JOURNAL OF THE NACAA

ISSN 2158-9429

VOLUME 15, ISSUE 2 – DECEMBER, 2022

Editor: Linda Chalker-Scott

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Nitrogen Application and Management to Hops

Abstract

A two-year study to determine the optimum nitrogen (N) rate for hops *(Humulus lupulus)* grown in Wisconsin. Seven varieties were grown under five N application rates at three locations. Secondary objectives evaluated the effect of N rate on hop quality parameters, correlated petiole sap measurements with petiole tissue nitrate concentration, and evaluated plant uptake and soil nutrient concentrations following hop harvest. Variety and nitrogen rate significantly affected biomass and cone yield. Hop quality parameters were affected by variety. Nitrogen rate significantly affected hop storage index and total oil. Petiole sap nitrate concentrations correlated well to laboratory-determined petiole tissue nitrate concentration. Results suggest optimum N rates for hop production are variety-dependent and are lower than current state recommendations.

Introduction

The renaissance of the craft brewing industry in the United States over the past decade has raised interest in growing local ingredients for the industry. The number of craft breweries in the United States grew from 1,409 in 2006 to 8,275 in 2019 (Brewers Association, 2021). The production of hops *(Humulus lupulus)* in the Midwest and Wisconsin has increased as hops is a key ingredient in the production of craft beers (Morton et al., 2017).

Hops prefer well-drained soils which can increase the risk of nitrate-N movement leaching to groundwater (Cochran, 2016). Movement of nitrate-N in these soils is vital to determine both amounts and timing of N applications for profitable hop production while reducing risk of nitrate-N movement to groundwater. Matching N application to crop N demand can reduce the risk of nitrogen leaching to groundwater (Bundy et al., 1991).

Tissue testing of hops helps provide confirmation of nutrient levels within the plant and help guide nutrient needs (Gent et al., 2015). Petiole testing is a method recommended to determine plant nitrate-N nutrient needs and detect deficiencies (Sirrine, 2016). Large-scale field demonstrations have shown no yield increase of additional N fertilizer applied when petioles contain more than 4,000 ppm nitrate nitrogen in June (Sullivan et al., 1999).

Hop production is a competitive and global agricultural industry (Kubes, 2021). Midwest craft brewers desire locally grown hops and want hops competitively priced with other hop sources. Wisconsin hop growers were beginning to understand and meet the tough quality standards for hops set by the industry. Growers are now challenged to concentrate on producing quality hops at a cost that is competitive in the world market.

For hops growers to be competitive in the marketplace, input costs such as soil nutrients need to be managed for growers to be profitable. Hops are a high user of N, producing more than two tons of dry matter per acre per year of biomass in cones and bines (Bavec et al., 2003). Nitrogen application rates can range from 80 to 200 lbs. per acre depending on soil type and organic matter content (Takle and Cochran, 2017).

Current Wisconsin N recommendations are based on 1990 University of Wisconsin guidelines and more recent data from research conducted in the Pacific Northwest (Laboski and Baxter, 2017).

Results of a 2019 survey indicated over half of the growers were ambivalent, unsatisfied, or very unsatisfied with their fertility planning and application practices (Anonymous, n.d.). Replicated local research on optimizing N applications was needed for Wisconsin's growing hops industry. Research is lacking on hops production practices and impacts on yield and quality in Wisconsin and the upper Midwest. Proper N application rates need to be researched to understand costs and maintain or increase hops quality to provide a local source of hops to craft brewers.

The purpose of the study was to determine effect of N rates to hop production on cone yield and quality. No Wisconsin data currently exist to assist hop growers with decisions on N management.

Methods

The on-farm study was conducted at the same three locations in 2019 and 2020 in Wisconsin. Three locations were selected to represent different growing regions and soil types. Locations, varieties, and soil types are listed in Table 1. 'Willamette' was substituted for 'Nugget' in 2020 due to availability of 'Nugget' within the hop yard.

Table 1. Locations, varieties, and soil type of hop N trials

	Rosholt		Tomah	Waterloo
Year	2019	2020	2019 and 2020	2019 and 2020
*Varieties	Magnum	Magnum	Centennial	Chinook
	Nugget	Willamette	Cascade	Tahoma
^Soil type	Graycalm Loamy Sand		Bilson Sandy Loam	McHenry Silt Loam

*Hop source determined by grower availability
^United States Department of Agriculture Natural Resources Conservation Service Web Soil Survey

Area precipitation amounts and temperature recorded are in Figures 1 and 2. Neither location was equipped with a weather station within the hop yard. Precipitation and temperature were extracted from the National Weather Service. Seasonal temperature averages were experienced both years in all locations. All locations experienced drier conditions in 2020 compared to 2019.

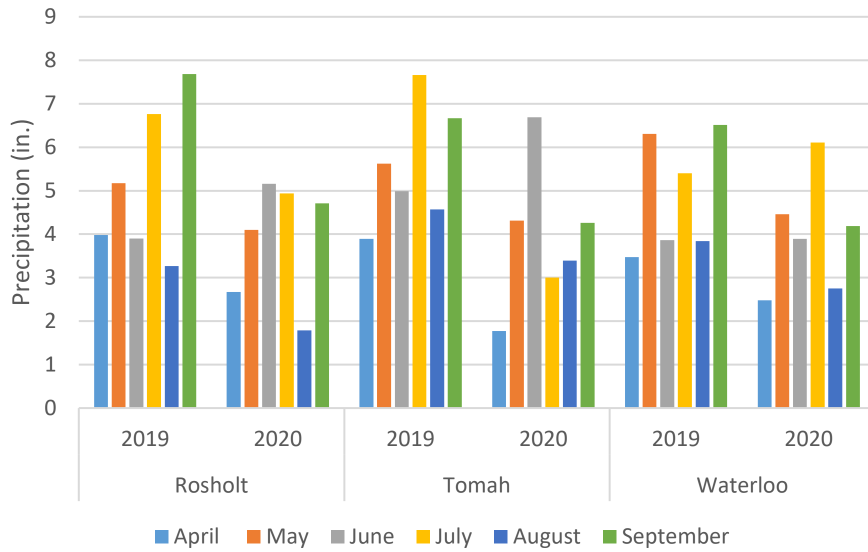

Figure 1. Average precipitation received per month at three locations in 2019 and 2020

