2021 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 of State Hemp Programs intending to grow are required to follow state and federal regulations regarding hemp production and registration. Growers must register within their intended state for production, and must adhere to most current or active rules and 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. Please refer to this https://agriculture.vermont.gov/sites/agriculture/files/documents/PHARM/hemp/Vermont_State_plan_2021_12_1.pdf for a detailed outline of most recent approval from the Agricultural Marketing Service of the USDA of the Vermont Hemp Production Plant. The approved plan supports the Vermont Hemp Rules and governs registration, production, sampling and compliance for hemp cultivation beginning in 2022.

Additional information regarding the Vermont Agency of Agriculture, Food and Markets (VAAFM) Hemp Program can be found on the VAAFM website here:

https://agriculture.vermont.gov/public-health-agricultural-resource-management-division/hemp-program

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, 2021.

Location	**Borderview Research Farm Alburgh, VT**
Soil type	Benson rocky silt loam, 3-5% slope
Previous crop	Mixed forage crop
Plot size	25' x 20'
Plant spacing (ft)	5' x 5'
Variety	Elektra
Plant material	Seedling
Planting date	2-Jun
Harvest date	21-Sep

Individual seeds were sown one seed per cell in Deep 50 cell plug trays on 12 May 2021. 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 three weeks after sowing, hemp seedlings (variety Elektra) were hardened off and transplanted on 2-Jun in Alburgh. Hemp plants were transplanted on a 5 x 5 spacing without black plastic into a seed be prepared with conventional tillage. Drip irrigation was setup to supply moisture as needed by the hemp plants. 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 prior to planting (2-Jun) and one 25-Jun 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	**Ammonium sulfate application rate 21-0-0-24S**	**Gypsum application rate 0-0-0-16S**
lbs N ac^{-1}	**lbs $plot^{-1}$**	**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 middle three plants in 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 fan its fan leaves. Flowers were separated from individual branches using a BuckmasterPro bucker (Maple Ridge, BC, Canada) in Vermont. In Vermont, bucked flower was then fed through the CenturionPro 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 ProVerde Laboratories in Portland, ME for cannabinoid analysis. The percent moisture at harvest was used to calculate total dry matter and flower dry matter yields. Samples for whole plant nutrient analysis and leaf nitrogen measurements were sent to DairyOne Laboratories in (Ithaca, NY).

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). The growing season saw hot and dry periods through initial plant establishment. July was much cooler than normal. Overall dry conditions persisted throughout the summer months resulting in below average precipitation for the season. Average temperatures during the growing period were 5.97 degrees higher than the 30-year average for the season with a 4.69% higher growing degree day accumulation for the year.

Table 3. Seasonal weather data collected in Alburgh, VT, 2021.

Alburgh, VT	June	July	August	Sept	Oct
Average temperature (°F)	70.3	68.1	74.0	62.8	54.4
Departure from normal	2.81	-4.31	3.25	0.14	4.07
Precipitation (inches)	3.06	2.92	2.29	4.09	6.23
Departure from normal	-1.20	-1.14	-1.25	0.42	2.40
Growing Degree Days (50-86°F)	597	561	727	394	217
Departure from normal	73	-134	85	7	79

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

Plants heights differed between treatments with the highest observed values seen in the 100 lbs N ac^{-1} rate at 182 cm and was statistically similar to the 200 lbs N ac^{-1} treatment and the control, with an average trial height of 166 cm (Table 4). No significant differences were observed in plant width or whole plant weight at harvest, but plants within the trial averaged 165 cm in width and 19.8 lbs plant^{-1}.

Table 4. Hemp whole plant weight, height, and width, Alburgh, VT, 2021.

Treatment lbs N ac^{-1}	Plant height Cm	Plant width cm	Plant weight lbs plant^{-1}
0	165a†	169	18.3
50	151b	152	19.8
100	182a	176	20.2
150	153b	154	19.7
200	179ab	174	20.8
LSD (0.10) ‡	28.1	NS¥	NS
Trial Mean	166	165	19.8

†Within a column, treatments with the same letter are not significantly different from each other.

‡LSD – Least significant difference at p=0.10.

