NORTHWEST CROPS & SOILS PROGRAM

2020 Hop Nitrogen Fertility Trial

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THE UNIVERSITY OF VERMONT EXTENSION

2020 HOP NITROGEN FERTILITY TRIAL

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Until now, commercial hop (*Humulus lupulus* L.) production has not occurred in the northeast (NE) region of the United States for 150 years. A combination of the spread of hop downy mildew, the expansion of production in western states, and prohibition laws from the 1920's contributed to the decline of the 19th century NE hop industry. Today, the Pacific Northwest states of Washington, Oregon, and Idaho remain the dominant hop production sites of the U.S. However, hop production in non-traditional regions is growing and now accounts for over 2% of the total U.S. hop acreage. Nationally, there has been recent and unprecedented growth in the craft beer sector, which has dramatically increased demand for local hop production.

There are more than 400 acres of hops in the Northeast with hop yards ranging in size from 0.25 to 25 acres. Hop yields in the region are often limited by pest damage and nutrient deficiencies. This is a reemerging industry in the Northeast and growers are asking for research to determine practices that will help them optimize hop yield. Yields reach 1500-2000 lbs/acre in other production regions yet most NE growers are below 800 lbs/acre. The investment to start a hop farm is significant and higher yields must be achieved to help growers be successful and profitable. The goal of this research project was to identify proper nitrogen (N) rate and timing to optimize hop yield and quality.

MATERIALS AND METHODS

The experimental design was a randomized complete block with split plots and 4 replicates. The main plots were fertility treatments (Table 1) and the split plots were hop varieties Cascade and Centennial. Nitrogen was applied in the form of calcium ammonium nitrate (CAN) 27-0-0 during a base spring application (14-May) and an 8 week split application period from 28-May through 16-Jul in the form of ammonium nitrate plus sulfur (URAN 28-0-0) applied directly to individual plants (Table 1). Calcium ammonium nitrate was applied as a granular fertilizer at the beginning of the season whereas ammonium nitrate plus sulfur was applied as a dilution through the 8 week split application period.

Table 1. Nitrogen fertility treatment application rates, 2020.

Treatment Total lbs N ac^{-1}	Spring base application lbs N ac^{-1}	Weekly application total lbs N ac^{-1}	Weekly application rate lbs N ac^{-1}
100	100	0	0
150	100	50	6.25
200	100	100	12.5
250	100	150	18.8
150	50	100	12.5
200	50	150	18.8

Hills were strung between 6-May and 8-May using a double coir string leading up to the top wire and trained 20-May. Beginning on 28-May, the entire hop yard was sprayed with Champ WG (Alsip, IL) at a rate of 1 lb per acre, and diluted in 100 gallons of water, and was sprayed on a weekly basis through 25-Jun. During this period, plots were scouted weekly for downy mildew basal spikes and aerial spikes. Plants were additionally scouted on a weekly basis starting 10-Jun for pest and beneficial insects through 5-Aug. Two plants and three random leaves per plant within each plot (variety) were visually inspected. The number of potato leaf hoppers (PLH), hop aphids (HA), two-spotted spider mites (TSSM), and mite destroyers (MD) present on each leaf was recorded.

Hop harvest was targeted for when cones were at 21-27% dry matter. At harvest, hop bines were cut in the field and brought to a secondary location to be run through our mobile harvester. Centennial plants were harvested from 26-Aug through 28-Aug and Cascade plants were harvested from 11-Sep through 14-Sep. Plants were harvested using a Hopster 5P hop harvester (HopsHarvester LLC, Honeoye, NY). The number of individual plants harvested and total cone yield was recorded for each treatment. Four bines from each plot were chipped, dried, and sent to Dairy One in Ithaca, NY to be analyzed for whole plant nutrient analysis. Cone samples were weighed and dried to determine dry matter content. Cones were also rated in browning severity on a 1-10 scale where 1 indicates low browning and 10 indicates severe browning as a result of disease. All hop cones were dried to 8% moisture, baled, vacuum sealed, and then placed in a freezer. Hop samples from each plot were analyzed for alpha acids, beta acids and Hop Storage Index (HSI) by the University of Vermont's testing laboratory. 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 872 hills (1744 strings) ac^{-1}.

