NORTHWEST CROPS & SOILS PROGRAM

2022 Hemp Flower Nitrogen Fertility Trial

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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 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, 2021.

Location	**Borderview Research Farm Alburgh, VT**
Soil type	Benson rocky silt loam, 8-15% slope
Previous crop	Spring Grains
Plot size	25’ x 20’
Plant spacing (ft)	5’ x 5’
Variety	Elektra
Plant material	Seedling
Planting date	6-Jun
Harvest date	27-Sep, 28-Sep

Individual seeds were sown one seed per cell in Deep 50 cell plug trays on 10-May 2022. 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 6-Jun in Alburgh. Hemp plants were transplanted on a 5 x 5 spacing without black plastic into a seed bed 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 after planting (8-Jun) and one 30-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 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 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 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 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 cooler overall temperatures with well above average precipitation, especially during the establishment period of the hemp plants in the month of June. As a result, growing conditions accumulated below average Growing Degree Days (GDD’s) and temperatures were an average of 4.91 degrees cooler than the 30-year average.

Table 3. Seasonal weather data collected in Alburgh, VT, 2022.

Alburgh, VT	June	July	August	Sept
Average temperature (°F)	65.3	71.9	70.5	60.7
Departure from normal	-2.18	-0.54	-0.20	-1.99
Precipitation (inches)	8.19	3.00	4.94	4.4
Departure from normal	3.93	-1.06	1.40	0.73
Growing Degree Days (50-86°F)	459	674	630	343
Departure from normal	-64	-20	-11	-44

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

Plant heights, widths, and whole plant weights were significantly different across all treatments (Table 4). Plant heights and widths did not show any distinct trends with increases to nitrogen rates with highest observed plant heights seen in the 50 lbs N ac^{-1} at 163 cm and was statistically similar to the 200 lbs N ac^{-1} treatment. Similarly, plant widths showed no trends corresponding to increasing nitrogen rates though highest observed widths were seen at the 200 lbs N ac^{-1} treatment at 117 cm and was statistically similar to the 50 lbs N ac^{-1} treatment. Whole plant weights showed highest values in the highest three nitrogen rates within the trial. The 150 lbs N ac^{-1} treatment had the highest overall whole plant weight at 13.0 lbs and was statistically similar to the 150 and 100 lbs N ac^{-1} treatments at 12.4 and 12.2 lbs per plant respectively.

Table 4. Hemp whole plant weight, height, and width, Alburgh, VT, 2022.

Treatment lbs N ac^{-1}	Plant height cm	Plant width cm	Plant weight lbs plant^{-1}
0	135 b†	86.0 c	3.10 b
50	**163 a**	114 ab	6.10 b
100	138 b	85.0 c	12.2 a
150	144 b	89.0 bc	**13.0 a**
200	148 ab	**117 a**	12.4 a
LSD (0.10) ‡	16.3	26.6	3.05
Trial Mean	145	98.0	9.40

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

‡LSD – Least significant difference at p=0.10.

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 the 100-200 lbs N ac^{-1} treatments and were significantly higher than the control treatment.

Table 5. Hemp plant growth metrics, Alburgh, VT, 2022.

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	0.9	c	28.2	b	1.65	c	**58**	**a**	0.825	b	27.0	bc	**2.27**	**a**	1.04	bc
50	2.3	b	**35.7**	**a**	2.75	b	43.9	b	1.18	b	21.7	c	1.26	b	0.67	c
100	**3.8**	**a**	31.1	ab	**4.25**	**a**	35.5	b	4.15	a	33.4	ab	1.15	b	1.08	b
150	3.7	ab	28.3	ab	**4.25**	**a**	32.9	b	**5.03**	**a**	38.8	a	1.18	b	1.38	ab
200	3.4	ab	26.7	b	4.23	a	34.2	b	4.78	a	**39.1**	**a**	1.30	b	**1.50**	**a**
LSD (0.10)	1.37		7.53		1.07		12.57		1.06		7.88		0.706		0.377	
Trial Mean	2.80		30.0		3.43		40.9		3.19		32.0		1.43		1.13	

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

‡LSD – Least significant difference at p=0.10.