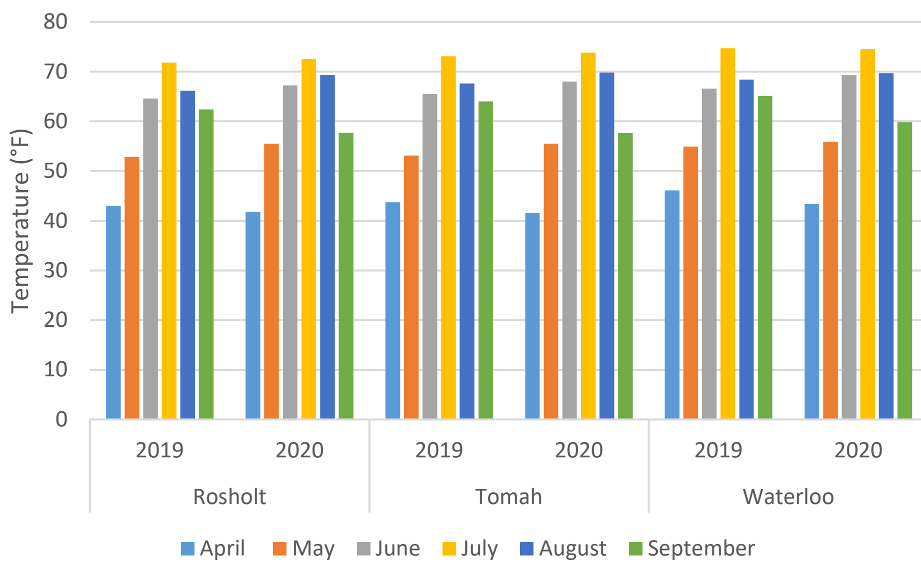

Figure 2. Average temperature recorded per month at three locations in 2019 and 2020

The study was implemented using a randomized, complete block design with four replications per variety at each location with N applied to five plants per replication. Nitrogen was applied as ammonium nitrate and applied at the rates of 0, 50, 100, 150 and 200 lbs/acre. Irrigation drip line emitters were closed in the study areas to prevent additional N application when the remainder of the yard was fertilized. All N rates were split applied at training and again after majority of bines reached top wire. Soil samples were taken at a depth of six inches prior to N application and maintenance rates of potassium (100 lbs K_2O/ac), phosphorous (30 lbs P_2O_5/ac), zinc (3.5 lbs Zn/ac), and boron (1 lb B/ac) were applied according to University of Wisconsin guidelines (Laboski and Peters, 2012).

Random petioles samples were collected from a height of five feet when bines were ½ - ¾ to top of trellis. Petiole tissue samples were analyzed for sap nitrate using a Horiba® LAQUAtwin Model NO3-11 compact Nitrate Ion Meter. Plots were harvested at discretion of the grower between August and September depending on the variety. Composite soil samples were taken at a depth of 0-6 inches from each plot and were collected in the row immediately after harvest. The three middle plants of the five treated plants were harvested to avoid any border effect of nutrient application. Whole plants were harvested with a hedge-trimmer and weighed. Cones were machine-picked by running whole plants through Wolf® harvesters at each location. Cones were captured and weighed. Subsamples were collected of freshly harvested bines and cones for determination of moisture, nutrient, and cone quality parameters.

Nutrient analysis of bines and cones were conducted. Samples were dried at 140° F and ground. Hop quality analyses (Hop Storage Index (HSI), total oils, alpha acids, beta acids, and the alpha/beta ratio) were conducted on freshly picked hop cones for three location-varieties (‘Cascade’, ‘Chinook’, and ‘Magnum’) in 2019 and all location-varieties in 2020. Cone dry weights were adjusted to 10% moisture for yield reporting.

Minitab was used for data analysis (Minitab 18.1,2017). One-way Analysis of Variance (ANOVA) was conducted using year, location-variety, and nitrogen rate as factors. Mean comparisons were completed using mean comparisons were made using Fisher’s

LSD test (95% C.I.). Location and variety were not used as an independent variable because varieties were not replicated at all locations.

Soil and plant tissue nutrient analysis was conducted using standard methods by the University of Wisconsin Soil and Plant Analysis Laboratory in Marshfield, WI. Cone subsamples were analyzed for quality parameters in 2020 by AAR Labs in Madison, WI.

Results

Location-variety had a highly significant effect on biomass yield (Table 2). Biomass and cone yield varied widely by year, location-variety, and N rate as represented in Figure 3 and Figure 4. Year and N rate had a highly significant effect on both biomass and cone yield ($P<0.001$). Biomass and cone yields were lower in 2020 compared to 2019. All nitrogen rates increased biomass and cone yield compared to the control (zero N rate). Several varieties showed decline in biomass and cone yield at higher nitrogen rates.

Table 2. One-way ANOVA P-values for factors year, location-variety, and N-rate for Biomass dry matter and adjusted 10% moisture cone yield.

