2023 Hemp Flower Nitrogen Fertility Trial

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Hemp is a non-psychoactive variety of *Cannabis sativa* L. The crop is one of historical importance in the U.S. and re-emerging worldwide importance as medical providers and manufacturers seek hemp as a renewable and sustainable resource for a wide variety of consumer and industrial products. Hemp grown for all types of end-use (health supplement, fiber, and seed) contains less than 0.3% tetrahydrocannabinol (THC). Some hemp varieties intended to produce a health supplement contain relatively high concentrations of a compound called cannabidiol (CBD), potentially 10-15%. The compound CBD has purported benefits such as relief from inflammation, pain, anxiety, seizures, spasms, and other conditions. The CBD compound is the most concentrated in the female flower buds of the plant, however, it is also in the leaves and other plant parts as well.

To produce hemp for flower, the plant is generally grown intensively as a specialty crop and the flowers are cultivated for maximum growth. The various cannabinoids and terpenes concentrated in the flower buds are often extracted and incorporated into topical products (salves, lip balm, lotion) and food and is available in pill capsules, powder form, and more, which can be found in the market today. To help farmers succeed, agronomic research on hemp is needed in the United States. University of Vermont, in partnership with the University of Maine, evaluated the impact of five different nitrogen (N) application rates on the growth habit, yield, flower quality, and whole plant nutrient concentration of hemp.

Participants intending to grow hemp are required to follow state or federal regulations regarding hemp production and registration. Growers must either register with their intended state for production or adhere to federal regulations for production within a grower's given state. Regulations are subject to change from year to year with the development and approval of proposed program rules and it is important to note that regulations may vary across state lines and may be impacted by pending federal regulations. For the 2023 growing season, the Vermont Agency of Agriculture, Food and Markets Hemp program is no longer accepting registrations for growing or processing hemp in the state of Vermont.

Please refer to this https://www.ams.usda.gov/rules-regulations/hemp for detailed information on USDA hemp guidelines for production.

MATERIALS AND METHODS

The trial was initiated at Borderview Research Farm in Alburgh, Vermont (Table 1) and the experimental design was a randomized complete block design with four replications. Plots consisted of five plants spaced 5' apart in the row and plot treatments consisted of five N application rates including a Control (0 lbs N ac^{-1}), 50, 100, 150, and 200 lbs N ac^{-1}.

Table 1. Agronomic information for the hemp nitrogen fertility trial, Alburgh, VT, 2023.

Location	**Borderview Research Farm Alburgh, VT**
Soil type	Benson rocky silt loam, 8-15% slope
Previous crop	Barley
Plot size	25' x 20'
Plant spacing (ft)	5' x 5'
Variety	Elektra
Plant material	Seedling
Planting date	16-Jun
Harvest date	28-Sep, 29-Sep

Individual seeds were sown one seed per cell in Deep 50 cell plug trays on 11-May 2023. Supplemental lighting was provided during the day, and plants were given 18 hours of light. Soil was watered to keep the soil surface sufficiently moist to effect germination and two fertilizations were made with a low analysis 2-2-2 liquid fertilizer. Plants were grown in the greenhouse for 3 weeks prior to transplanting in the field.

At four weeks after sowing, hemp seedlings (variety Elektra) were hardened off and transplanted on 16-Jun in Alburgh. Hemp plants were transplanted on a 5 x 5 spacing without black plastic into a seed bed prepared with conventional tillage. Plots received nitrogen fertility in two split applications in the form of ammonium sulfate (21-0-0-24S) applied to entire plot (Table 2). Ammonium sulfate (21-0-0-24) was applied to each plot at 0, 50, 100, 150, and 200 lbs N/ac. Gypsum was applied to balance the sulfur in each treatment. Applications for the 100, 150, and 200 lbs N/ac rates were applied to the field in split applications, one just after planting (16-Jun) and one 14-Jul to avoid potential salt or fertilizer injury. Weeds were controlled through bi-weekly hand weeding during plant establishment.

Table 2. Nitrogen fertility sources and rates.

Treatment lbs N ac^{-1}	**Ammonium sulfate application rate 21-0-0-24S** lbs $plot^{-1}$	**Gypsum application rate 0-0-0-16S** lbs $plot^{-1}$
0	0.00	16.4
50	2.74	12.3
100	5.48	8.2
150	8.21	4.1
200	10.95	0.00

Pre-harvest, measurements for plant height and plant width were taken from three plants in the middle of each plot. For harvest measurements, two plants were cut at the base approximately 10 cm above the ground with loppers and the plant weight was recorded. An additional plant from each plot was harvested and run through a chipper shredder to determine whole plant dry matter and whole plant nutrient content.