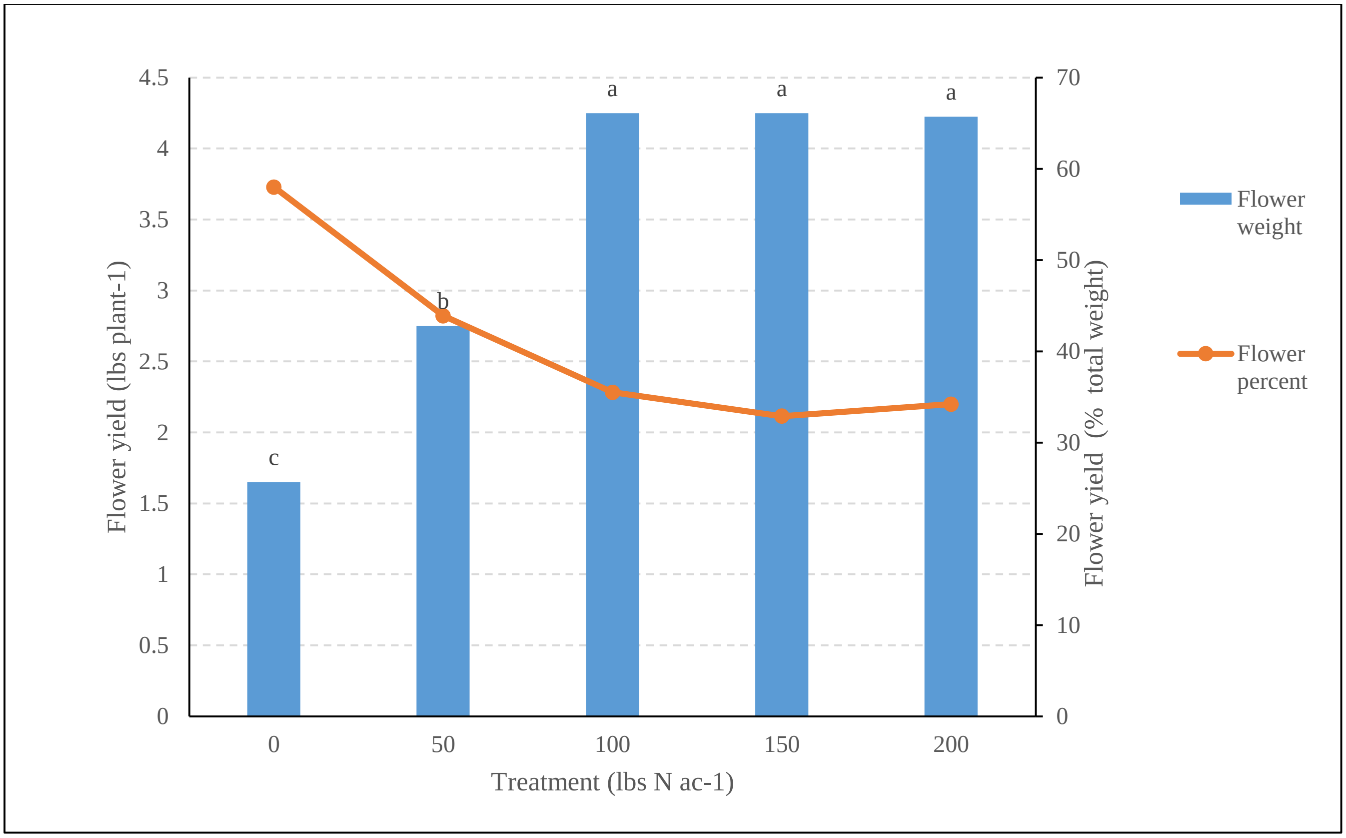

Figure 1. Hemp flower yields Alburgh, VT, 2022.