Variations in yield and quality can occur because of variations in genetics, soil, weather and other growing conditions. Statistical analysis makes it possible to determine whether a difference among varieties is real, or whether it might have occurred due to other variations in the field. At the bottom of each table, a LSD value is presented for each variable (i.e. yield). Least Significant Differences (LSD's) at the 10% level of probability are shown. Where the difference between two treatments within a column is equal to or greater than the LSD value at the bottom of the column, you can be sure in 9 out of 10 chances that there is a real difference between the two varieties. Treatments that were not significantly lower in performance than the highest value in a particular column are indicated with an asterisk. In this example, A is significantly different from C but not from B. The difference between A and B is equal to 1.5, which is less than the LSD value of 2.0. This means that these varieties did not differ in yield. The difference between A and C is equal to 3.0, which is greater than the LSD value of 2.0. This means that the yields of these varieties were significantly different from one another. The asterisk indicates that B was not significantly lower than the top yielding variety. Within the trial there were no significant variety x treatment interactions so data was pooled across varieties and is presented based on nitrogen treatment impacts.

Treatment	Yield
A	**2100***
B	1900*
C	1700
LSD	300

RESULTS

Table 2 shows a summary of the temperature, precipitation and growing degree-day (GDD) summary. In the 2019 growing season, there were an accumulated 2544 GDDs, 66 more than the historical 30-year average with greatest deviations from the norm occurring in July, 121 GDD's above average. The 2020 growing season experienced a dry summer with well below average precipitation occurring during the months of May and June. Supplemental irrigation was applied to plants at a rate of 4500 gal ac^{-1}, however drier summer months and limited well capacity resulted limited the ability to provide adequate water to the crop.

Table 2. Temperature, precipitation and growing degree day summary, Alburgh, VT, 2019.

Alburgh, VT	March	April	May	June	July	August	Sept
Average temperature (°F)	35.0	41.6	56.1	66.9	74.8	68.8	59.2
Departure from normal	3.94	-3.19	-0.44	1.08	4.17	0.01	-1.33
Precipitation (inches)	2.79	2.09	2.35	1.86	3.94	6.77	2.75
Departure from normal	0.57	-0.72	-1.04	-1.77	-0.28	2.86	-0.91
Growing Degree Days (50-86°F)	16	44	298	516	751	584	336
Departure from normal	-6	-67	6	35	121	2	-24

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. (http://www.nrcc.cornell.edu/page_nowdata.html).

Pest and disease

Within the trial, fertility rates appeared to have little to no impact on observed pests with the exceptions of hop aphids in the Centennial variety (Table 3). No treatment differences were observed for the Cascade variety for pests. Hop aphid populations were highest in the 50/150 lbs N ac^{-1} treatment at 3.06 aphids per leaf. All N rates either higher or lower had significantly lower HA compared to the 50/150 N treatment rate. The two-spotted spider mite (TSSM) and potato leaf hopper (PLH) populations were not impacted by the fertility treatments. In general, populations of HA were lower than previous years and much higher levels of TSSM populations. Populations of TSSM peaked in the hundreds per leaf prior to miticide application in the summer largely as a result of ideal hot and dry conditions conducive to TSSM outbreaks. Weekly basal and aerial downy mildew spikes developing during the scouting period were not impacted by fertility treatments for either variety.

Table 3. Average insect pest and disease scouting incidence for nitrogen fertility rates on Centennial hops, Alburgh, VT, 2020.