Harvested plants were separated into individual branches and stripped of its fan leaves. Flowers were separated from individual branches using a BuckmasterPro bucker (Maple Ridge, BC, Canada) in Vermont. Bucked flower was then fed through the Centurion Pro Gladiator Trimmer (Maple Ridge, BC, Canada) (Image 1). Wet bud weight and unmarketable bud weight were recorded. Stems were also collected and weighed. Flower dry matter content was assessed by collecting a flower subsample and drying the flower sample overnight in a small dehydrator. A subsample of flower was taken and sent to Bia Diagnostics in Colchester, VT for cannabinoid analysis. The percent moisture at harvest was used to calculate total dry matter and flower dry matter yields.

Image 1. Centurion Pro Gladiator Trimmer (Maple Ridge, BC, Canada).

Yield data and stand characteristics were analyzed using mixed model analysis using the mixed procedure of SAS (SAS Institute, 1999). Replications within the trial were treated as random effects, and treatments were treated as fixed. Treatment mean comparisons were made using the Least Significant Difference (LSD) procedure when the F-test was considered significant (p<0.10).

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 treatments is real or whether it might have occurred due to other variations in the field. At the bottom of each table a p-value is presented for each variable that showed statistical significance (p-value ≤ 0.10). In this case, the difference between two treatments within a column is equal to or greater than the least significant difference (LSD) value and you can be sure that for 9 out of 10 times, there is a real difference between the two treatments. In this example, treatment C is significantly different from treatment A but not from treatment B. Treatment B and treatment C have share the same letter ‘a’ next to their yield value, to indicate that these results are statistically similar. The difference between treatment C and treatment B is equal to 1.5, which is less than the LSD value of 2.0. This means that these treatments did not differ in yield. The difference between treatment C and treatment A is equal to 3.0, which is greater than the LSD value of 2.0. This means that the yields of these treatments were significantly different from one another. The letter ‘b’ next to treatment A’s yield value shows that this value is significantly different from treatment B and treatment C, which have the letter ‘a’ next to their value.

Treatment	Yield
A	6.0 b
B	7.5a
C	**9.0**a
LSD (p-value ≤ 0.10)	2.0

RESULTS

Seasonal precipitation and temperature were recorded with a Davis Instrument Vantage Pro2 weather station, equipped with a WeatherLink data logger at Borderview Research Farm in Alburgh, VT (Table 3). Much of the growing season in 2023 was defined by heavy rains and below average temperatures during the peak vegetative growth period of the season. For the given cultivation period, temperatures were on average 4.7 °F below the 30-year average for Alburgh, VT. Additionally precipitation was significantly higher, 8.29" above average, as a result of major storms and flooding that occurred throughout the region with greatest storm events observed in July and August. As a result of these conditions, we saw significantly less cumulative growing degree days (GDDs) during critical maturation periods in August for floral hemp, 63 GDDs below average and a total cumulative GDDs of 2184 for the season.

Table 3. Seasonal weather data collected in Alburgh, VT, 2023.

Alburgh, VT	June	July	August	Sept
Average temperature (°F)	65.7	72.2	67.0	63.7
Departure from normal	-1.76	-0.24	-3.73	1.03
Precipitation (inches)	4.40	10.75	6.27	2.40
Departure from normal	0.14	6.69	2.73	-1.27
Growing Degree Days (50-86°F)	483	712	540	449
Departure from normal	-41	17	-101	62

Historical averages are for 30 years of data provided by the NOAA (1991-2020) for Burlington, VT.

Plant heights, widths, and whole plant weights are presented in Table 4. Plant heights appeared to be greatest in the highest three fertility rates, with highest observed plant height seen at the 200 lbs N ac^{-1} rate at 155 cm. Plant widths and whole plant weights showed no trends corresponding to increasing nitrogen rates with plants averaging 11.3 lbs across the trial at harvest.

Table 4. Hemp whole plant weight, height, and width, Alburgh, VT, 2023.

Treatment	Plant height		Plant width	Plant weight
lbs N ac^{-1}	cm		cm	lbs plant^{-1}
0	137	c	119	12.5
50	140	bc	116	10.5
100	150	ab	125	12.0
150	149	abc	119	10.7
200	**155**	**a** †	122	10.8
LSD (0.10) ‡	12.2		NS	NS
Trial Mean	146		120	11.3

†Within a column, treatments with the same letter are not significantly different from each other. The top performing treatment is shown in **bold.**

‡LSD – Least significant difference at p=0.10.

NS- No significant difference across treatments.

Total bud weight, leaf weight, and stem weight were measured at harvest to further evaluate growth characteristics of plants from each nitrogen application rate (Table 5). Compared to previous years, some nitrogen response in plant metrics was observed across treatments. When looking at the fractionated components of the plants (stem, flower, and leaf material) on a per weight basis, those treatments showing highest yields included all but the 50 lbs N ac^{-1} treatment with the highest observed yields seen at the 100 lbs N ac^{-1} treatment with an average of 3.99 lbs plant^{-1}. Similarly, this resulted in the highest average percentage of floral material per plant at 33.3% of the total plant weight.