Factor	Biomass DM yield	Adjusted 10% Moisture Cone Yield
	--------------------------- P-value -----------------------	
Year (N=90)	<0.001	<0.001
Location-variety(N=15 or 30)	<0.001	0.066
N-rate (N=36)	<0.001	<0.001

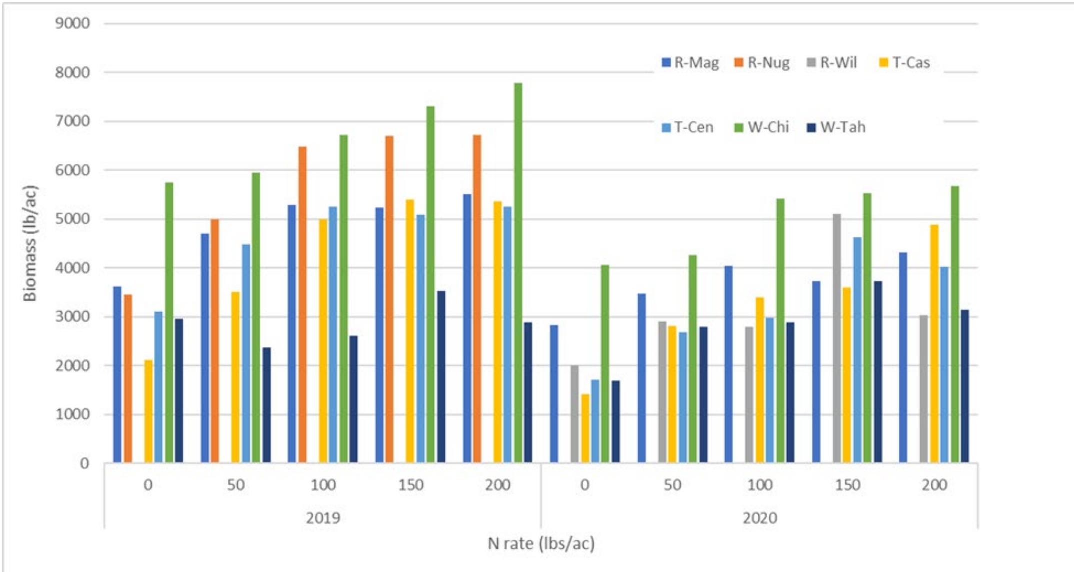

Figure 3. Biomass yield by year and N rate for each location-variety (N=3). R-Mag=Rosholt-‘Magnum’; R-Nug=Rosholt-‘Nugget’; R-Wil= Rosholt-‘Willamette’; T-Cas=Tomah-‘Cascade’; T-Cen=Tomah-‘Centennial’; W-Chi=Waterloo-‘Chinook’; W-Tah= Waterloo-‘Tahoma’.

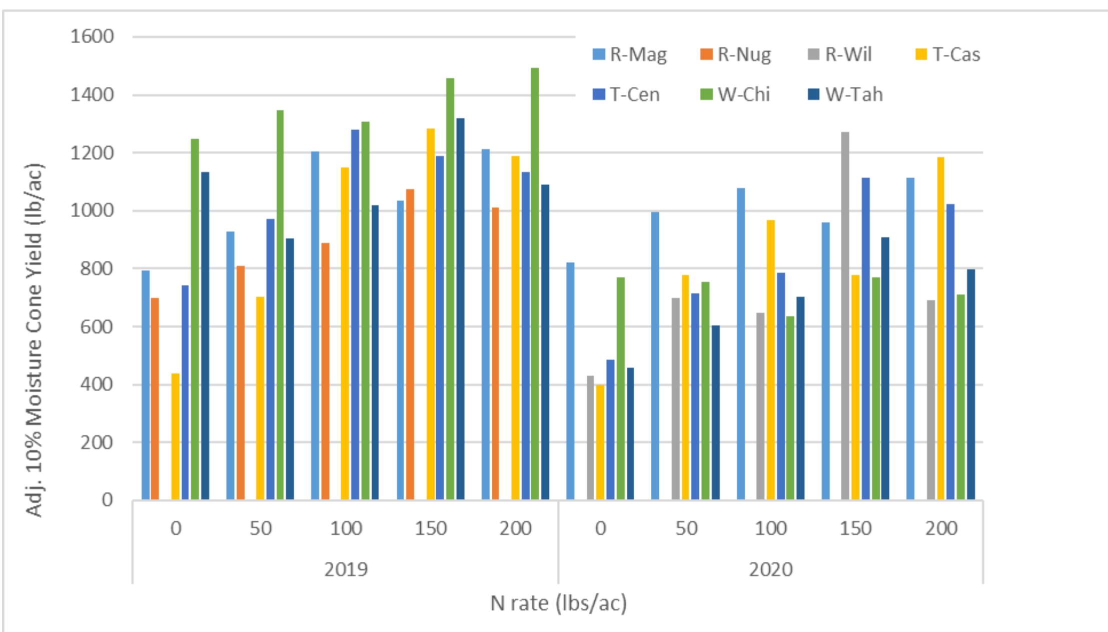

Figure 4. Adjusted 10% moisture individual variety effect of nitrogen rates on cone yield by year and N-rate for each location-varieties (N=3). R-Mag=Rosholt-‘Magnum’; R-Nug=Rosholt-‘Nugget’; R-Wil= Rosholt-‘Willamette’; T-Cas=Tomah-‘Cascade’; T-Cen=Tomah-‘Centennial’; W-Chi=Waterloo-‘Chinook’; W-Tah= Waterloo-‘Tahoma’.

Overall bine biomass yield increased with increasing nitrogen rate and were not significantly different at rates greater than 100 lbs N/acre (Figure 5). Cone yield did not significantly increase at N rates greater than 100 lbs N/acre. Average yield was slightly lower at the 200 lbs/ac N rate compared to the 150 lbs/ac N rate (Figure 6). Over both years of the study, 5 of 7 varieties showed greatest average cone yield at the nitrogen rate of 150 lbs N/ac.

