2019 Hop Soil Health Trial

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THE UNIVERSITY OF VERMONT EXTENSION

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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.

This project looks to assess the impact of manure applications on soil health and hop yields and attempts to quantify the impact of organic amendments on soil health and hop essential oil and resin profiles. This trial used manure amendments in plots to compare manure application rate impact on soil health and microbial activity within plots. Many farmers in Vermont, and other dairy production regions, have access to manure as a soil amendment and nutrient source. Farmers have claimed that applying manure has aided in reducing disease pressure and improving soil quality, making this a potentially valuable resource that would be beneficial to some farmers.

MATERIALS AND METHODS

The experimental design was a randomized complete block with split plots and 3 replicates. The main plots were manure fertility treatments (Table 1) and the split plots were hop varieties Cascade and Nugget. Prior to manure application, soil samples were taken (22-Apr) from each plot and sent to Cornell Soil Health Lab in Ithaca, NY. The standard soil health analysis was performed on the samples (https://soilhealth.cals.cornell.edu/). This was done to establish a baseline for soil health in the 2019 season and will be built upon and compared to in subsequent years of the study. Solid manure was applied on 6-May in a three foot swath for each plot at respective manure application rates. A manure sample was then taken from the source stack and sent to UVM Agricultural and Environmental Testing Lab for nutrient analysis (Table 2). Results from manure analysis were used to calculate primary nutrients applied from manure for each application rate. An additional 50 lbs N ac^{-1} was applied on 30-May.

Table 1. Nutrients applied from manure treatment application rates, 2019.

Treatment	Total nitrogen lbs ac^{-1}	Ammonium nitrogen lbs ac^{-1}	Organic nitrogen lbs ac^{-1}	Phosphorus lbs ac^{-1}	Potassium lbs ac^{-1}
14 tons ac^{-1}	157	12.6	144	44.8	54.6
7 tons ac^{-1}	78.4	6.30	72.1	22.4	27.3
0 tons ac^{-1}	0	0	0	0	0

Table 2. Manure nutrient analysis, 2019.

Nutrient	Nutrients lbs wet ton^{-1}
Total nitrogen	11.2
Ammonium nitrogen	0.90
Organic nitrogen	10.3
Phosphorus	3.20
Potassium	3.90
Calcium	8.80
Magnesium	1.40
Sodium	0.50
Copper	0.01
Zinc	0.03
Iron	0.30
Manganese	0.07
Boron	0.01
Dry matter (%)	19.2
Density (lbs gal-1)	8.34

Hills were trained on 30-May. Beginning on 24-May, the entire hop yard was sprayed with Champ WG (Alsip, IL) at a rate of 1 lb per ac^{-1} and sprayed on a weekly basis through 28-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 17-Jun for pest and beneficial insects through 19-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. Cascade plants were harvested on 10-Sep and Nugget plants were harvested on 16-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. 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. All hop cones were dried to 8% moisture, baled, vacuum sealed, and then placed in a freezer. Hop samples from each plot were shipped overnight to Cornell Agritech, Geneva, NY and analyzed for alpha acids, beta acids and Hop Storage Index (HSI), essential oils, and total oils. 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}.

Data was analyzed using SAS Version 9.4. For the hop quality data, we conducted a linear mixed model analysis with repeated measures (PROC MIXED). Fixed effects included collection date, replicate, year, and collection date by year. All statistics will be run at the 0.10 level of significance and generated using SAS Version 9.4 (Copyright 2014, SAS Institute Inc., Cary, NC, USA).

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 letter 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 manure treatment impacts.

Treatment	Yield
A	**2100a**
B	1900ab
C	1700c
LSD	300

RESULTS

Table 3 shows a summary of the temperature, precipitation and growing degree-day (GDD) summary. In the 2019 growing season, there were an accumulated 2322 GDDs, 157 less than the historical 30-year average with greatest deviations from the norm occurring in April and July. The 2019 growing season experienced a wet spring followed by a dry summer with well below average precipitation occurring during the month of July. Supplemental irrigation was applied to plants at a rate of 4500 gal ac^{-1}, however drier summer months and limited well capacity limited the ability to provide adequate water to the crop.

Table 3. Temperature, precipitation and growing degree day summary, Alburgh, VT, 2019.