Table 5. Hemp plant growth metrics, Alburgh, VT, 2023.

Treatment	Stem weight	Stem weight	Bud weight		Bud weight		Leaf weight	Leaf weight	
lbs N ac^{-1}	lbs plant^{-1}	% total	lbs plant^{-1}		% total		lbs plant^{-1}	% total	
0	4.39	35.0	3.89	a	31.2	a	4.25	33.8	b
50	3.95	38.6	2.72	b	25.2	b	3.81	36.2	ab
100	4.16	34.1	**3.99**	**a**	**33.3**	**a**	3.82	32.6	b
150	3.54	33.7	3.04	ab†	28.2	ab	4.10	38.1	a
200	3.92	36.3	3.11	ab	28.9	ab	3.75	34.8	ab
LSD (0.10)‡	NS	NS	1.11		4.42		NS	4.29	
Trial Mean	3.99	35.5	3.35		29.4		3.95	35.1	

†Within a column, treatments with the same letter are not significantly different from each other.
The top performing treatment is shown in **bold.**
‡LSD – Least significant difference at p=0.10.
NS- No significant difference across treatments

At harvest, a composite subsample of flower material was collected from each plot and dried down to determine flower dry matter and calculate dry matter flower yields (Table 6). This year flower dry matter and dry matter yields did not appear to be impacted by nitrogen rates. Overall, plants yielded approximately 200 lbs ac^{-1} more flower on a dry matter basis when compared to the 2022 growing season with a trial average of 1565 lbs ac^{-1}. Unmarketable flower included any flower that had suffered from disease, rot, soil contamination, or otherwise damaged flower material.

Table 6. Hemp flower bud yield, Alburgh, VT, 2023.

Treatment	Flower dry matter	Dry matter flower yield €	Flower yield @ 8% moisture	Unmarketable flower
lbs N ac^{-1}	%	lbs ac^{-1}	lbs ac^{-1}	lbs ac^{-1}
0	25.3	1735	1885	307
50	26.5	1294	1407	413
100	28.5	1993	2167	250
150	24.0	1275	1386	152
200	28.0	1527	1660	190
LSD (0.10)‡	NS	NS	NS	NS
Trial Mean	26.4	1565	1701	262

‡LSD – Least significant difference at p=0.10.
NS- No significant difference across treatments

Dried flower samples were also analyzed for CBD and THC concentrations (Table 7). Results for cannabinoids are on a dry matter basis (0% moisture). Concentrations of cannabinoids appeared to be impacted by nitrogen application rates with highest observed concentrations seen in the control (receiving no supplemental nitrogen) and lowest observed concentrations seen in the 200 lb N ac^{-1} rate. Total potential CBD was highest in the control at 10.8% including the highest total potential THC at 0.433% and was statistically similar to the 50, 100, and 150 lb N ac^{-1} rates.

Table 7. Hemp flower cannabinoid concentrations. Alburgh, VT, 2023.

Treatment	CBDa		CBD	THCa		D9-THC	Total potential CBD ŧ		Total potential THC‡		Total cannabinoids	
lbs N ac^{-1}	%		%	%		%	%		%		%	
0	**12.2**	**a**	0.133	**0.490**	**a**	0.000	**10.8**	**a**	**0.433**	**a**	**13.3**	**a**
50	10.0	ab	0.180	0.390	ab	0.008	8.95	ab	0.348	ab	11.0	ab
100	9.94	ab	0.085	0.405	ab	0.000	8.80	ab	0.358	ab	10.9	ab
150	10.9	ab	0.098	0.448	ab	0.000	9.64	ab	0.390	ab	11.8	ab
200	9.04	b	0.148	0.375	b	0.005	8.08	b	0.338	b	10.0	b
LSD (0.10) ¥	2.42		NS	0.104		NS	2.15		0.091		2.75	
Trial Mean	10.4		0.129	0.422		0.003	9.25		0.373		11.40	

ŧ Total potential CBD = (0.877 x CBDA) + CBD.

‡Total potential THC = (0.877 x THCA) + Δ-9 THC.

§Within a column, treatments with the same letter are not significantly different from each other. The top performing treatment is shown in **bold.**

¥LSD – Least significant difference at p=0.10.

NS – No significant difference between treatments.

