

Within a column values followed by the same letter are not significantly different.
Letters in **bold** indicate top performing varieties.

Three to four of the healthiest looking bines were trained per string. By harvest, some of these bines had either died, or untrained themselves, while additional bines self-trained. At harvest the number of living bines at the base of the string was counted. There was no correlation between number of living bines at harvest and bine height or 100-cone weight. A positive correlation was found between number of living bines at harvest and pre-pick bine weight; meaning that more trained bines will increase overall plant biomass, but not necessarily increase cone yield (Table 5).

Table 5. Number of living bines at the base of the string at harvest and growth characteristics: Pearson correlation coefficients and probability levels, 2013 harvest.

Measurement	Number of living bines at the base of the string at harvest	
	r	Probability level
Bine height	0.1034	0.4440
Pre-pick bine weight	0.2413	0.0706
100-cone weight	0.1949	0.1461

Chinook had the largest cones of all the varieties (Table 6). Of the commercially available varieties, Newport was highest yielding, producing 0.99 lbs of hops per hill at 8% moisture, or 618 lbs per acre. Liberty was the worst performing variety (Table 6, Figure 6). The top 5 varieties for yield per acre at 8% moisture; Newport, Chinook, Nugget, Galena, and Centennial respectively, all produced over 500 pounds per acre. There were also two varieties (Newport, and Chinook) that produced over 2,000 pounds per acre at harvest moisture (Figure 7).

Table 6. 100 cone weight and yields at 8% moisture, Alburgh, VT, 2013.

Variety	100 cone weight at 8% moisture		Yield at 8% moisture			
	g		lbs/hill		lbs/acre	
Cascade	11.5	def	0.67	abc	415	ab
Centennial	14.2	bc	0.82	abc	509	ab
Chinook	**16.7**	**a**	0.99	a	613	a
Cluster	11.8	def	0.60	abc	376	ab
Crystal	7.4	ij	0.20	bc	124	ab
Fuggle	8.0	ihj	0.65	abc	405	ab
Galena	15.7	ab	0.82	abc	511	ab
Glacier	6.3	j	0.38	abc	239	ab
Liberty	8.0	ihj	0.08	c	53	b
Mt. Hood	9.8	fgh	0.34	abc	212	ab
Newport	13.1	cd	**0.99**	**a**	**618**	**a**
Nugget	15.5	ab	0.86	ab	535	ab
Perle	8.7	ghi	0.34	abc	211	ab
Saaz	9.7	fgh	0.13	bc	83	b
Santiam	12.5	cde	0.38	abc	238	ab
Sterling	8.5	ghij	0.29	bc	178	ab
Tettnang	6.7	ij	0.38	abc	235	ab
Vanguard	10.4	efg	0.37	abc	231	ab
Willamette	10.2	fg	0.72	abc	450	ab
p-value	<0.0001				<0.0001	

Within a column values followed by the same letter are not significantly different.
Letters in **bold** indicate top performing varieties.

A positive correlation was found between 100-cone weight and bine height, indicating that taller bines yield larger cones. A positive correlation was also found between 100-cone weight and pre-pick bine weight, indicating that plants with more biomass will yield larger cones. No statistical correlation was found between 100-cone weight and number of living bines at base of string at harvest, meaning that training more bines will not lead to larger cones (Table 7).

Table 7. 100 cone weight: Pearson correlation coefficients and probability levels, 2013 harvest.

Measurement	100 Cone weight	
	r	Probability level
Bine height	0.2412	0.0707
Pre-pick bine weight	0.5455	<0.0001
# living bines at base of string at harvest	0.1949	0.1461

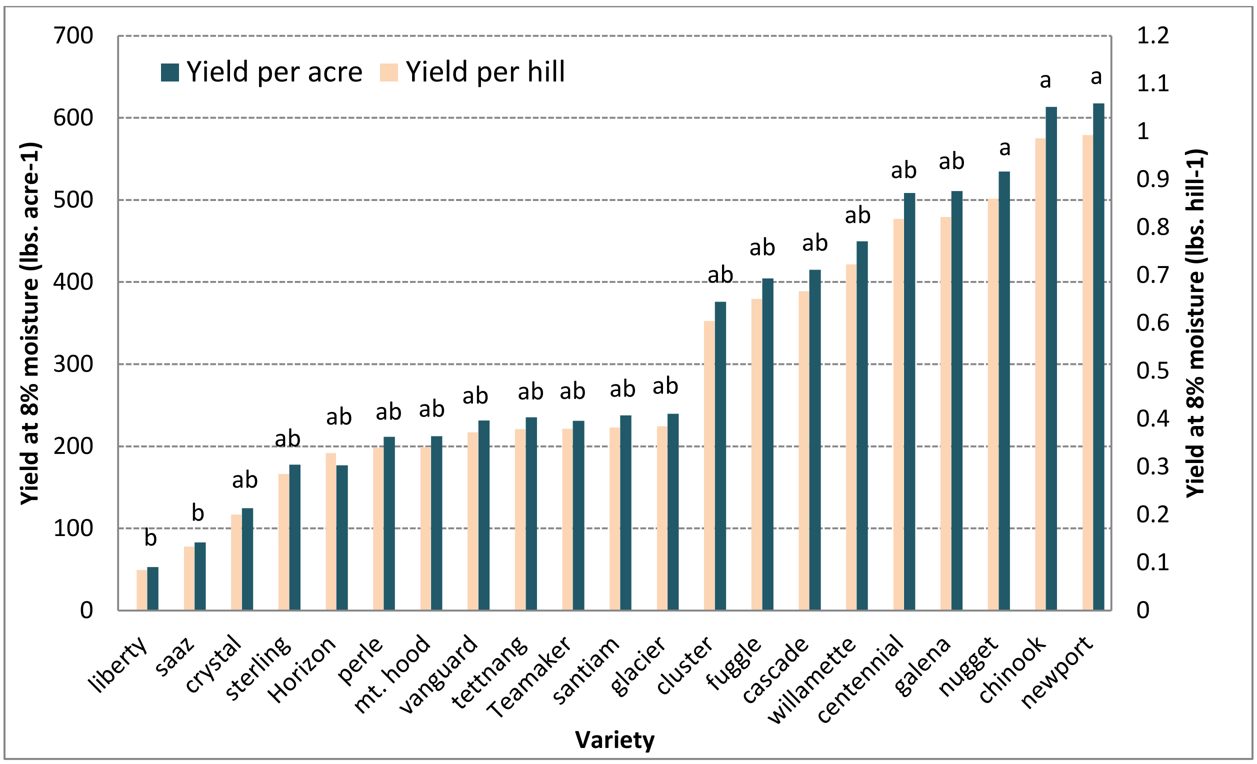

Figure 6. Yield by variety at 8% moisture for the third year of harvest in the UVM Extension research hopyard, Alburgh, VT. Varieties followed by the same letter are not significantly different.