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 and dry matter yields appeared to be impacted by nitrogen rates. Overall, the lowest dry matter was observed in the 200 lbs N ac^{-1} treatment at 19.6% and was statistically similar to the 100 and 150 lbs N ac^{-1} treatments and 22.4 and 23.4% respectively. Similarly, the three highest yields were observed across the 100-200 lbs N ac^{-1} treatments, however the greatest observed yield was seen at 150 lbs N ac^{-1} at 1731 lbs ac^{-1}, though this treatment also showed significantly higher yield losses through unmarketable flower at 104 lbs ac^{-1} of floral material. 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, 2022.

Treatment	Flower dry matter		Unmarketable wet flower yield		Dry matter flower yield €	
lbs N ac^{-1}	%		lbs ac^{-1}		lbs ac^{-1}	
0	25.0	b†	**10.6**	**a**	700	c
50	26.3	b	22.1	a	1223	b
100	22.4	ab	10.8	a	1655	a
150	23.4	ab	104.1	b	**1731**	**a**
200	**19.6**	**a**	29.8	ab	1413	ab
LSD (0.10) ‡	3.95		77.1		398	
Trial Mean	23.3		35.5		1345	

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

‡LSD – Least significant difference at p=0.10.

€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 potassium, phosphorus, calcium, magnesium, sulfur, manganese, boron, and zinc. 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, 2022.

Treatment	Nitrogen	Potassium		Phosphorus		Calcium		Magnesium		Sulfur		Carbon
lbs N ac^{-1}	%	%		%		%		%		%		%
0	2.32	1.79	b†	0.761	ab	2.17	ab	0.260	ab	0.225	ab	21.8
50	2.09	1.96	ab	0.610	cd	2.02	ab	0.218	bc	0.230	ab	25.3
100	2.21	1.86	ab	**0.844**	**a**	2.04	ab	0.258	ab	0.220	ab	22.4
150	2.51	1.82	ab	0.510	d	1.72	b	0.212	c	0.203	b	20.3
200	2.69	**2.07**	**a**	0.674	bc	**2.36**	**a**	**0.276**	**a**	0.265	a	19.3
LSD (0.10) ‡	NS¥	0.273		0.147		0.538		0.044		0.049		NS
Trial Mean	2.36	1.90		0.680		2.06		0.245		0.229		21.8

†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.

Table 7 cont. Hemp whole plant nutrient analysis, Alburgh, VT, 2022.

Treatment lbs N ac^{-1}	Manganese ppm		Iron ppm	Copper ppm	Boron ppm		Zinc ppm	
0	104	b	231	14.4	28.9	ab	34.7	b
50	90.5	b	205	13.2	23.6	b	35.2	b
100	78.0	b	214	16.7	25.9	ab	35.2	b
150	172	a	218	12.8	24.5	ab	38.2	ab
200	**173**	**a**	285	15.9	**29.7**	**a**	**47.4**	**a**
LSD (0.10) ‡	62.2		NS ¥	NS	6.05		9.58	
Trial Mean	123.3		231	14.6	26.5		38.1	

†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). Concentrations of cannabinoids were largely not impacted by nitrogen rates with the exception of CBD in which the 100 lb N ac^{-1} was significantly higher than all other rates at 0.123%. This had little impact on overall concentrations of total potential CBD with no significant differences observed in treatments. Across the trial, total potential CBD averages 8.39% with total potential THC averages reaching 0.338%.

Table 8. Hemp flower cannabinoid concentrations. Alburgh, VT, 2022.

Treatment	CBDa	CBD		THCa	D9-THC	Total potential CBD ŧ	Total potential THC‡	Total cannabinoids
lbs N ac^{-1}	%	%		%	%	%	%	%
0	7.88	0.040	b§	0.308	0.020	6.95	0.290	8.50
50	9.36	0.063	b	0.368	0.008	8.27	0.330	10.0
100	10.8	**0.123**	**a**	0.418	0.000	9.57	0.368	11.7
150	10.4	0.048	b	0.403	0.018	9.17	0.373	11.2
200	9.07	0.043	b	0.348	0.020	8.00	0.330	9.70
LSD (0.10) ¥	NS €	0.059		NS	NS	NS	NS	NS
Trial Mean	9.49	0.063		0.369	0.013	8.39	0.338	10.2

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.

¥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 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, 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.

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.

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.

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, 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 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.

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