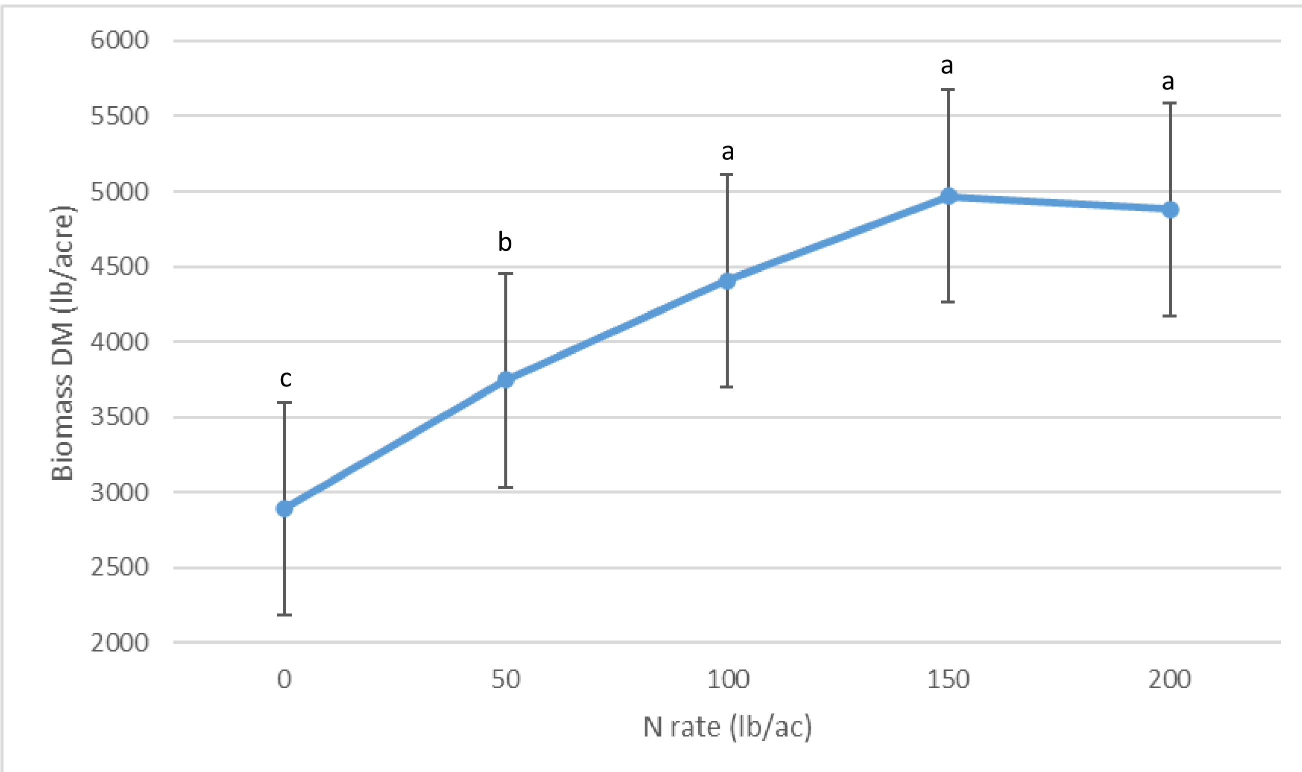

Figure 5. Nitrogen rate effect on bine biomass at for all locations and varieties. Means that do not share the same letter are significantly different. Mean comparisons were completed using the according to Fisher's LSD method with 95% C.I. (N=36). Error bars indicate pooled standard deviation.

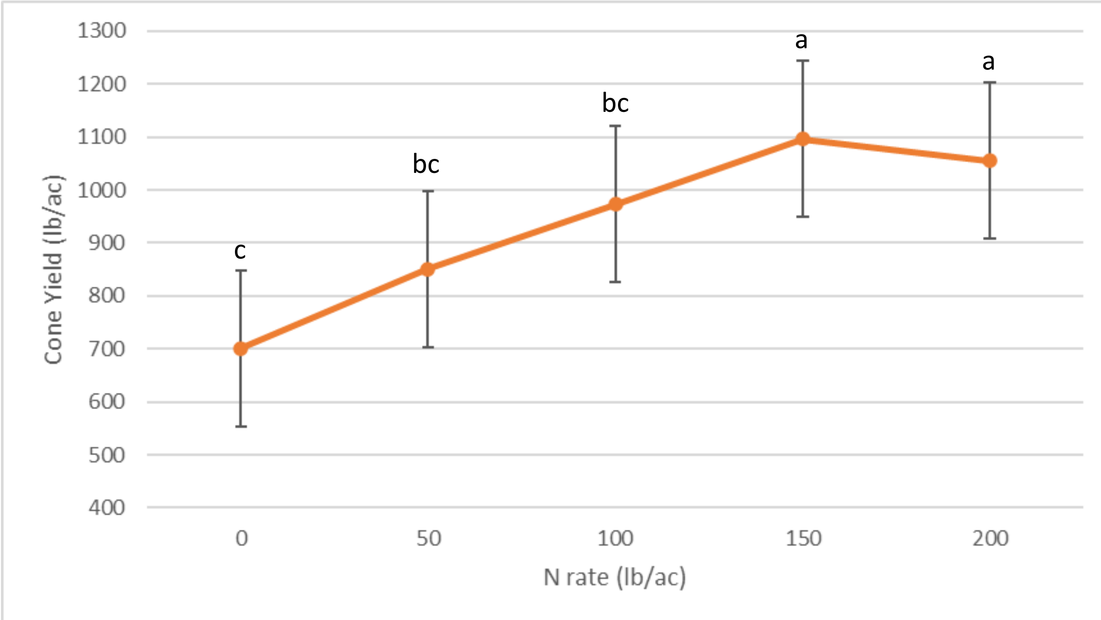

Figure 6. 10% moisture-adjusted cone yield for all locations and varieties. Means that do not share the same letter are significantly different according to Fisher's LSD method with 95% C.I (N=36). Error bars indicate pooled standard deviation.