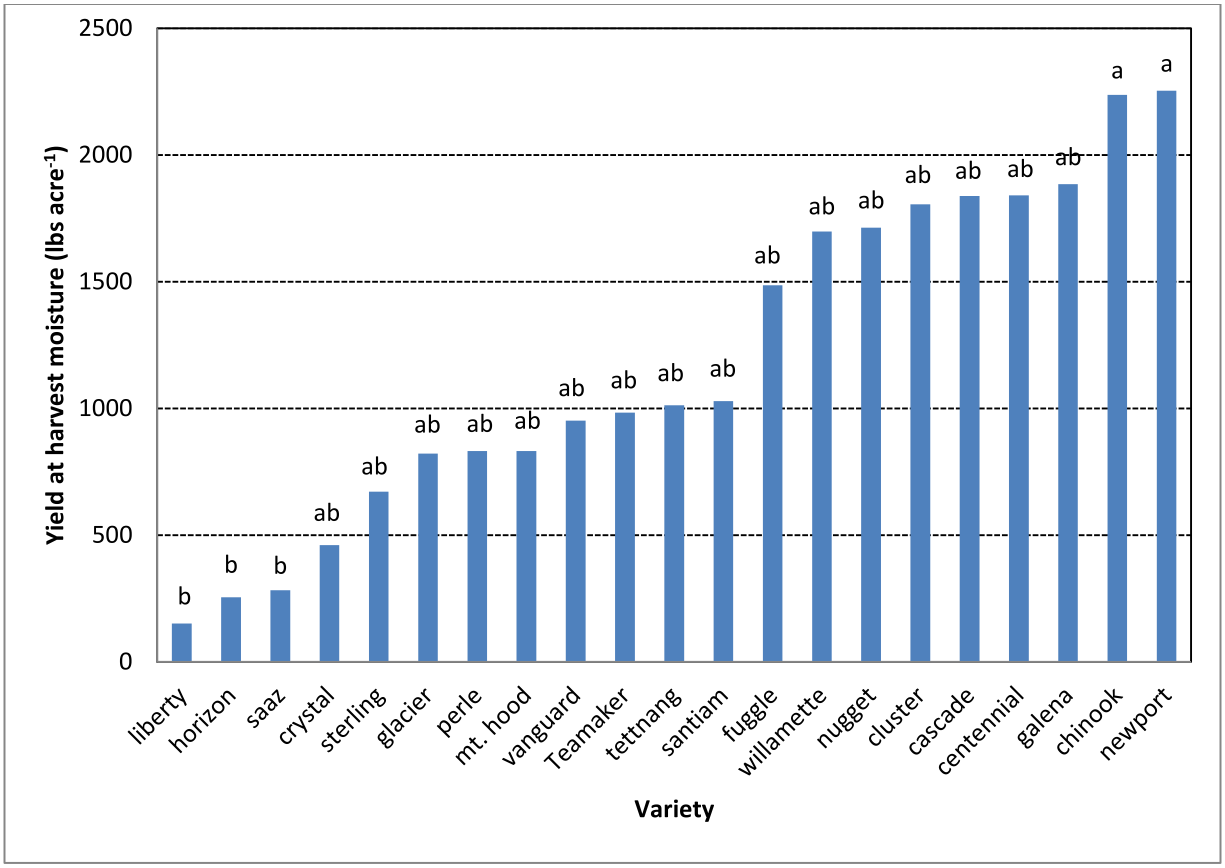

Figure 7. Yield by variety at harvest moisture for the third year of harvest in the UVM Extension research hopyard, Alburgh, VT. Varieties followed by the same letter are not significantly different.

A correlation was found between yield and bine height, indicating that taller bines lead to higher yields (Table 8). No correlation was found between yield and number of living bines at the base of the string at harvest, indicating that more bines per string does not necessarily lead to higher yields. A strong correlation was found for both pre-pick bine weight and 100 cone weight with regard to yield, meaning that plants with higher yields had higher pre-pick weight and 100 cone weight.

Table 8. Bine growth habit and yield: Pearson correlation coefficients and probability levels, 2013 harvest.

Measurement	Yield	
	r	Probability level
Bine height	0.392	0.0026
Pre-pick weight	0.758	<0.0001
Number of living bines at the base of the string at harvest	0.138	0.3070
100 cone weight	0.733	<0.0001

There were few significant differences in yields among the varieties (Table 6). This is likely due to the fact that yields varied considerably by plot (Table 9). At the time of the hopyard establishment each plot contained 5 hills with two crowns per hill. Over the last 3 years several of the hills have been lost to disease, insect, or other production pressures. Several of the plots also have hills that have just been severely weakened from environmental and/or pest pressures. For example, the eastern section of our hopyard suffers from some degree of shading during the morning hours.

Table 9. Range of yields by variety, Alburgh, VT, 2013.

Variety	**Yield @ 8% moisture**	
	Minimum	**Maximum**
	lbs per acre	
o55	0	345
o74	0	614
Cascade	196	613
Centennial	444	579
Chinook	140	1016
Cluster	258	493
Crystal	39	228
Fuggle	341	463
Galena	153	722
Glacier	183	318
Horizon	0	327
Liberty	39	65
Mt. Hood	161	308
Newport	415	845
Nugget	433	632
Perle	132	257
Saaz	57	103
Santiam	118	358
Sterling	116	225
Tettnang	129	341
Teamaker	2	433
Vanguard	58	352
Willamette	338	505

Brew Values

Over half of the hop varieties met or exceeded the industry standard for alpha acids in 2013 (Table 10, Figure 8). All hop varieties met the industry standards for beta acids in 2013 (Table 10, Figure 9). Within the figures, black quartiles denote industry averages.

Table 10. Brew values for hops from the 2013 harvest, Alburgh, VT.

Variety	Alpha acids	Beta acids	HSI
	%	%	
Cascade	7.1	8.5	0.47
Centennial	9.2	5.2	0.28
Chinook	11.6	5.0	0.24
Cluster	7.2	5.4	0.22
Crystal	3.0	7.3	0.22
Fuggle	3.2	3.6	0.23
Galena	13.5	9.0	0.23
Glacier	5.6	8.7	0.23
Horizon	9.6	8.5	0.23
Liberty	3.6	3.9	0.25
Mt. Hood	4.5	8.2	0.23
Newport	11.5	9.2	0.23
Nugget	15.2	4.9	0.23
Perle	8.3	6.9	0.24
Saaz	2.0	3.1	0.24
Santiam	2.7	6.6	0.24
Sterling	4.5	6.1	0.25
Teamaker	1.4	10.7	0.22
Tettnang	3.3	3.6	0.28
Vanguard	6.1	7.9	0.24
Willamette	8.7	4.6	0.26

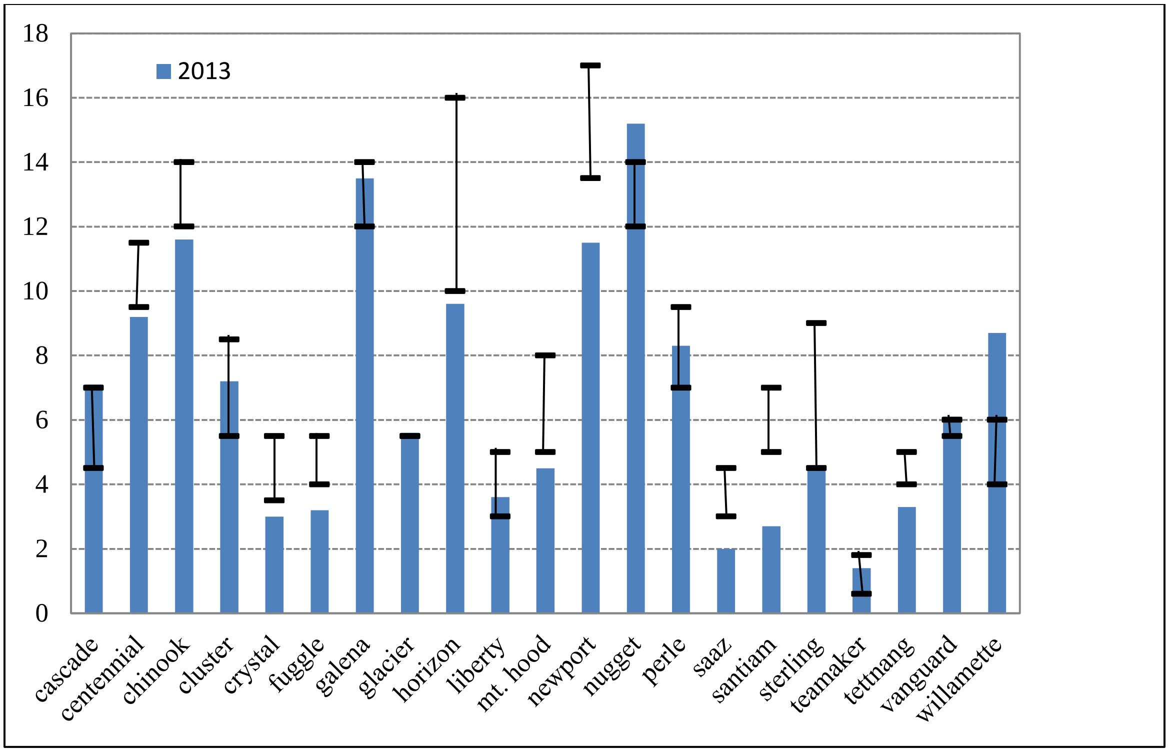

Figure 8. Alpha acid levels for hops from the 2013 harvest, Alburgh, VT.