Treatment Spring/Summer	Total applied N	Basal spike	Aerial spike	TSSM	PLH	HA	
lbs N ac^{-1}	lbs N ac^{-1}	$plot^{-1}$	$plot^{-1}$	$leaf^{-1}$	$leaf^{-1}$	$leaf^{-1}$	
100	100	0.261	1.25	15.2	5.26	1.13	b†
100/50	150	0.875	0.667	12.4	4.79	1.64	b
50/100	150	0.300	0.333	13.4	4.24	1.56	b
100/100	200	0.458	0.083	9.98	3.60	1.34	b
50/150	200	0.463	0.667	13.2	5.28	**3.06**	**a**
100/150	250	0.521	0.250	14.1	5.37	1.69	b
LSD (0.10) ‡		NS ¥	NS	NS	NS	1.23	
Variety Mean		0.480	0.542	13.0	4.76	1.74	

HA= hop aphid. PLH = Potato leaf hopper. TSSM = two-spotted spider mites.

†Within a column treatments marked with the same letter were statistically similar (p=0.10). Top performers are in **bold.**
‡LSD –Least significant difference at p=0.10.
¥NS –No significant difference between treatments.

Tissue analysis

Whole bines were processed for nutrient analysis (Tables 4 & 5). For the Cascade variety, N rate treatments were statistically different in phosphorus, manganese, and iron concentrations across treatments. For Centennial, treatment differences were observed in nitrogen, potassium, phosphorus, calcium, manganese, and iron. Highest nitrogen and manganese concentrations were observed in the 100/150 lbs N ac^{-1} treatment for Centennial at 2.44% and 72.8ppm respectively. Total plant nitrogen decreased with each tier of down to the lowest value observed at 2.01% for the 100 lbs N ac^{-1} treatment with manganese following some similar general trends. Other macronutrients such as potassium and phosphorus were highest in the Centennial hops at the lowest Nitrogen application rates whereas others showed peak tissue concentrations for mid-range total nitrogen treatments such as iron and calcium. Cascade hops appeared to have a visible decline in plant growth and quality from year two to year three (2020). This became much more apparent as normal side arm initiation occurred in the Centennial hops and the Cascade hops failed to develop side arms with much smaller hop clusters borne directly from the main bines. Nitrogen management of soil is closely linked to the plant uptake of a wide number of nutrients. The trial results (specifically for the Centennial variety) indicated that application of N can help to improve the availability and subsequent uptake of other essential nutrients, but highest rates may reduce the uptake of some.

Table 4. Cascade whole plant nutrient analysis at harvest, Alburgh, VT, 2020.

Treatment Spring/Summer	Nitrogen	Potassium	Phosphorus		Calcium	Magnesium	Manganese		Iron		Copper	Boron	Zinc
lbs N ac-1	%	%	%		%	%	ppm		ppm		ppm	ppm	ppm
100	2.06	1.52	**0.458**	**a**	2.04	0.403	57.5	ab	74.1	b	81.1	37.9	23.5
100/50	2.05	1.40	0.407	ab†	2.02	0.430	60.5	ab	75.1	ab	61.3	37.1	24.5
50/100	2.02	1.43	0.417	ab	2.00	0.397	53.0	b	78.0	ab	73.1	36.5	23.8
100/100	2.00	1.48	0.421	ab	2.02	0.391	**65.5**	**a**	85.7	ab	81.2	38.7	26.9
50/150	2.11	1.45	0.398	b	2.07	0.426	65.3	a	86.5	ab	70.4	38.2	24.2
100/150	2.06	1.38	0.406	ab	2.05	0.415	63.8	ab	123	a	75.8	38.2	23.8
LSD (0.10) ‡	NS¥	NS	0.057		NS	NS	11.5		48.8		NS	NS	NS
Variety Mean	2.05	1.44	0.418		2.03	0.410	60.9		87.1		73.8	37.8	24.4

†Within a column treatments marked with the same letter were statistically similar (p=0.10). Top performers are in **bold.**
‡LSD –Least significant difference at p=0.10.
¥NS –No significant difference between treatments

Table 5. Centennial whole plant nutrient analysis at harvest, Alburgh, VT, 2020.