Sap nitrate-N was moderately correlated with tissue nitrate-N concentrations in Figure 7. Observations revealed the sampling time of the day of the sampling impacted sap values. Collection times were modified to achieve consistent measurements. Data indicate that petiole sap nitrate concentration may be a viable alternative to tissue testing if threshold nitrate-N values for tissue are established.

Increasing the N rate also increased the N concentration in bines (Figure 8) and to a lesser extent in cones, (P<0.001, Figure 9). While increasing N rate consistently increased N concentration in bines and cones, the magnitude of increase was variable among location-variety and year.

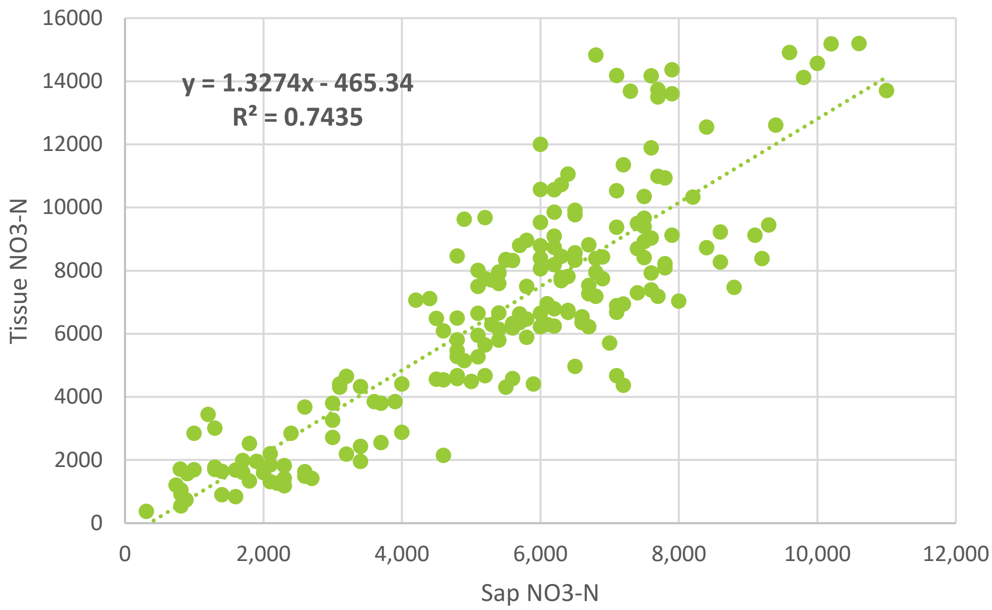

Figure 7. Petiole tissue and sap nitrate concentrations

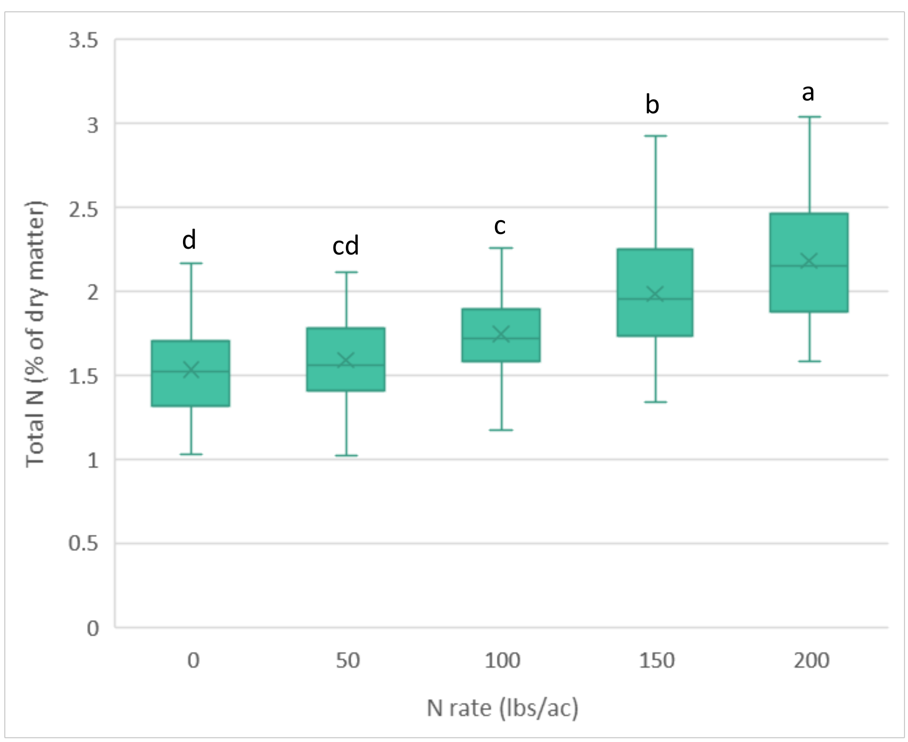

Figure 8. Nitrogen concentration in harvested bines for all locations and varieties. Means that do not share the same letter are significantly different according to Fisher's LSD method with 95% C.I. (N=36). Box plot represents mean, median, and quartile ranges across all location-varieties in 2019 and 2020.