¥NS – No significant difference between 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). In general, plants across treatments appeared to be uniform in growth habit with little to no observable differences in appearance. Across the trial, very few differences were apparent when looking at the weights of the fractionated components with no significant differences observed in stem weight, bud weight, or leaf weight. When looking at the component in terms of percentage of total plant weight or proportions in relation to one another, some differences emerged in stem weight and leaf weight percentages. This highest total percentage of stem was seen in the 200 lbs N ac^{-1} treatment at 36.9% and was statistically similar to all but the 50 lbs N ac^{-1} treatment. Conversely, the 200 lbs N ac^{-1} treatment had the lowest percentage of leaf material at 26.5%. highest leaf proportions were seen in the 100 lbs N ac^{-1} treatment at 33.9%. The amount of total leaf or stem material can influence a number of factors such as harvest time to remove excess leaf material for trimmed flower or harvestable plant material in a biomass production system. Amount of time required to harvest plants could vary drastically depending on desired end-product and intricacy of trimming, influenced largely by overall plant size and proportions of bud, leaf, and stem material. While not statistically significant, the average bud weight for the control treatments were lower than all other treatments at 6.37 lbs plant^{-1} with other treatments ranging from 7.06-8.17 lbs plant^{-1}.

Table 5. Hemp plant growth metrics, Alburgh, VT, 2021.

Treatment lbs N ac^{-1}	Stem weight lbs plant^{-1}	Stem weight % total	Bud weight lbs plant^{-1}	Bud weight % total	Leaf weight lbs plant^{-1}	Leaf weight % total	Bud:stem	Leaf:stem
0	6.28	33.8ab	6.37	35.6	5.67	30.7ab	1.09	0.910ab
50	6.04	30.5b	8.17	41.1	5.61	28.5ab	1.35	0.940ab
100	6.32	31.3ab	7.06	34.8	6.85	33.9a	1.22	1.18a
150	6.03	31.0ab	7.62	38.0	6.03	31.0ab	1.25	1.01ab
200	7.58	36.9a†	7.61	36.6	5.63	26.5b	1.02	0.750b
LSD (0.10) ‡	NS¥	6.06	NS	NS	NS	5.93	NS	0.332
Trial Mean	6.45	32.69	7.37	37.2	5.96	30.1	1.19	0.96

†Within a column, treatments with the same letter are not significantly different from each other.
‡LSD – Least significant difference at p=0.10.
¥NS – No significant difference between 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). Flower dry matter was not significantly different across treatments and there were no significant differences in yields across nitrogen fertility treatments within this trial. 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, 2021.

Treatment lbs N ac^{-1}	Flower dry matter %	Unmarketable wet flower yield lbs plant^{-1}	Dry matter flower yield € lbs ac^{-1}
0	21.2	73.3	2387
50	21.8	66.2	3081
100	21.5	82.6	2625
150	19.5	90.9	2525
200	20.1	51.8	2622
LSD (0.10) ‡	NS¥	NS	NS
Trial Mean	20.8	72.9	2648

‡LSD – Least significant difference at p=0.10.
¥NS – No significant difference between treatments.
€Dry matter yield is reported at 0% moisture.

Whole plants were chipped and analyzed for primary and secondary plant nutrients (Table 7). There were significant differences across treatments for concentrations of nitrogen, phosphorus, calcium, sulfur, carbon, iron, and zinc. Highest values for nitrogen, calcium and sulfur were observed in the 150 lbs N ac^{-1} treatment at 2.96%, 2.19%, and 0.280% respectively. Lowest concentrations for many of these nutrients were observed in the 50 lbs N ac^{-1} treatment with the exception of iron which showed the highest concentrations for the treatment at 831 ppm. Nitrogen management of soil is closely linked to the plant uptake of a wide number of nutrients. Differences in primary and secondary nutrient uptake could have been impacted by changes in soil pH as a result of increased nitrogen application rates or weather conditions.

Table 7. Hemp whole plant nutrient analysis, Alburgh, VT, 2021.