Alburgh, VT	March	April	May	June	July	August	Sept
Average temperature (°F)	28.3	42.7	53.3	64.3	73.5	68.3	60.0
Departure from normal	-2.79	-2.11	-3.11	-1.46	2.87	-0.51	-0.62
Precipitation (inches)	1.36	3.65	4.90	3.06	2.34	3.50	3.87
Departure from normal	-0.85	0.83	1.45	-0.63	-1.81	-0.41	0.23
Growing Degree Days (Base 50)	9	59	189	446	716	568	335
Departure from normal	-13	-52	-103	-36	86	-14	-25

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).

Soil samples were taken on 22-Apr and analyzed for soil health and nutrient analysis (Table 4 and 5). Obtained samples were collected to establish a baseline for soil health and nutrients in order to later determine the impact that manure applications might have on soil health. Various aspects of soil health that were analyzed scored high across the various plots, but there were no differences across any of these tested treatment areas. Soils also had a high overall score with a trial average of 86.5 (out of 100). Soil nutrient analysis similarly showed uniformity across plot treatment area within the hop yard with some minor differences in iron concentrations in plots that later received the 7 ton manure ac^{-1} treatment.

Table 4. Baseline soil health analysis 22-Apr 2019, Alburgh, VT.

Treatment tons manure ac^{-1}	Aggregate stability %	Available water capacity m/m	Surface hardness psi	Sub-surface hardness psi	Organic matter %	Active carbon ppm	Soil proteins N mg/soil g	Soil respiration CO_2 mg/soil g	Overall score
0 (control)	81.6	0.272	140	244	14.1	1299	24.8	3.73	88.9
7	81.1	0.268	171	256	17.3	1322	28.8	4.27	84.9
14	80.4	0.266	176	230	16.9	1392	26.4	4.32	85.8
LSD (0.10) †	NS ‡	NS	NS	NS	NS	NS	NS	NS	NS
Trial Mean	81.1	0.269	162	243	16.1	1338	26.7	4.11	86.5

†LSD –Least significant difference at p=0.10.
‡NS –No significant difference between treatments.

Table 5. Baseline soil nutrient analysis taken prior to manure application 22-Apr 2019, Alburgh, VT.

Treatment tons manure ac^{-1}	pH	Phosphorus ppm	Potassium ppm	Magnesium ppm	Iron ppm	Manganese ppm	Zinc ppm
0 (control)	7.44	28.3	197	292	4.33 ab†	33.5	7.18
7	7.40	34.1	274	315	**5.63 a**	48.7	8.55
14	7.40	34.7	273	306	3.42 b	38.8	7.70
LSD (0.10) ‡	NS ¥	NS	NS	NS	2.04	NS	NS
Average	7.41	32.4	248	304	4.46	40.3	7.81

‡LSD –Least significant difference at p=0.10.
¥NS –No significant difference between treatments.

Within the trial, manuring rates appeared to have little to no impact on observed pests (Table 6). There were fairly uniform populations of insects across the board with the exception of hop aphids, which were lowest in the control plots. While there was no statistical difference, the high application rates, which received greater amount of total nitrogen, may have led to slightly higher populations for aphids, however none of the differences in observed pest populations were statistically significant. Cone quality, disease, and yields were also recorded at harvest (Table 7). Diseased cones were lowest for the control plot, but was statistically similar to the 14 tons manure ac^{-1} rate with 79% diseased cones and 83% diseased cones respectively. Other metrics including 100 cone weight, disease severity, harvest dry matter, and yield at 8% moisture showed no significant differences across treatments.

Table 6. Average insect pest and disease scouting incidence for manure application rates, Alburgh, VT, 2019.

Treatment	Aerial spikes	Basal spikes	HA†	PLH	TSSM
tons manure ac^{-1}	$plot^{-1}$	$plot^{-1}$	$leaf^{-1}$	$leaf^{-1}$	$leaf^{-1}$
0 (control)	10.9	3.53	0.889	1.30	0.204
7	6.64	2.80	1.42	1.33	0.704
14	10.1	3.30	1.69	1.34	0.167
LSD (0.10) ‡	NS ¥	NS	NS	NS	NS
Trial mean	9.22	3.21	1.33	1.32	0.358

†HA= hop aphid. PLH = Potato leaf hopper. TSSM = two-spotted spider mites.
‡LSD –Least significant difference at p=0.10.
¥NS –No significant difference between treatments.

Table 7. Yields and cone quality for manure rate treatments, Alburgh, VT, 2019.