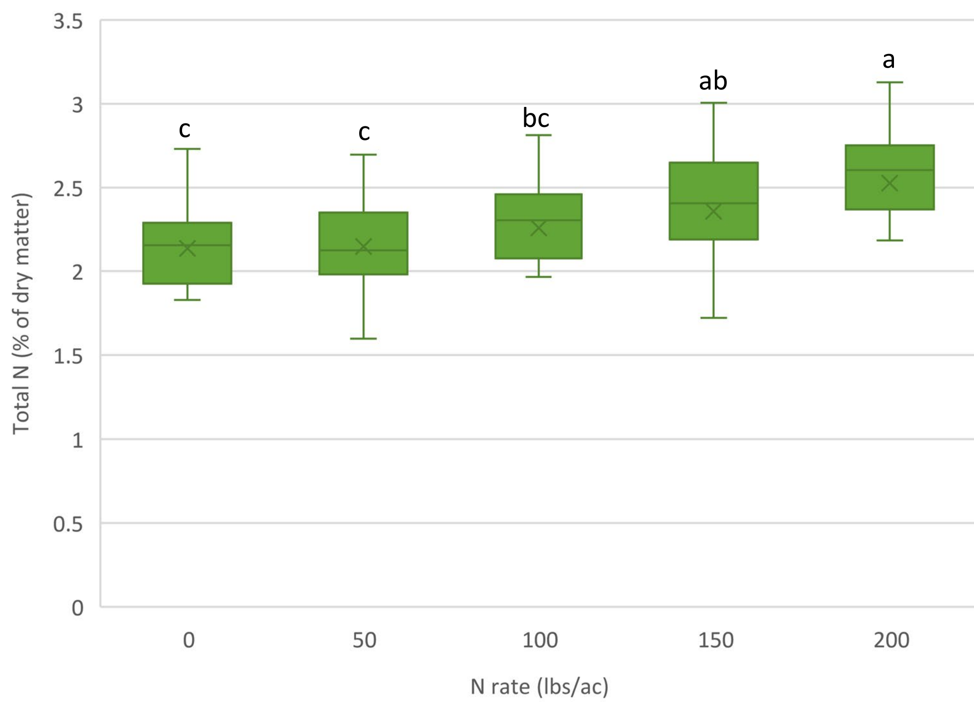

Figure 9. Nitrogen concentration in harvested cones. Means that do not share the same letter are significantly different according to Fisher's LSD method with 95% C.I. (N=36). Box plot represents mean, median, and quartile ranges across all location-varieties in 2019 and 2020.

Nitrogen treatment had no significant effect on soil test phosphorous or organic matter but significantly ($P<0.001$) affected pH (Figure 10) and soil test potassium (Figure 11). On average, the 200 lbs/acre N rate plots resulted in pH dropping 0.5 units and potassium dropping 52 ppm compared to the 0 N plots (Figure 11).

Nitrogen rate did not significantly affect hop quality parameters in 2019 and only showed a slight trend ($P=0.193$) toward decreasing Hop Storage Index (HSI) with increasing N rate in 2020 (Figure 12). Hop quality parameters were largely dependent on location-varieties.

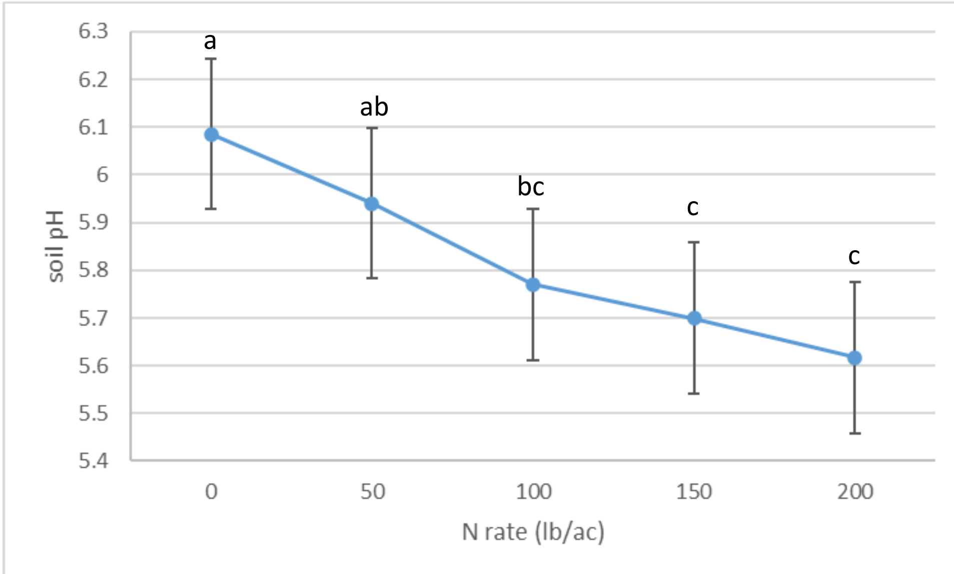

Figure 10. N-rate effect on in-row soil pH for all location-varieties in 2019 and 2020. Means that do not share the same letter are significantly different according to Fisher's LSD method with 95% C.I (N=36). Error bars indicate pooled standard deviation.