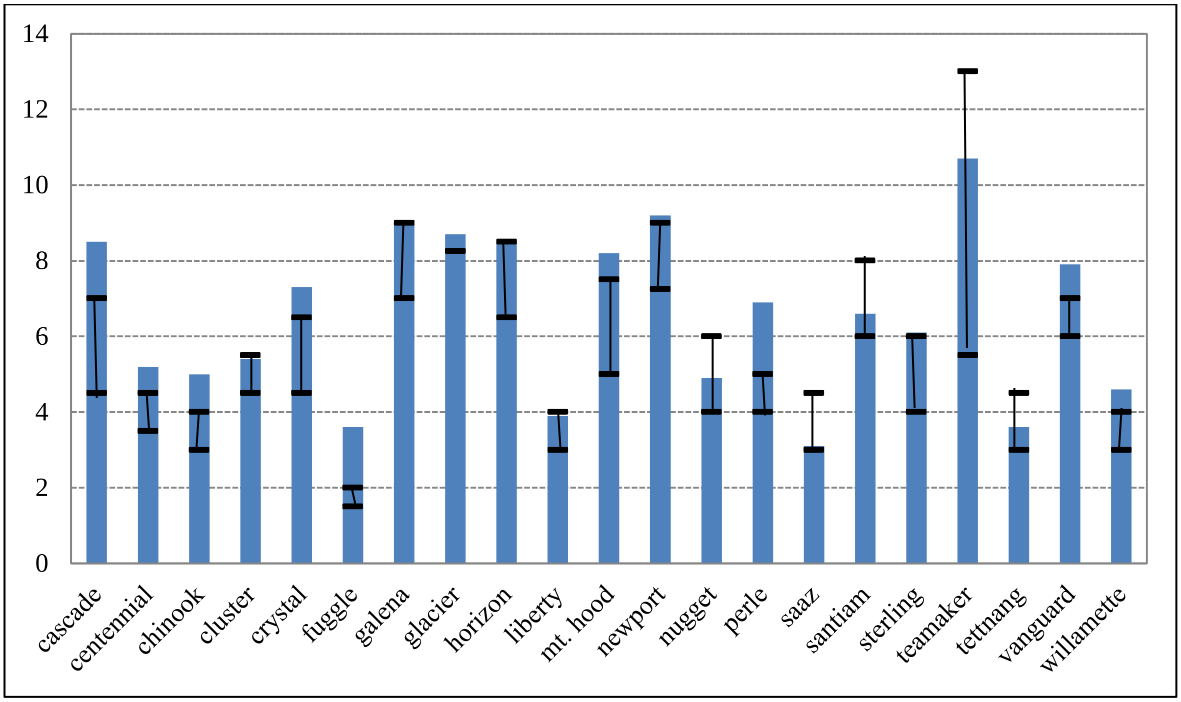

Figure 9. Beta acid levels for hops from the 2013 harvest, Alburgh, VT.

Bine Nutrients

Bine material was sent to Cumberland Valley Analytics in Maryland to be analyzed for macro/micronutrient. Nitrogen, ideally, will comprise 3% of the total plants biomass at harvest while phosphorus will comprise .50%, and potassium 2%. In our variety trial, variety 'Galena' had the highest percent nitrogen at 2.52% (Table 11). Newport had the highest percent phosphorus (0.56%). Potassium was highest in variety Liberty (1.99%). Interestingly, most varieties were close to meeting the nutrient requirement for phosphorus and potassium while none of the varieties met the 3% nitrogen concentration. It is highly likely that yields are being limited by nutrient deficiences, especially nitrogen.

Table 11. Bine Nutrients for 2013 in our hops variety trial, Alburgh, VT.

Variety	Nitrogen	Phosphorus	Potassium
	%	%	%
Cascade	2.42	0.42	1.73
Chinook	1.59	0.42	1.57
Crystal	2.22	0.37	1.56
Galena	**2.52**	0.39	1.82
Glacier	2.09	0.40	1.49
Liberty	1.90	0.43	**1.99**
Newport	1.66	**0.56**	1.80
Nugget	2.11	0.44	1.52
Perle	2.37	0.33	1.59
Sterling	1.97	0.28	1.46
Teamaker	1.92	0.30	1.54
Vanguard	2.08	0.48	1.85
Willamette	1.17	0.32	1.26

Numbers in **bold** indicate top performing varieties.

Year-to-year comparisons

Yield comparisons between 2012 and 2013 show that a few varieties did not improve production (Figure 10); Glacier, Liberty, Perle, and Santiam yields were worse than they were the previous year. Variety 'Tettnang' yielded similarly between years. All other varieties performed better in 2013, with many yields well over double their production of the previous year (2012).

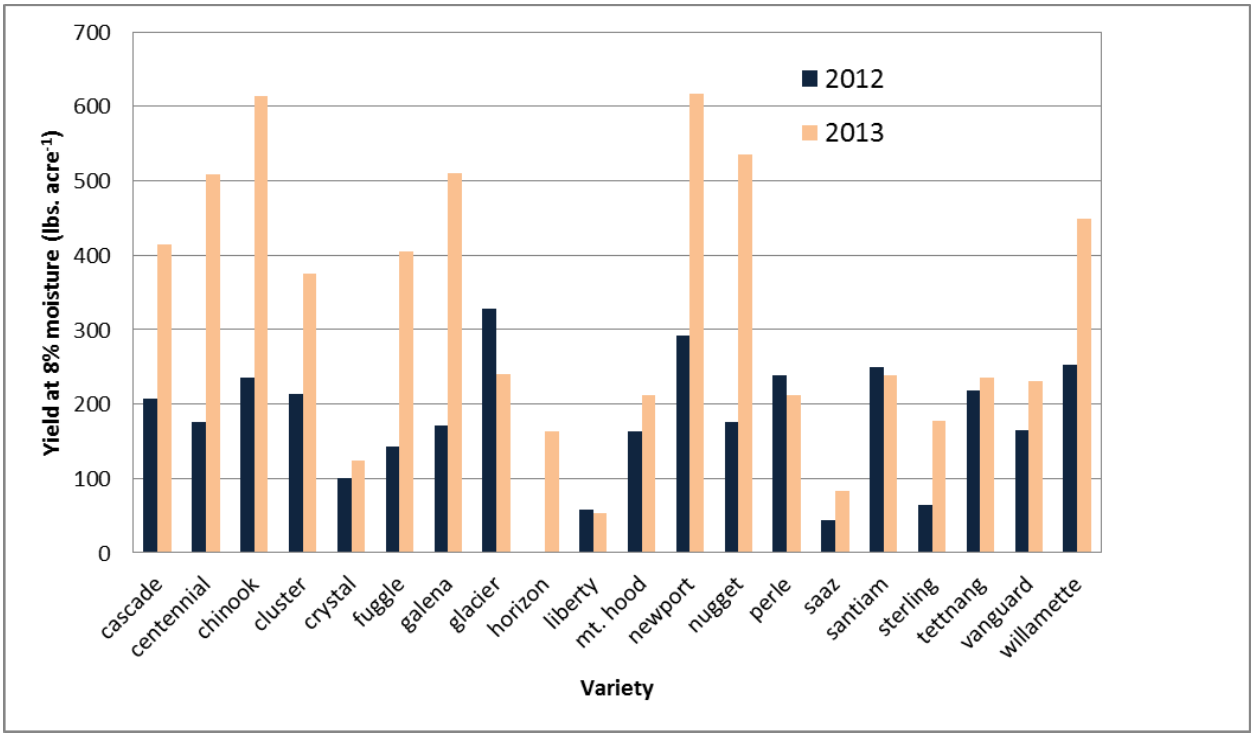

Figure 10. Yield comparison between 2012 and 2013 harvest, Alburgh, VT.

Alpha acids for all varieties except Cluster were higher in 2013 than they were in 2012 (Figure 11). Variability of alpha acids may indicate that their quality may be more easily impacted by variations in year-to-year growing conditions, the maturity of the plant, or water and nutrient deficiencies.