Treatment lbs N ac^{-1}	Nitrogen %	Potassium %	Phosphorus %	Calcium %	Magnesium %	Sulfur %	Carbon %
0	2.81a	1.69	0.370a	2.02ab	0.304	0.265a	16.8ab
50	2.36b	1.56	0.279b	1.74b	0.265	0.205b	19.8a
100	2.38b	1.63	0.346ab	1.87ab	0.263	0.225b	19.8a
150	2.96a	1.80	0.365ab	2.19a	0.261	0.280a	16.0b
200	2.7ab	1.68	0.327ab	1.82ab	0.264	0.250a	17.5ab
LSD (0.10) ‡	0.398	NS¥	0.091	0.42	NS	0.051	3.02
Trial Mean	2.64	1.67	0.337	1.93	0.271	0.245	18.0

†Within a column, treatments with the same letter are not significantly different from each other.
‡LSD – Least significant difference at p=0.10.
¥NS – No significant difference between treatments.

Table 7 cont. Hemp whole plant nutrient analysis, Alburgh, VT, 2021.

Treatment lbs N ac^{-1}	Manganese ppm	Iron ppm	Copper ppm	Boron ppm	Zinc ppm
0	129	540b	17.0	32.0	47.3ab
50	116	831a	12.6	26.6	41.0b
100	142	492b	13.5	27.1	43.2ab
150	168	551b	15.9	30.4	55.4a
200	185	393b	16.0	26.3	46.5ab
LSD (0.10) ‡	NS¥	206	NS	NS	10.8
Trial Mean	148	562	15.0	28.5	46.7

†Within a column, treatments with the same letter are not significantly different from each other.
‡LSD – Least significant difference at p=0.10.
¥NS – No significant difference between treatments.

Dried flower samples were also analyzed for CBD and THC concentrations (Table 8). Results for cannabinoids are on a dry matter basis (0% moisture). Each of the analyzed cannabinoids showed no significant differences across treatments throughout the study with a trial average for total potential THC reaching 0.494% and a total potential CBD concentration reaching 11.9%.

Table 8. Hemp flower cannabinoid concentrations. Alburgh, VT, 2021.

Treatment	D9-THC	CBD	THCa	CBDa	Total potential THC ŧ	Total potential CBD‡	**Total cannabinoids**
	%	%	%	%	%	%	%
0	0.047	0.452	0.478	12.3	0.466	11.2	13.9
50	0.153	0.452	0.508	13.2	0.497	12.0	14.7
100	0.054	0.486	0.533	13.8	0.522	12.6	15.5
150	0.049	0.478	0.476	12.5	0.467	11.4	14.1
200	0.138	0.445	0.537	13.4	0.517	12.2	15.1
LSD (0.10) ¥	NS€	NS	NS	NS	NS	NS	NS
Trial Mean	0.088	0.462	0.506	13.0	0.494	11.9	14.6

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

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

¥LSD – Least significant difference at p=0.10.

€NS – No significant difference between treatments.

DISCUSSION

As we continue to investigate nitrogen response in high cannabinoid hemp, some similarities can be observed between past research done in grain and fiber, however through three years of study in flower hemp, there appears 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 growth. In 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. However, in 2021, there appeared to be little influence on hemp growth and developments as a result of nitrogen fertility treatments. Similar trends were observed in Maine where this trial was replicated, with no significant difference observed across treatments in terms of plant dry matter yields or flower yields. Given the maturation rate of the selected variety for this trial and potentially as a result of disease resistance, there appeared to be little to no observable pest issues in this trial, whereas adjacent trials suffered from powdery mildew and Septoria leaf spot issues.

When whole plant nitrogen concentrations were extrapolated to a crop removal rate per acre, it appeared 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, this could potentially suggest that nitrogen application rates above 125 lbs ac^{-1} may be applied in excess under given soil and environmental conditions. Current recommendations for hemp crops range from 100-200 lbs N ac^{-1} depending on crop type, soil type and growing region.

Cannabinoid concentrations in this year of study did not appear to be impacted by nitrogen application rate. In past years of studies there were similar responses, or lack thereof, for several cannabinoids however some differences were observed in other years with different hemp varieties. In past years, increased nitrogen application rates have led to depressions in cannabinoid concentrations with a nearly 4% difference between 150 lbs N ac^{-1} rates and control rates receiving no additional nitrogen. From this past 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. 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, it will be increasingly important to continue research and evaluation not only of available cultivars but also fertility practices to provide region specific information to optimize farmer yields within the Northeast. It is also important to note that only one variety and one fertility source was tested within this trial and other macronutrients or micronutrients could potentially impact cannabinoid profiles or expression under different growing conditions. Upon completion of cannabinoid analysis, this report will be updated to include 2021 season results.

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