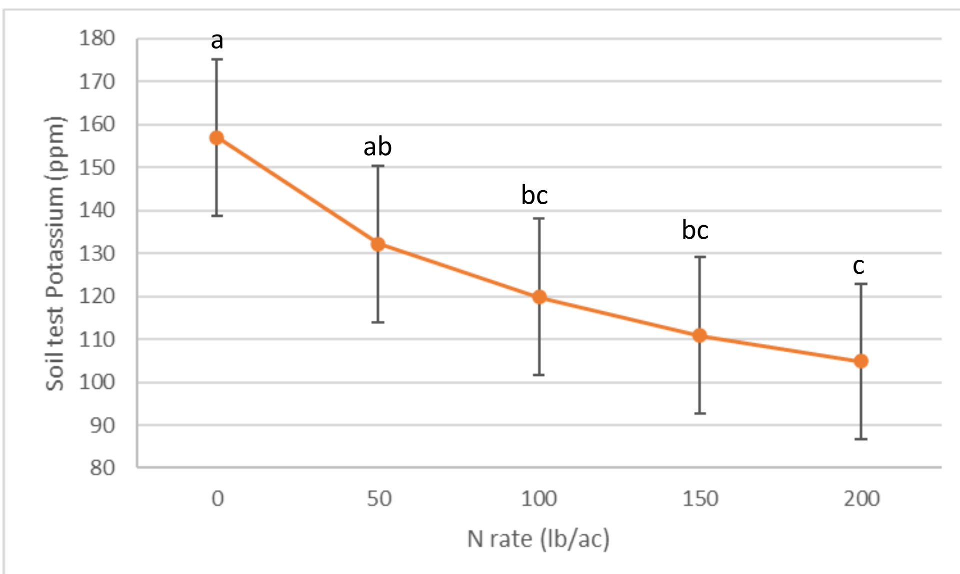

Figure 11. N-rate effect on in-row soil test potassium for all location-varieties in 2019 and 2020. Means that do not share the same letter are significantly different according to Fisher's LSD method with 95% C.I (N=36). Error bars indicate pooled standard deviation.

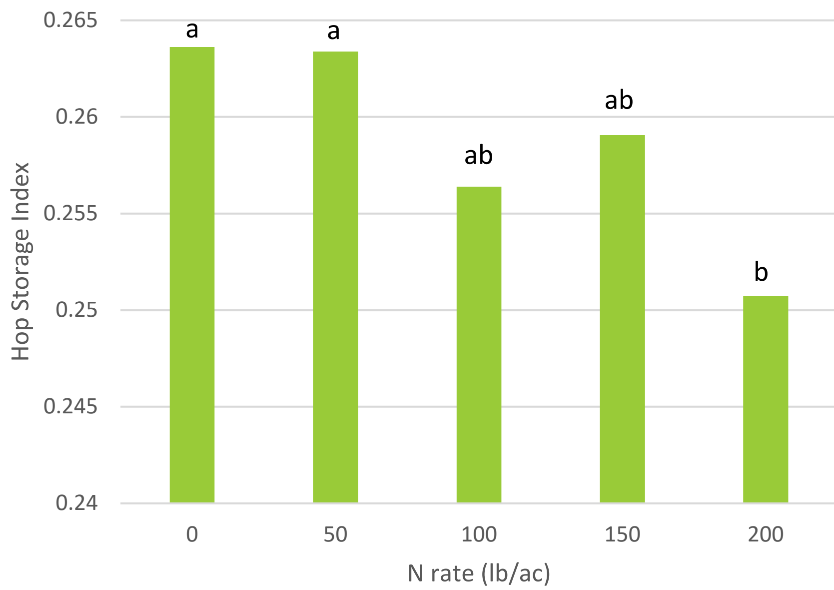

Figure 12. Hop storage index for samples collected in 2020 at different nitrogen rates. Means that do not share the same letter are significantly different according to the Fisher LSD method with 95% C.I. (N=18).

Average nutrient removal rates during the study for 150 lbs N application rate is shown in Table 3. Removal rates agree with University of Wisconsin-Extension recommendations for phosphorus of 30 lbs P_2O_5/ac and potassium of 100 lbs K_20/ac maintenance rates (Laboski, 2012).

Table 3. Hop nutrient removal at harvest

Nutrient	Bines	Cones	Total
	---------- lb/ac ----------		
Nitrogen	80	24	104
Phosphorus (as P_2O_5)	20	9	29
Potassium (as K_2O)	63	22	85
Calcium	58	5	63
Magnesium	18	3	21
Sulfate	5.7	1.7	7.4
Zinc	0.09	0.03	0.12
Manganese	0.55	0.05	0.60
Boron	0.19	0.03	0.22

The yield response curve generated for the entire data set indicates a wide range in response to nitrogen rate. While the effect of N rate on relative yield was highly significant ($P<0.001$), the correlation between N rate and relative yield was poor ($R2=0.21$) across the entire data set (Figure 13). The poor correlation of N rate with yield indicates other factors influenced cone yield in addition to the rate of N applied. Additionally, the small plot size used in this study is subject to greater variation in yield than larger plots typically used for yield estimations. However, four of nine yield response curves for specific location-variety and year showed R2 values greater than 50% (Figure 14). In these cases, N rate for maximum yield ranged between 135-229 lbs N/acre.