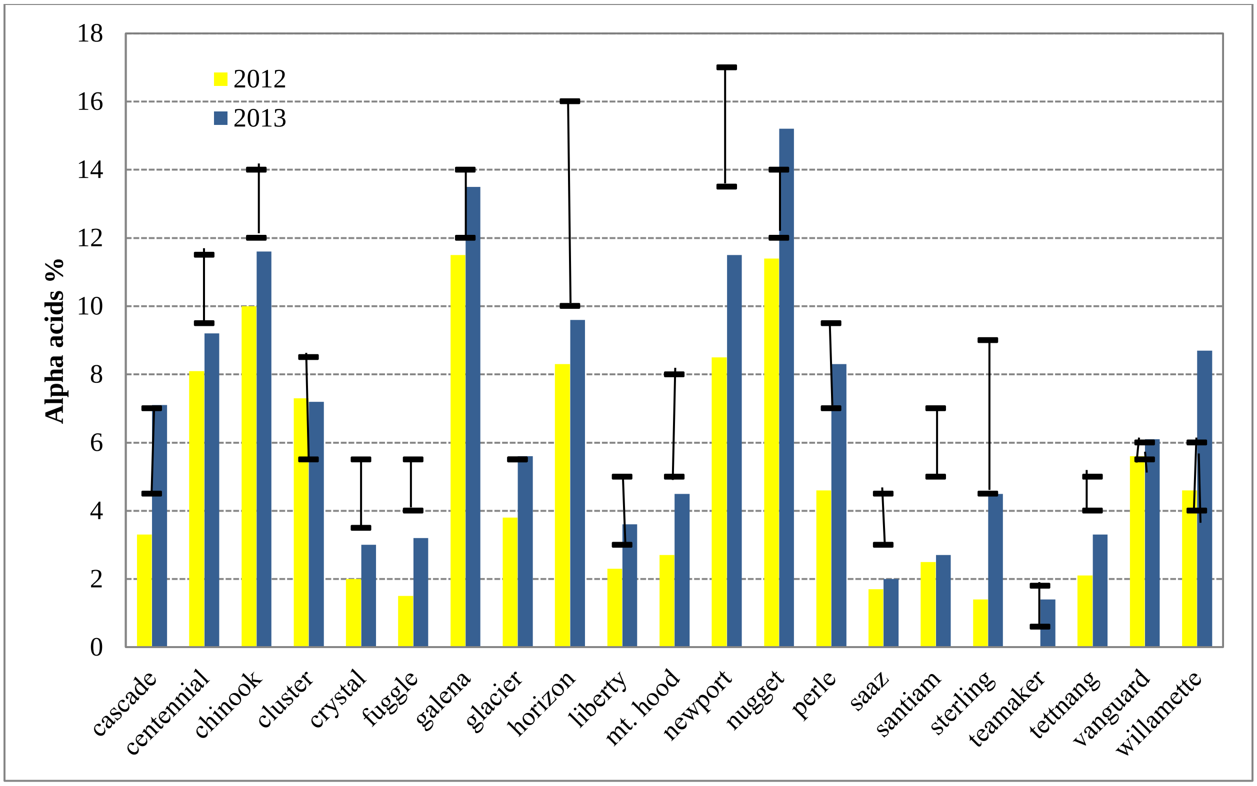

Figure 11. Alpha acid values for 2012 and 2013 harvests, Alburgh, VT.

Some variability was also observed from year-to-year in beta acids. In 2013, all varieties met or exceeded the industry standard. All varieties had higher beta acid levels in 2013 than in 2012, except for Chinook, Saaz, and Santiam (Figure 12).

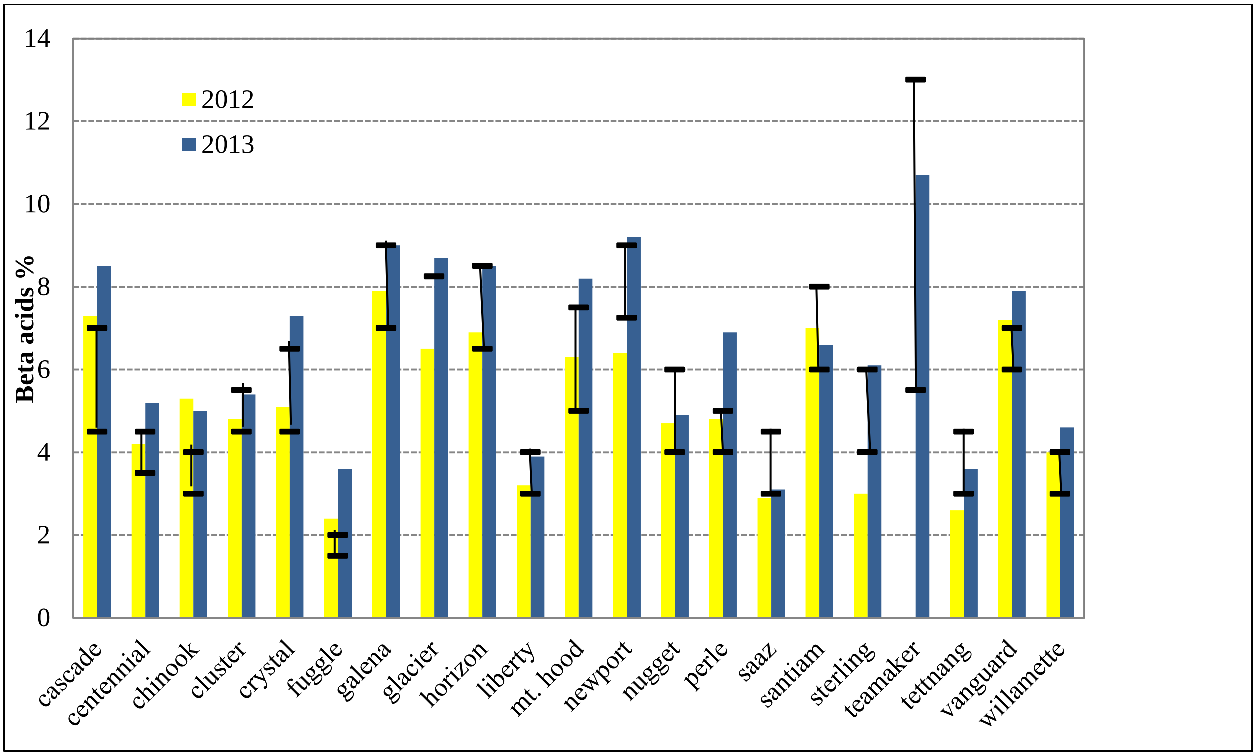

Figure 12. Beta acid values for 2012 and 2013 harvests, Alburgh, VT.

Pest pressure – Two-spotted spider mites

A slight significant difference was found between varieties for the pest two-spotted spider mite (TSSM) (Table 12). Mt. Hood, Liberty, and Vanguard all had high levels of TSSM, while Teamaker, Sterling, and Cascade had the lowest number of TSSM per leaf.

Figure 13. Spider mite destroyer, larva, pupa, and adult (inset).

Table 12. Average number of TSSM per leaf by variety in 2013, Alburgh, VT.

Variety	Spider mites leaf^{-1}	
Cascade	0.39	a
Centennial	0.89	a
Chinook	1.06	ab
Cluster	1.00	ab
Crystal	1.36	ab
Fuggle	1.44	ab
Galena	0.80	a
Glacier	0.76	a
Horizon	0.81	a
Liberty	1.60	ab
Mt. Hood	2.85	b
Newport	0.44	a
Nugget	0.81	a
Perle	1.18	ab
Saaz	1.13	ab
Santiam	1.08	ab
Sterling	0.33	a
Teamaker	0.13	a
Tettnang	0.42	a
Vanguard	1.56	ab
Willamette	0.66	a
	0.0064	

Within a column values followed by the same letter are not significantly different.

Populations of TSSM and mite destroyers differed significantly by sample date (Table 13, Figure 13). The TSSM thrive in hot dry conditions, such as those found in mid-July through August. TSSM population's spiked from late July through harvest, which is when climate conditions are usually suitable for the pest. There was a significant interaction between variety and sample date for TSSM (p-value= <0.001).

Table 13. Average number of TSSM and mite destroyer per leaf by sample date in 2013, Alburgh, VT.*

Sample date	Spider mites leaf^{-1}		Spider mite destroyers leaf^{-1}	
3-Jun	0.00	a	0.00	b
10-Jun	0.00	a	0.00	b
18-Jun	0.00	a	0.01	b
24-Jun	0.00	a	0.01	b
1-Jul	0.00	a	0.01	b
9-Jul	0.30	a	0.03	ab
16-Jul	0.06	a	0.09	ab
24-Jul	0.21	a	0.02	b
29-Jul	0.00	a	0.01	b
5-Aug	2.84	b	0.00	b
12-Aug	2.11	b	0.00	b
19-Aug	5.97	c	0.14	a
p-value	<0.0001		0.0031	

Within a column values followed by the same letter are not significantly different.