Treatment	100 cone weight	Diseased cones	Disease severity	Harvest dry matter	Yield at 8% moisture
tons manure ac^{-1}	g	%	1-10 €	%	lbs ac^{-1}
0 (control)	44.8	**79 a†**	5.00	26.8	503
7	40.8	87 b	5.67	27.6	468
14	46.0	83 ab	5.00	26.8	492
LSD (p=0.10) ‡	NS ¥	6.59	NS	NS	NS
Trial mean	43.9	83	5.22	27.1	488

†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.

There were also no differences in overall cone quality across treatments for resins or essential oils (Table 8). While values were highest for alpha acids in the two treatments receiving manure, differences were not significant, whereas values for beta acids were highest in the control plots, but were once again not significantly higher. Some slight differences in total oil and myrcene were observed with highest values at the 14 tons manure ac^{-1} rate but differences across the board for essential oils were not significant and appeared to not be impacted by manure treatments (Table 9).

Table 8. Brew quality for manure rate treatments, Alburgh, VT, 2019.

Treatment	Alpha acids	Beta acids	HSI
tons manure ac^{-1}	%	%	
0 (control)	6.10	4.99	0.183
7	7.01	4.44	0.197
14	6.78	4.33	0.207
LSD (0.10) ‡	NS ¥	NS	NS
Trial mean	6.63	4.59	0.196

‡LSD –Least significant difference at p=0.10.
¥NS –No significant difference between treatments.

Table 9. Hop essential oil and total oil analysis for manure rate treatments, Alburgh, VT, 2019.

Oil profile	0	7	14	LSD (0.10)†	Trial mean
	tons manure ac^{-1}				
Total oil (ml/100g hop)	1.45	1.43	1.59	NS‡	1.49
Essential oil (mg/g hops)					
Beta-pinene	0.069	0.064	0.078	NS	0.070
Myrcene	5.44	5.22	6.46	NS	5.71
Limonene	0.019	0.018	0.023	NS	0.020
Linalool	0.064	0.065	0.060	NS	0.063
Caryophyllene	1.22	1.28	1.21	NS	1.24
Humulene	2.81	2.91	2.82	NS	2.84
Geranyl acetate	0.283	0.265	0.284	NS	0.278
Beta-citronellol	0.006	0.023	0.011	NS	0.013
Nerol	0.163	0.148	0.138	NS	0.150
Geraniol	0.008	0.007	0.009	NS	0.008

†LSD –Least significant difference at p=0.10.

‡NS –No significant difference between treatments.

DISCUSSION

With this first year of study, it appeared as if no significant differences arose as a result of variable manure application rates for the majority of observed metrics. Dry conditions in summer months, in addition to limited well capacity, may have resulted in low and variable yields across fertility treatments as the crop received approximately 4 inches of water less than is generally required for hop production. Yields may have further been impacted by late season cone disease, in addition to insect pest pressure within the trial. Our high baseline for soil health may also make it difficult to observe any potential differences or impacts that may arise from consecutive years of manure applications.

Soil health refers to the "capacity of the soil to function as a vital living ecosystem that sustains plants, animals, and humans[1]." As we continue to use the soil for means of agricultural production, it is important for us to consider the functions and services that the soil provides for us: nutrient retention and cycling, carbon sequestration, infiltration and storage of water, suppression of pests, diseases, and weeds, chemical detoxification, and production of food and other plant derived products. As demand for craft beer continues to rise, so does hop production and the continued need for soil and environmental stewardship. While hop plants can be hardy and vigorous under the right conditions, plants and soil still need to be taken care of in order to maintain productivity.

By assessing the health of our soils in hop producing regions, we can begin to quantify the impacts of various management practices on our soils. This will further allow us to identify key problematic areas resulting from poor quality soils. A healthy soil can be recognized as one with good tilth, water storage capacity, low pest populations, high populations of beneficial organisms, minimal chemical residues, low weed pressure, adequate nutrients for plant growth, and resistance to soil loss and degradation. The converse of each of these factors can result in poor crop growth and economic loss for producers. While this first year of study indicated that manure applications had no impact on the majority of our analyzed parameters, it does indicate that there were no detrimental effects and manure could provide adequate nutrients for producing a crop. Subsequent years of study may provide additional insight into the impact of manure applications on soil health as well as hop quality, yields, and pest pressure.

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[1] Natural Resources Conservation Services: Soil Health. 2012. Retrieved May 24, 2019 from http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/. The Soil Renaissance accepted this definition in 2014.