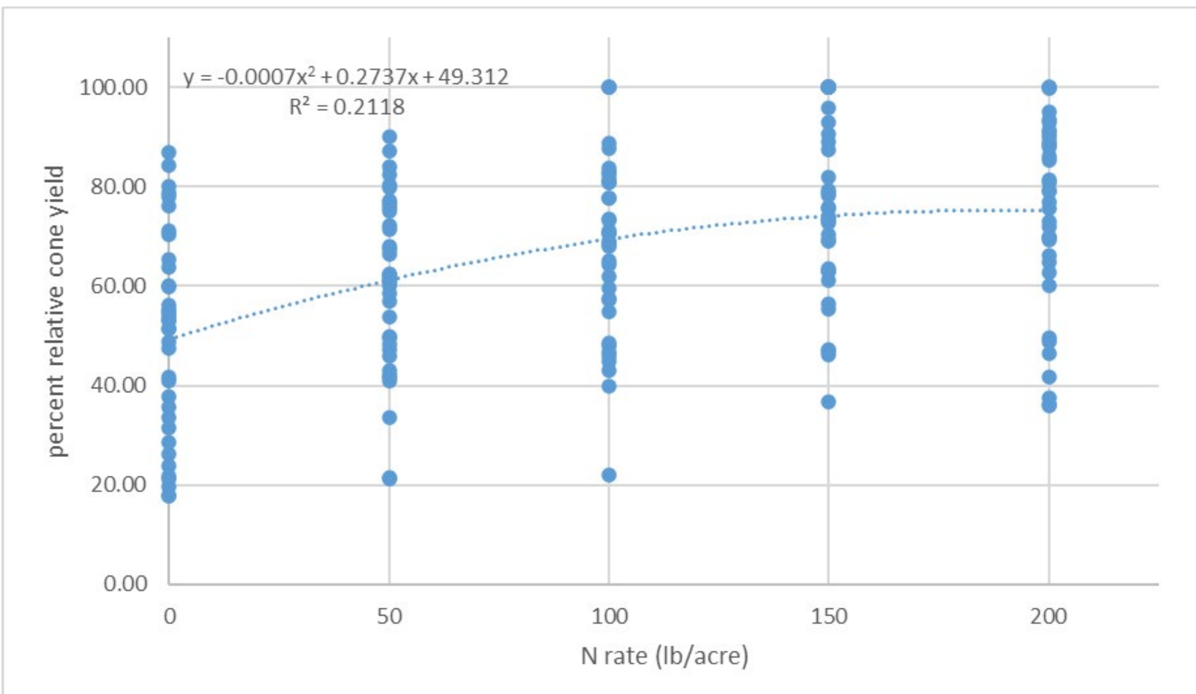

Figure 13. Yield response curve for all location-varieties in 2019 and 2020.

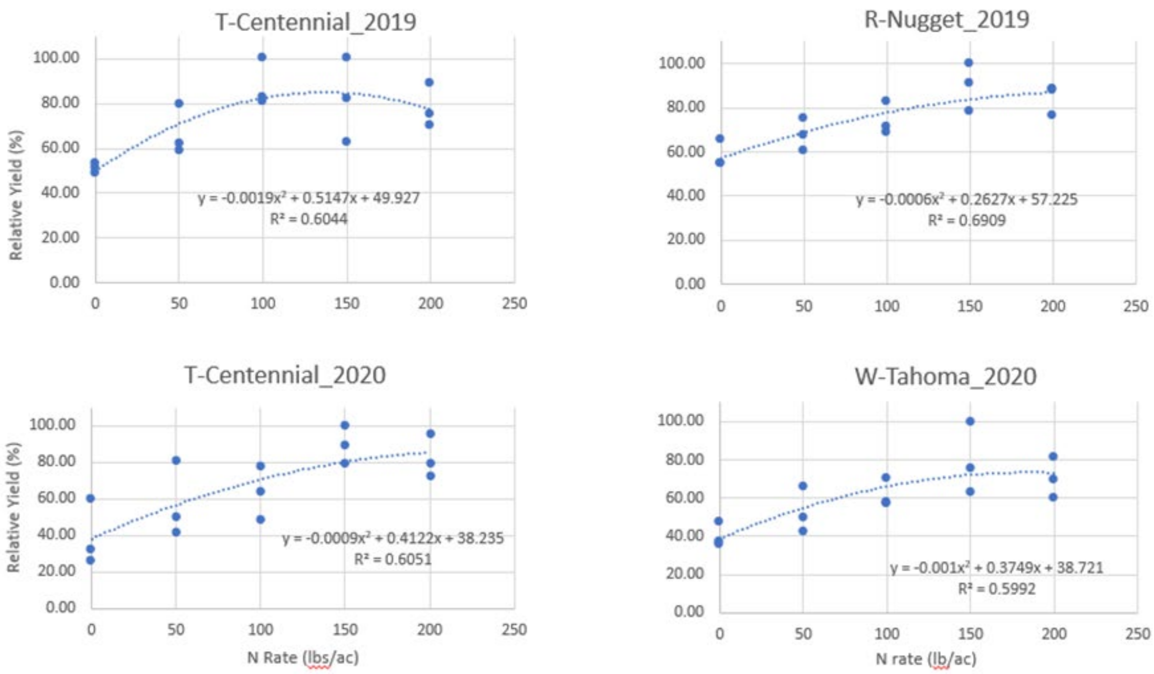

Figure 14. Yield response curves for location-variety and year where R2> 0.50.

Conclusions

Recommended N rates of 100 to 150 lbs/acre for established hops from other states are likely too high for most hop varieties grown in Wisconsin. Nitrogen rates above 100 lbs/acre did not increase cone yield over all varieties investigated. Multiple factors influence N response in hops including variety, soil type, and growing conditions. The data suggest a N rate above 150 lbs/acre was sufficient to maximize cone yield for most varieties in both years of the study. Petiole sap testing has promise for in-season adjustment of nitrogen rates. A reduction in cone yield at high N rates may be an effect of increased insect and disease pressure with more succulent plants. Managing soil pH and potassium inputs are important considerations for hop growers. Calculated nutrient removal agrees with current guidelines for phosphorous and potassium maintenance rates. Additional studies are needed to determine optimum N rate guidelines applicable to a range of variety and weather conditions Upper Midwest and Wisconsin hop growers are encouraged to focus on maintaining adequate N rather than maximizing growth with N rates more than recommended N rates. Economic N rates would vary by location-variety due to the large range in maximum yield and variability of variety grown and price per pound of the variety.

Use of these data during extension hop educational programming in 2020-2021 resulted in twelve producers indicating they reduced their N application rate by 50 lbs/acre.

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