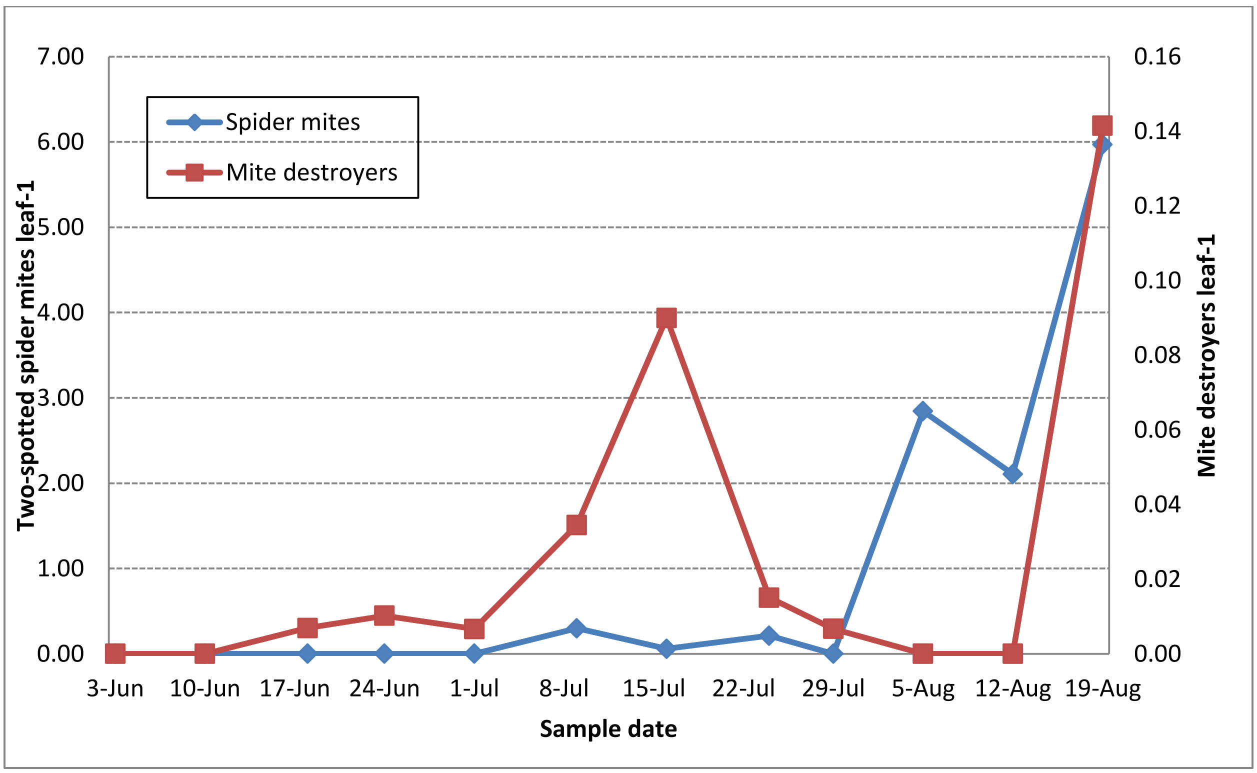

Figure 14. Average number of TSSM and mite destroyers per leaf by sample date in 2013, Alburgh, VT.

There was not a significant interaction between TSSM and mite destroyers (Table 14). Meaning that, statistically, mite destroyer populations did not correlate to TSSM populations. Although the classic boom-and-bust cycle of predator prey relationships is present (Figure 14). Overall TSSM pressure in the hopyard was low in 2013 as compared to 2012.

Table 14. Pearson correlation coefficients and probability level: TSSM and mite destroyers, Alburgh, VT.

Measurement	Two-spotted spider mites	
	r	Probability level
Mite destroyers	0.0192	0.4757

Pest pressure – Potato leafhoppers

Significant differences were determined between varieties for average number of PLH across the season. Cluster had the least number of PLH for the second year in a row, although all varieties were statistically similar except for Fuggle, Liberty, Mt. Hood, Newport, and Saaz (Table 15, Figure 15). The worst affected varieties for PLH were Liberty, Newport, and Fuggle.

Table 15. PLH incidence by variety, Alburgh, VT.

Variety	Potato leafhopper leaf^{-1}	
Cascade	0.80	abcde
Centennial	0.67	a
Chinook	0.68	ab
Cluster	0.36	a
Crystal	0.69	ab
Fuggle	2.28	cdef
Galena	0.53	a
Glacier	1.24	abcdef
Horizon	0.51	a
Liberty	2.61	f
Mt. Hood	2.17	cdef
Newport	2.29	ef
Nugget	0.78	abcd
Perle	1.63	abcdef
Saaz	2.11	bcdef
Santiam	1.26	abcdef
Sterling	1.08	abcde
Teamaker	0.50	a
Tettnang	1.61	abcdef
Vanguard	1.20	abcdef
Willamette	1.43	abcdef
	<0.0001	

Within a column values followed by the same letter are not significantly different.

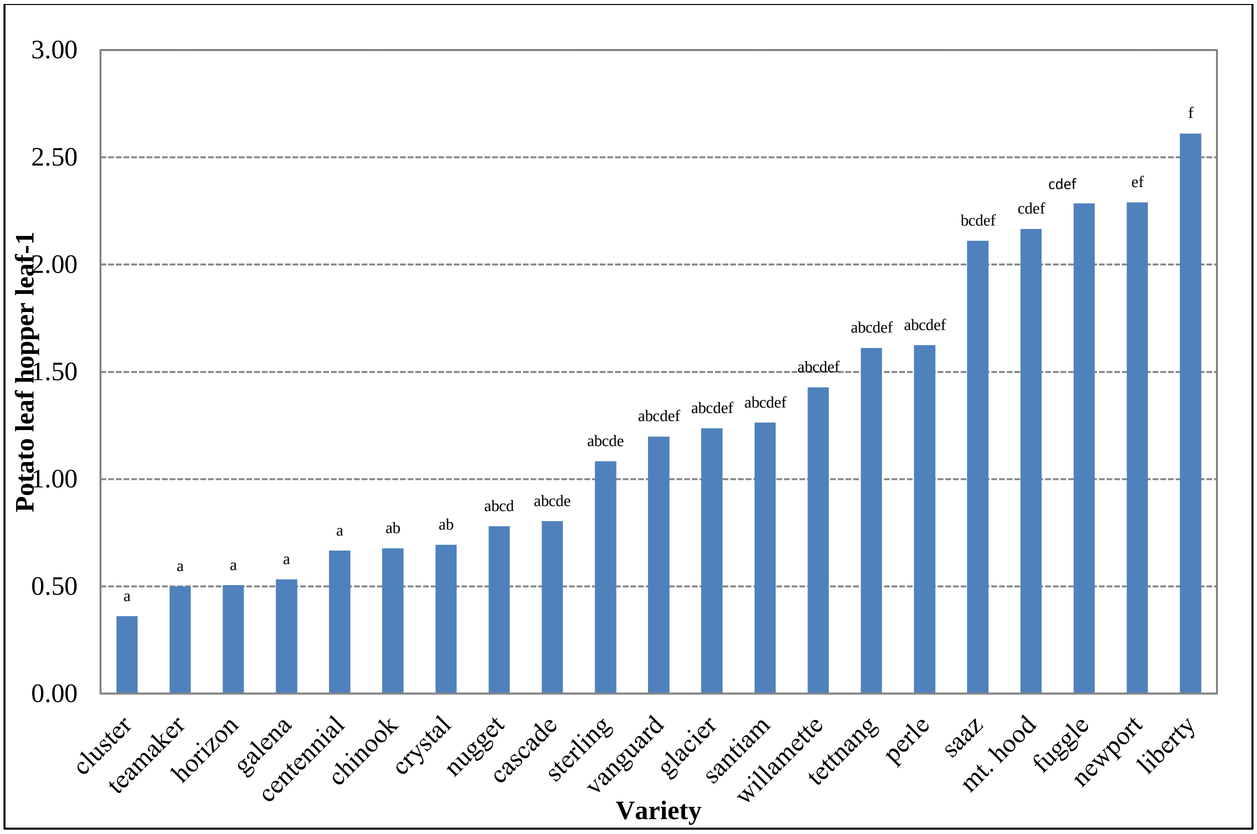

Figure 15. PLH incidence by variety across the growing season, Alburgh, VT. Varieties followed by the same letter are not significantly different.