Treatment Spring/ Summer	Nitrogen		Potassium		Phosphorus		Calcium		Magnesium	Manganese		Iron		Copper	Boron	Zinc
lbs N ac-1	%		%		%		%		%	ppm		ppm		ppm	ppm	ppm
100	2.01	c	**1.56**	**a**	**0.468**	**a**	2.03	b	0.385	45.3	d	91.3	ab	99.1	32.6	23.8
100/50	2.12	bc	1.49	ab	0.374	b†	2.11	ab	0.385	54.0	bcd	70.1	b	86.2	28.7	22.4
50/100	2.15	bc	1.49	ab	0.390	b	2.15	ab	0.392	47.8	dc	**219**	**a**	91.6	31.4	24.6
100/100	2.26	ab	1.34	b	0.342	b	**2.26**	**a**	0.410	63.8	abc	81.1	ab	105	30.1	22.1
50/150	2.27	ab	1.43	ab	0.348	b	2.03	b	0.402	65.3	ab	70.4	b	82.9	28.6	20.9
100/150	**2.44**	**a**	1.47	ab	0.344	b	2.19	ab	0.405	**72.8**	**a**	73.4	b	79.8	29.4	22.2

LSD (0.10) ‡	0.209	0.170	0.058	0.210	NS¥	16.1	145	NS	NS	NS
Variety Mean	2.21	1.46	0.378	2.13	0.396	58.1	101	90.7	30.1	22.7

†Within a column treatments marked with the same letter were statistically similar (p=0.10). Top performers are in **bold.**

‡LSD –Least significant difference at p=0.10.

¥NS –No significant difference between treatments

Yields and cone quality

At harvest, 100 cone weight, diseased cone percentages, disease severity, harvest dry matter, and yields were recorded (Table 6 and 7). For both the Cascade and Centennial hops, there was no difference across treatments for bine weight or 100 cone weights within variety. For the Cascade hops, significant differences were only observed in the percentage of diseased cones with the highest percentage observed (79.3%) in the 100/50 lbs N ac^{-1} treatment. It's also worth noting that, overall, the percentage of diseased cones for the Cascade hops (69.5% average) was much higher than the Centennial average (29.9% average) in addition to greater disease severity by 1.67 points on the given 1-10 scale. More treatment differences were observed within the Centennial hops including diseased cones, disease severity, harvest dry matter, and yields (Table 7). Within the variety, harvest dry matter was highest for the 50/150 lbs N ac^{-1} treatment though was statistically similar to all other treatments receiving summer applied nitrogen applications. Similarly, highest yields in the Centennial hops were seen in the 50/150 lbs N ac^{-1} treatment and was statistically similar to the 100/50, 50/100, and 100/100 lbs N ac^{-1} treatments.

Table 6. Cascade yields and cone quality, Alburgh, VT 2020.

Treatment Spring/Summer lbs N ac^{-1}	Total applied N lbs N ac^{-1}	Bine weight lbs	100 cone weight g	Diseased cones %		Disease severity 1-10 €	Harvest dry matter %	Yield at 8% moisture lbs ac^{-1}
100	100	2.58	32.1	65.3	ab	2.75	21.7	300
100/50	150	2.76	29.2	**79.3**	**a**	2.75	21.6	329
50/100	150	2.65	29.0	59.8	**b**	3.00	22.9	316
100/100	200	3.36	29.2	70.3	ab†	3.00	21.6	363
50/150	200	3.24	27.6	70.8	ab	2.75	21.8	267
100/150	250	3.16	30.7	71.8	ab	3.75	22.4	336
LSD (0.10) ‡		NS ¥	NS	16.0		NS	NS	NS
Variety Mean		2.96	29.6	69.5		3.00	22.0	319

†Within a column treatments marked with the same letter were statistically similar (p=0.10). Top performers are in **bold.**

‡LSD –Least significant difference at p=0.10.