DISCUSSION

As we investigated nitrogen response in high cannabinoid hemp, some similarities were observed between past research done in grain and fiber. However, through four years of study in flower hemp, there appeared to be greater variability in nitrogen uptake for flower production. Some grain and fiber hemp research have shown that the majority of nitrogen uptake occurs during the first month of growth during vegetative periods. This ends up being a critical growth period for high cannabinoid hemp as well with the rapid uptake of nitrogen occurring during the vegetative production period. Additionally, a positive yield and biomass response in grain and fiber varieties is seen with increased nitrogen application rates up to approximately 130 lbs N ac^{-1}. Past this point, additional nitrogen appears to have no major impact on grain yields. In the 2020 hemp flower nitrogen fertility trial, those treatments that received the highest three nitrogen application rates resulted in greatest whole plant biomass, showing some similarities to past research results in grain and fiber hemp. In 2021 and 2023, there appeared to be little influence on hemp growth and development as a result of nitrogen fertility treatments. However, greater treatment impacts were noted in the 2022 growing season as noted earlier. These were largely seen in flower yields and concentrations of flower and stem material for plants in each treatment.

This trial was also conducted with University of Maine at The Rogers Farm in Stillwater, Maine to capture seasonal differences in the Northeast. The impacts of varying weather conditions became more apparent through comparisons across research sites. While 2021 was hot and dry in Vermont and 2022 was comparatively cool and wet, Maine saw opposite weather conditions in each year and similar trending for gathered metrics in flower dry matter and flower yields. In 2023, both sites received significantly higher amounts of rainfall and increased disease pressure and in some cases complete loss. These were likely contributing factors in this year's trial as plants were visibly impacted by leaf disease and the overall cooler and wetter growing conditions.

As we've gathered more information on nitrogen application rates in hemp, whole plant nitrogen concentrations were extrapolated to a crop removal rate per acre over the past few years to gain a clearer picture of hemp uptake. From this it appears as if plants within the trial would remove anywhere between 70 and 190 pounds of nitrogen per acre depending on individual plant analysis and nitrogen treatment, with an average of approximately 125 pounds of nitrogen removed per acre. With no yield response with increase nitrogen rates over 100 lbs ac^{-1} from this trial, this could potentially suggest that nitrogen application rates above 100 lbs ac^{-1} may be applied in excess under given soil and environmental conditions when factoring in the breakdown of organic matter to plant available nitrogen. Pairing this information with results from 2021 and 2022 replicated over two locations and comparing hemp flower yields and other fractionated components of the plant, it appears as if applying nitrogen in excess of 100 lbs ac^{-1} largely results in an increase in leaf and stem biomass, however, does not impact flower yields.

Current recommendations for hemp crops range from 100-200 lbs N ac^{-1} depending on crop type, soil type and growing region. It is also important to note that between the Vermont and Maine trial sites, soils were also within the ~3.5-4.0% organic matter range. Hemp plants grown within soils with higher concentrations of organic matter may also be capable of effectively scavenging nitrogen within the soil. Reducing applications to 50-100 lbs N ac^{-1} for flower hemp may be more beneficial from a yield and labor standpoint for soils with higher organic matter. Conversely, low organic matter soils may require higher concentrations of nitrogen to provide adequate flower yields.

In 2023, as well as previous years of nitrogen trials, increased nitrogen application rates have led to depressions in cannabinoid concentrations with a nearly 4% difference between 200 lbs N ac^{-1} rates and control treatments receiving no additional nitrogen. 2023 showed similarities to other years of study showing a 3.3% total cannabinoid difference from the control treatment to the 200 lbs N ac^{-1} application rate, with the highest value observed in the control at 13.3%. From this past data, and 2021 data, it did not appear that higher rates of nitrogen increased CBD or THC concentration and may in fact depress overall potential cannabinoid concentration with higher nitrogen rates. Similar results were found using the 'Elektra' variety at University of Maine research farm in Stillwater, further indicating the lack of a positive cannabinoid response to increased nitrogen rates in hemp. Under current regulations, there are major concerns for producing compliant crops. With such wide scale variations in growth habits, yield, and quality of various cultivars there is potential that other flower varieties might be impacted by nitrogen application rates differently, especially those with differing maturation periods or intended end uses. While cannabinoid concentrations could be altered in relation to nitrogen application rates, starting with compliant genetics would be the most reliable method for producing a THC compliant crop. Future regulations may also greatly impact levels for compliancy making it important to remain current with regulation for compliancy with hemp.

ACKNOWLEDGEMENTS

Special thanks to Roger Rainville and the staff at Borderview Research Farm for their generous help with the trials. This project was supported by and was funded through our partnership with Northeast SARE Partnership Grant award number ONE19-333. We would also like to thank Anna Brown, Catherine Davidson, Hillary Emick, Ivy Krezinski, Lindsey Ruhl, Laura Sullivan, Sophia Wilcox Warren, and Sara Ziegler for their assistance with data collection and entry. The information is presented with the understanding that no product discrimination is intended and no endorsement of any product mentioned or criticism of unnamed products is implied.

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