Potato leafhopper populations were the highest from the last week in June through the first week of July (Table 16, Figure 16). These dates reflect when the southern migration of PLH has reached their peak populations. A significant difference was found between sample dates for PLH (Table 16), with the first week in July seeing the highest number of PLH per leaf (Figure 16).

Table 16. PLH incidence by sample date, Alburgh, VT.

Sample date	Potato leafhopper leaf^{-1}	
3-Jun	0.39	a
10-Jun	0.29	a
18-Jun	0.76	ab
24-Jun	2.87	c
1-Jul	5.05	d
9-Jul	1.61	b
16-Jul	0.55	ab
24-Jul	0.57	ab
29-Jul	0.60	ab
5-Aug	0.72	ab
12-Aug	0.40	a
19-Aug	0.43	a
p-value	<0.0001	

Within a column values followed by the same letter are not significantly different.

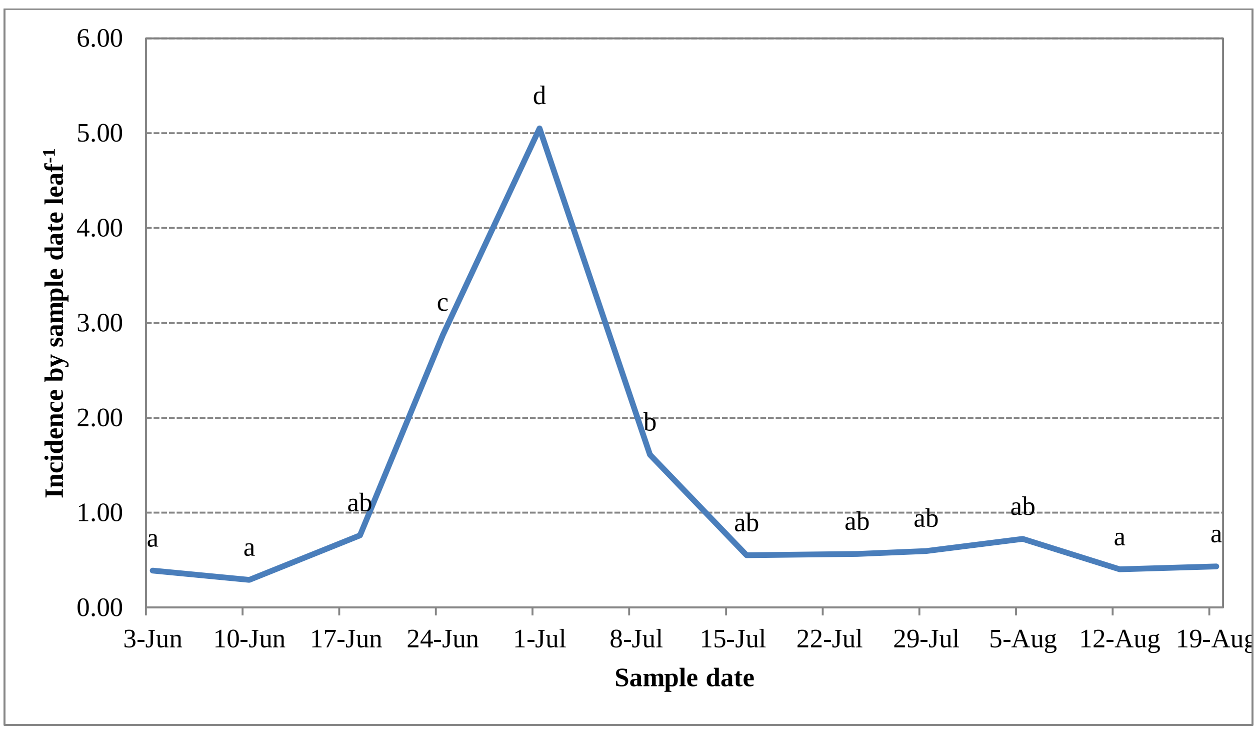

Figure 16. PLH incidence by sample date, Alburgh, VT. Sample dates followed by the same letter are not significantly different.

Pest Pressure- Aphids

Aphids were the pest that most severely infested our hopyard in 2013, by both variety and sample date. Significant differences were determined between varieties for average number of aphids across the season. Cascade had the lowest average number of aphids per leaf (Table 17), although only statistically different from Crystal and Willamette.

Table 17. Aphid incidence by variety, Alburgh, VT.

Variety	Aphid leaf^{-1}	
Cascade	2.03	a
Centennial	6.40	ab
Chinook	5.69	ab
Cluster	3.81	ab
Crystal	6.81	b
Fuggle	4.37	ab
Galena	5.88	ab
Glacier	5.88	ab
Horizon	4.21	ab
Liberty	5.32	ab
Mt. Hood	3.36	ab
Newport	4.41	ab
Nugget	3.54	ab
Perle	4.92	ab
Saaz	3.53	ab
Santiam	4.28	ab
Sterling	3.89	ab
Teamaker	2.68	ab
Tettnang	5.67	ab
Vanguard	5.95	ab
Willamette	6.84	b
	<0.0001	

Within a column values followed by the same letter are not significantly different.

Aphid populations were the highest from early July- harvest (Table 18). A significant difference was found between sample dates for aphids, with the second week in August seeing the highest number of aphids per leaf.

Table 18. Aphid incidence by sample date, Alburgh, VT.

Sample date	Aphid leaf^{-1}	
3-Jun	0.01	a
10-Jun	0.03	a
18-Jun	0.26	a
24-Jun	0.98	a
1-Jul	0.20	a
9-Jul	5.7	bcd
16-Jul	4.5	b
24-Jul	5.3	bc
29-Jul	8.7	de
5-Aug	8.1	cde
12-Aug	13.6	f
19-Aug	9.5	e
p-value	<0.0001	

Within a column values followed by the same letter are not significantly different.

Pest Pressure- All Major Pests

No organic pesticides were applied to the hopyard during the 2013 growing season. Data from 2012 suggested that pesticides may have played a role in actually fostering subsequent pest outbreaks. Some broad spectrum pesticides eliminate beneficial “predator” insects, as well as pests. When this occurs, pest populations will rebound much faster than their predator counterparts, leading to the same problems that led you to spray in the first place. Pesticides do have their positive applications, if they can be selective; but pest populations in 2013 were such that spraying was not deemed necessary this year. Timing is important when developing integrated pest management strategies. Annual tendencies should allow you to predict when certain pests will likely show up, or rapidly increase in number. Weather condition can help gauge what pests may be more prevalent at certain times. For example, TSSM thrive in hot and dry conditions, usually later in the growing season (late July-harvest). In contrast, aphids prefer cooler conditions such as those experienced throughout the 2013 growing season. Major pest populations throughout the 2013 growing season are shown in Figure 17. Weeks above economic threshold can be found in Table 19.

Table 19. Weeks above economic threshold for the three major pests, Alburgh, VT.