¥NS –No significant difference between treatments

€Cones were rated in browning severity on a 1-10 scale where 1 indicates low browning and 10 indicates severe browning.

Table 7. Centennial yields and cone quality, Alburgh, VT 2020.

Treatment Spring/Summer lbs N ac-1	Total applied N lbs N ac-1	Bine weight lbs	100 cone weight g	Diseased cones %		Disease severity 1-10 €		Harvest dry matter %		Yield at 8% moisture lbs ac^{-1}	
100	100	2.49	38.9	27.0	ab	1.25	b†	20.6	b	438	b
100/50	150	3.56	40.7	**33.5**	**a**	1.25	b	21.7	ab	542	ab
50/100	150	3.48	41.5	32.0	ab	1.25	b	21.7	ab	510	ab
100/100	200	3.11	39.5	25.8	b	1.00	b	21.0	ab	496	ab
50/150	200	3.24	43.6	32.5	a	**2.00**	**a**	**21.9**	**a**	**604**	**a**
100/150	250	2.89	38.7	28.5	ab	1.25	b	21.3	ab	482	b
LSD (0.10) ‡		NS ¥	NS	6.59		0.64		1.20		109	
Variety Mean		3.13	40.5	29.9		1.33		21.4		512	

†Within a column treatments marked with the same letter were statistically similar (p=0.10). Top performers are in **bold.**
‡LSD –Least significant difference at p=0.10.
¥NS –No significant difference between treatments
€Cones were rated in browning severity on a 1-10 scale where 1 indicates low browning and 10 indicates severe browning.

Brew quality

Higher rates of nitrogen appeared to have a negative impact on the brew quality of the Cascade cones for hop storage index (HIS) (Table 8). Values below 0.300 for HSI are considered to be of good quality with those reaching higher values above 0.400 becoming of questionable or poor quality. Highest observed values for HSI were seen at the 100/100 lbs N ac^{-1} treatment at 0.639 (poor quality) compared and was statistically similar to all other treatments receiving summer nitrogen with the lowest value observed in the 100 lbs N ac^{-1} treatment at 0.212. Beta acids were lowest at the 100/150 lbs N ac^{-1} treatment (250 lbs N total) at 1.87%. While differences in alpha acids were not significantly different, there are some observable differences between the highest nitrogen rates which were around 4% alpha acids and the lower nitrogen rates which were closer to 5-6%. This may also correspond to the higher HSI values observed in those treatments receiving higher nitrogen applications for Cascade. For the Centennial hops, HSI did not appear to be impacted by nitrogen fertility treatments with all values falling with acceptable or good quality ranges and relatively consistent observed values for alpha acids (Table 9). Beta acids in the Centennials once again varied with the highest 100/150 lbs N ac^{-1} treatment showing lowest overall beta acid percentage and all other treatments having statistically similar values.

Table 8. Cascade fertility trial brew quality, Alburgh, VT, 2020.

Treatment Spring/Summer lbs N ac-1	Total applied N lbs N ac-1	Alpha acids %	Beta acids %		HSI	
100	100	6.13	2.14	ab†	0.212	b
100/50	150	5.91	2.24	ab	0.276	ab
50/100	150	5.02	2.32	ab	0.378	ab
100/100	200	3.59	2.27	ab	**0.639**	**a**
50/150	200	3.85	**2.46**	**a**	0.524	ab
100/150	250	4.00	1.87	b	0.432	ab
LSD (0.10) ‡		NS ¥	0.489		0.385	
Variety Mean		4.75	2.22		0.410	

†Within a column treatments marked with the same letter were statistically similar (p=0.10). Top performers are in **bold.**
‡LSD –Least significant difference at p=0.10.
¥NS –No significant difference between treatments.

Table 9. Centennial fertility trial brew quality, Alburgh, VT, 2020.

Treatment Spring/Summer lbs N ac-1	Total applied N lbs N ac-1	Alpha acids %	Beta acids %		HSI
100	100	7.70	3.77	ab†	0.233
100/50	150	7.88	3.53	ab	0.235
50/100	150	7.28	**3.87**	**a**	0.311
100/100	200	6.94	3.41	ab	0.230
50/150	200	7.04	3.79	ab	0.319

100/150	250	7.30	3.32 b	0.251
LSD (0.10) ‡		NS ¥	0.50	NS
Variety Mean		7.36	3.62	0.263

†Within a column treatments marked with the same letter were statistically similar (p=0.10). Top performers are in **bold.**
‡LSD –Least significant difference at p=0.10.
¥NS –No significant difference between treatments.

DISCUSSION

As mentioned earlier, Cascade hops within this trial appeared to be impacted greatly by poor growth when compared to the Centennial hops. This may be a result of systemic downy mildew problems or perhaps some viral infection. After normal side arm initiation and burr formation of the hops, plants seemed to develop little to no side-arm growth with much smaller clusters of hops developing directly from the main bines. As the season progressed it was also apparent that the cones from the Cascade hops did not fully develop a strig and cones were noticeably stunted. This in conjunction with lack of side arm development also made them much more difficult to harvest with a greater amount of leaf material pulled in the harvester. At the moment, it is unclear the main cause of poor growth for the Cascade hops in the trial, but plant tissues will be sent for analysis in the 2021 season for evaluation. In addition to noticeably poor cone development and growth, nutrient uptake may have been impacted by these problems in the Cascade hops. Throughout the trial, there were generally very few noticeable treatment effects for the Cascade hops this year, even when looking at total plant nitrogen from tissue analysis. As seen in the Centennial hops, there was a clear increase in total plant nitrogen with increases to nitrogen application rates whereas no effects were observed in the Cascade hops.

There were some slight similarities between 2019 and 2020 when looking at hop brewing quality. 2019 treatments appeared to illicit a more pronounced, negative response to increased nitrogen applications as both alpha acids and beta acids appeared to decrease when looking primarily at nitrogen treatments. Some similarities were observed in the 2020 Cascade hops as well as beta acids overall, suggesting that excessive nitrogen rates may negatively impact levels of hop resins. Throughout both years, it is also apparent that nitrogen applications in this form have the potential to impact the uptake and availability of other nutrients in the plants. A wide array of factors can impact nutrient availability ranging from weather conditions to changes in soil pH, and it is known that nitrogen management within soil is closely linked to the uptake of a number of other nutrients. Other similarities were observed across years with highest hop aphid populations present in those plants receiving 200 lb N ac^{-1} of total nitrogen. Otherwise, most observed pest populations did not appear to be impacted by nitrogen treatments in either year, yet composition did differ from year to year with higher aphid populations present in 2019 and higher two-spotted spider mite populations present in 2020.

The use of an in-field nitrate meter could have the potential to become a useful tool with quick results. This would require some additional work to determine nitrogen fertility requirements corresponding to petiole nitrate readings for this crop. Based on some of the preliminary data collected in 2019, it appeared that the tested nitrogen rates provided adequate nitrogen fertility leading into the last week of vegetative growth. Lower applications of nitrogen may illicit a great response and deficiency in plants. Once again, dry conditions in summer months in addition to limited well capacity appeared to limit hop growth during vegetative production. May and June were particularly dry receiving nearly 3 inches less precipitation than the 30 year average. Greater precipitation and increased ability to irrigate may improve hop yields in conjunction with proper fertility. Given these growing conditions and evaluated treatments over the two years of study, it appeared as if differences in spring applications had little impact on plant growth on these soils and any differences were largely observed across the total nitrogen applications amount. Soils that are highly prone to leaching could also lead to greater nutrient loss, which may influence application rates and timing. In this case larger, single applications may want to be avoided in favor of split applications throughout the critical growth periods of vegetative production.

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