Pest Species	# of weeks above economic threshold	Dates
Potato leaf hopper	2	Last week in June- First week in July
Aphid	4	Late July- Harvest
Spider mite	1	Third week in August- Harvest

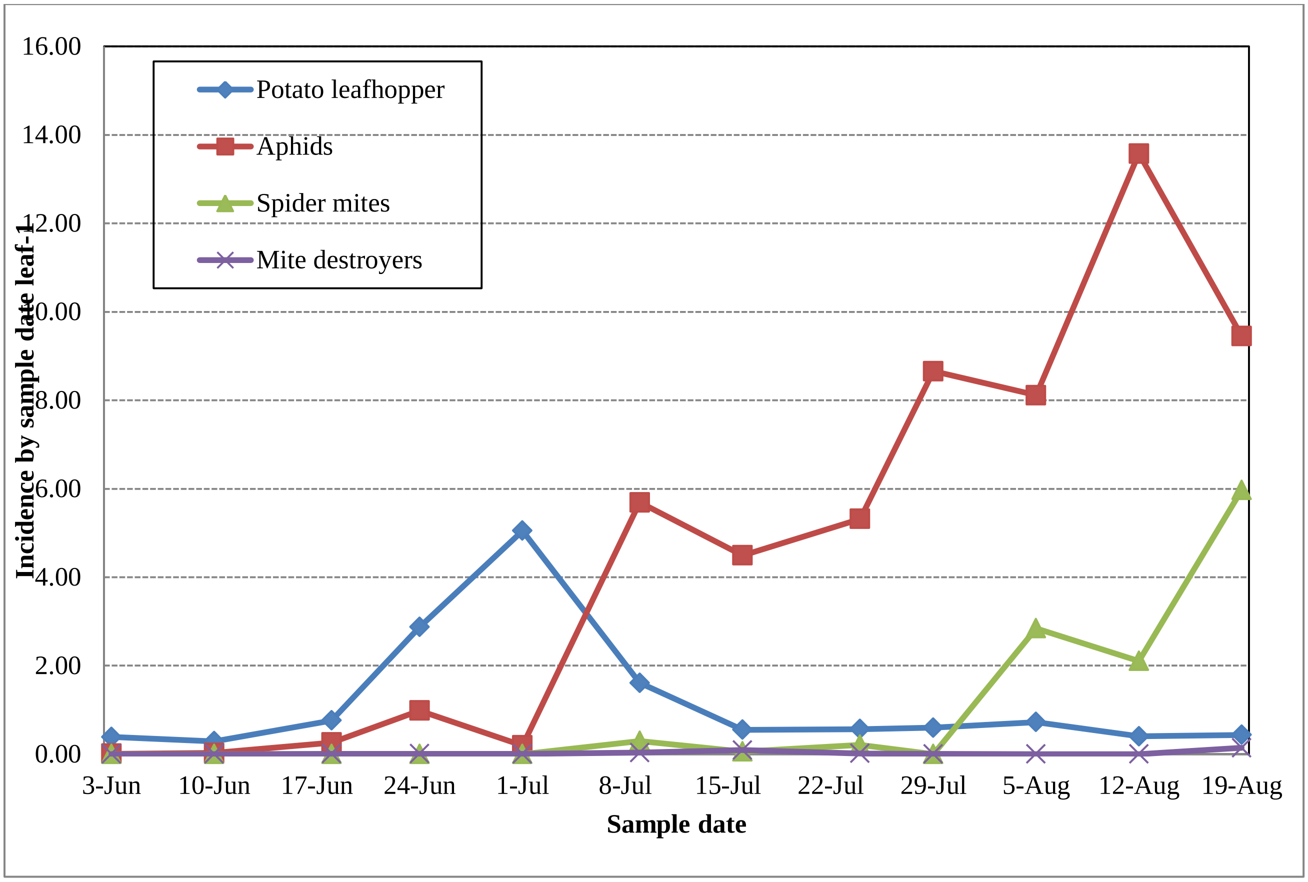

Figure 17. TSSM, PLH, Aphids, and mite destroyer populations through the 2013 growing season, Alburgh, VT.

DISCUSSION

Traditionally, hops are propagated by rhizome, which are planted in the early spring. Rhizomes can often carry diseases like Verticillium wilt, hop latent virus, and downy and powdery mildew. Unbeknownst to the grower, these diseases can easily be transplanted into a new hopyard. In an effort to minimize the possibility of this, the UVM Extension hopyard was planted with vegetative cuttings. The cuttings were propagated and sent across the country in a refrigerated truck, arriving in early August 2010. Some plants were adversely affected by the long distance traveled, some were too close to the refrigerator unit, and all plants arrived heavily infested with TSSM. This, combined with a late planting, resulted in reduced plant vigor dangerously close to winter. Soil saturation from the soggy October in 2010 and the spring floods of

2011 reduced the amount of oxygen in the soil and promoted root rot. In 2012, severe downy mildew pressure combined with outbreaks of TSSM led to further decline in overall plant health. The extent of the effect of the early conditions in the UVM hopyard on these perennial plants has been seen through reduced stands, plant vigor, and overall yield in the 3rd year of harvest. Hop growers from the Pacific Northwest (PNW) say that a poor first year will set back hops production on a yard for many years.

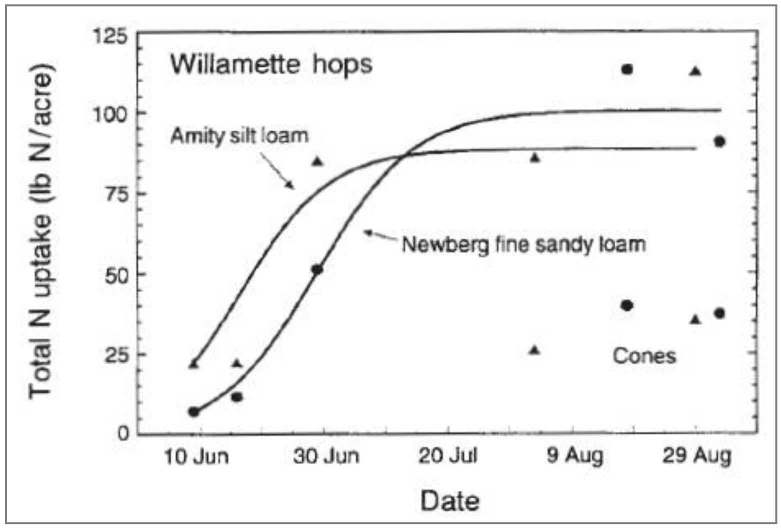

Figure 18. Rate of nitrogen uptake over time, Gingrich et al. 2000.

When hops are harvested, the lower few feet, or "tail", is left in the field to photosynthesize for the remainder of the growing season in order to strengthen the crown's reserves for the following season. Minimal snow cover and fluctuating temperatures such as we've seen in the last three years can also have an adverse effect on weaker crowns, sometimes leading to frost heaving and even death. Frost heaved plants can be mechanically damaged by the lifting, and the exposed crown can also become frost damaged by cold air temperatures and is prone to drying out. Snow cover will usually mitigate harsh winters by acting as an insulator. These factors have also contributed to lower than expected plant health and yields in the UVM Extension hopyard (Table 6 and Table 9).

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. Hop N needs are greatest in the month of June and into early July when the hop is growing quickly (Figure 18). Split applications should be timed for early spring at training, and again in early- to mid-June. There are few rapidly available sources of N approved for use in organic farming systems. 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. Fertilizer timing was imperfect in the UVM Extension research hopyard this year, resulting in undernourished hop plants, which ultimately affected yield. Heavy rain events in June likely resulted in significant leaching of nutrients. In addition, broadcast application methods are less than ideal resulting in uneven plant fertilization. This season a fertigation system will be implemented to add small quantities of N to plants weekly.

As hops production in the Northeast continues to expand, it is becoming more and more apparent how essential irrigation is to obtaining high yields. Hops need 30" of water during the growing season, and while we often receive that much precipitation over the course of a year in the Northeast, it is not necessarily at the time when hops need it most. The summer of 2013 was fairly ordinary in Vermont, and despite added irrigation, it may not have been sufficient to meet the crop's needs. Majer (1997) states that water stress during July and the beginning of August can cause a significant reduction in stomatal conductivity and net photosynthesis, with the result of a reduction in the weight of the hop's green mass, cones, and roots, and overall a reduction in hop cone yield. Plants that are weakened due to water stress are also more susceptible to spider mite damage. Continued fine tuning of irrigation timing and quantity will likely improve hop yields.

This year in the UVM Extension hopyard, we transitioned from complete hand-harvesting to predominantly using the mobile harvester. In past years, for a ¾ acre hopyard, it took 7 motivated individuals approximately a month to harvest the entire yard by hand. That shows just how economically unfeasible it is to hand harvest, especially with small windows of opportunity for optimum harvest dry matter. In 2013, one plant per plot was hand harvested in order to collect bine and growth data. All other plants per plot were harvested with the UVM mobile harvester. To determine individual yields for each of those plants, we first recorded a pre- and post-harvest weight for each plot. The number of bines on each plant was also counted. From there, the total post-harvest weight was divided by the number of bines per plant, to determine yield for that plant. The mobile harvester does a wonderful job in ensuring the cones stay intact and do not lose quality. Anecdotally, we did not see any yield loss when comparing mobile harvesting to hand harvesting.

Harvest was targeted for when the cones reached between 20-25% dry matter. A few of the varieties were harvested past the optimum dry matter due to break downs with the mobile harvester. However, whether drier cones are necessarily a drawback, remains to be seen. Murphy and Probasco (1996) have found that a 2% increase in dry matter can result in a 9% increase in production (lbs/acre). 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). The fact that there is no literature for harvest date in the Northeast, our harvest timing on the East Coast might be different than standards for the PNW. 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. It is entirely possible that while our alpha acid levels are not as high as one would estimate they should be, our essential oil levels might be exceptional, however the Northwest Crops and Soils Program does not have the budget to test for essential oil content. Very little publicly available research has been done on optimal harvest timing for most varieties, and whether or not the dry-matter content of green cone samples as a predictor of hop maturity is the best method of determining brewing quality has yet to be seen.

Yields for the 2013 growing season were, on average, better than in 2012. In 2013, there were 5 varieties that produced over 500 pounds per acre of hops at 8% moisture; whereas in 2012, the top performing commercially available variety yielded less than 400 pounds per acre at 8% moisture. Overall, the hopyard is yielding half to a third less than average yields in the Pacific Northwest. With 3 years of valuable learning experience behind us, we feel positive that higher yields can be achieved in the Northeast. There is no doubt that meeting the hop plants needs for water and nutrients is a challenge. However, improved management techniques continually show promise in enabling our hop plants to reach their maximum potential.

Alpha acids from this year’s harvest were, on average, an improvement from last year. Beta acids met the industry standard for all varieties, and continue to improve each year. When looking at across year trends, this seems to be the case for hops grown in the UVM experimental yard, and from grower reports. 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. High temperatures during cone ripening may also result in increasing the amount of alpha acids secreted by resin glands, and thereby boosting alpha acid levels.

Hops, like grapes, have terroir. Their brewing characteristics and oil content are reflective of their microclimate. Hop varieties grown on the East Coast, even though genetically the exact same as varieties grown elsewhere, will not be like hops in the Pacific Northwest or Europe due to different soils and different climates. Hops grown in the Northeast will present unique brewing characteristics. It is important to note that the hops from the UVM Extension research yard were only evaluated for alpha acids, beta acids, and HSI. No essential oil profiles were analyzed as it was cost-prohibitive. Further research is needed both at an industry-wide level and in the Northeast on the development of essential oils in hops, ranging from agronomic factors that affect essential oil development to the relationship between those essential oils and the final brewed product. Brew values produced in this trial will help brewers understand the quality profile displayed in this region. Continued data collection will help build a more accurate view of varietal profiles in the Northeast.

TSSM are a very significant pest in the UVM Extension research yard, another potential reason why yields were not as high as expected in 2013. Strong and Croft (1995) established TSSM thresholds of 1-2 mites per leaf in June, or 5-10 per leaf in July ***if no predators are present***. Further studies performed more recently by Weihrauch (2005) suggest that hops may be able to tolerate >90 mites per leaf without suffering economic loss. TSSM outbreaks were far less severe in 2013 than in 2012, likely due to cooler temperatures experienced during July and August. In addition, pesticides were not sprayed likely leading to increased populations of mite destroyers and reduced populations of TSSM.

Significance was determined between varieties for TSSM and mite destroyers. 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, effected 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. The industry acknowledges differences between the varieties, for example, according to the Hopunion Directory of Hop Data, Chinook and Fuggle are known as being “not excessively sensitive to insects,” while Nugget is sometimes characterized by being susceptible to spider mites, and Tettnang is classified as “sensitive” to mites.

The hop aphid presented a new pest management challenge in 2013. In 2011 and 2012 very few aphids were observed in the hopyard. During these years the weather was drier and hotter than average throughout the entire growing season. Aphids prefer a cool climate and in 2013 cool conditions were experienced throughout much of the growing season. Even though populations were high at some points throughout the season (4 weeks above economic threshold), they were not large enough to warrant pesticide usage, based on our discretion. This example illustrates how important insect scouting can be. If outbreaks had persisted or increased further, there is a chance that our hop cones could have been impacted by sooty mold. Aphids have the ability to secrete a sugary solution directly into hop cones, which can turn into sooty mold under ideal conditions.

Varietal differences in PLH preference are a new discovery (Table 15). Potato leafhoppers are not an economic pest in the major hop growing regions of the world. However, the UVM Extension hopyard is located within a grass/alfalfa field where these pests already inhabit. 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 in the end causing leaf necrosis. This occurred to varying degrees throughout the season, and in severe cases led to “hopper burn”. To the best of our knowledge, there are no established economic threshold levels for leafhoppers in hops. Reviews of threshold levels for raspberries, potatoes, and alfalfa, resulted in the establishment of a threshold level of two leafhoppers per leaf, although whether this will bear out to be an acceptable PLH threshold level remains to be seen. An informational article on potato leafhoppers in hops can be found on the UVM Extension Northwest Crops and Soils Program website: http://www.uvm.edu/extension/cropsoil/wp-content/uploads/Leaf_Hopper_Article.pdf. At this time it is unknown what draws leafhoppers to certain varieties or perhaps repels them from another. There are physical differences between hop variety leaves, as demonstrated by TSSM research (Peters and Berry 1980a), and these physical differences have been known to have an effect in alfalfa and the development of leafhopper-resistant alfalfa varieties. Leafhopper-resistant alfalfa varieties have dense hairs covered in a sticky substance that deter leafhopper nymphs.

A relationship was found between alpha acid levels and the number of PLH (Figure 19). It appears that as alpha acid levels increase, average number of PLH per leaf decreases. At this stage it is undetermined whether this is an indicator of PLH preferring lower alpha varieties, or of PLH causing lower alpha acid content in hops. Other possibilities for varietal preference among PLH include hop growth characteristics or nutrient levels acting as a deterrent or attractant. UVM Extension continues to look into the interaction between PLH and hops.

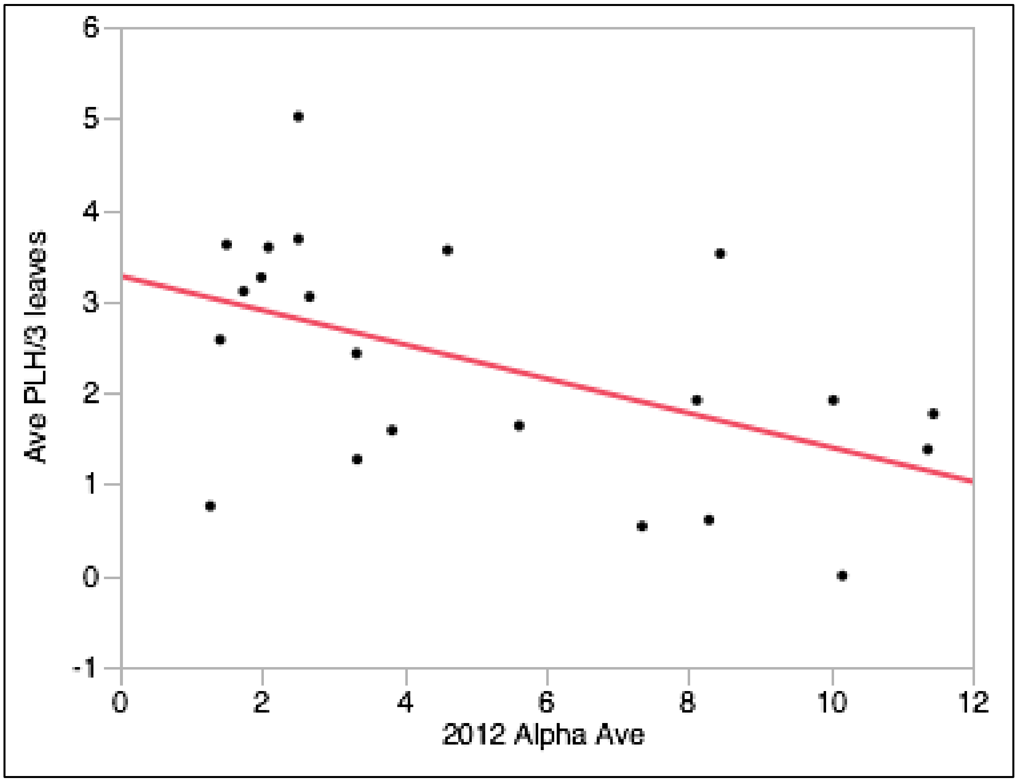

Figure 19. Relationship between alpha acid levels and average # PLH per leaf.

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