

# INDUSTRIAL HEMP RESPONSE TO NITROGEN APPLICATIONS IN MISSOURI

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## ABSTRACT

Industrial hemp (*Cannabis sativa* L.) is gaining attention as a multipurpose crop for fiber, grain, and cannabinoids, but region-specific guidelines on nitrogen (N) management are limited. Field experiments were conducted at two locations (Albany, Novelty) in northern Missouri in 2024 & 2025 to evaluate the effects of N applications on industrial hemp production. Experiments were laid in a randomized complete block design with a split-plot arrangement and four replications. Main plots included four varieties (Futura 83, Orion 33, Puma, and Yuma), and subplots consisted of five N rates (0, 40, 80, 120, and 160 lb N ac<sup>-1</sup>). In 2024, the plant population at Novelty was highest in the control and decreased with increasing N, while in 2025, N did not affect population. Puma and Yuma consistently produced the tallest plants and thickest stems across both locations, with plant height and stem diameter increasing with N rate up to 160 lb N ac<sup>-1</sup> at Novelty (2024-2025) and up to 80 lb N ac<sup>-1</sup> at Albany in 2025. At Novelty (2024), maximum biomass was recorded at 80-120 lb N ac<sup>-1</sup>. In 2025, biomass increased to 160 lb N ac<sup>-1</sup> at Novelty. At Albany (2025), biomass yield increased from 40-160 lb N ac<sup>-1</sup> but was comparable. Puma constantly produced the highest biomass yield, followed by Yuma. At Novelty, grain yield increased with N up to 120 lb N ac<sup>-1</sup> in 2024 and 160 lb N ac<sup>-1</sup> in 2025. At Albany, grain yield was maximum at 160 lb N ac<sup>-1</sup>. The linear-plateau model fit the 2024 Novelty data best ( $R^2 = 0.59$ ), whereas at Albany, yield showed no response to N ( $R^2 < 0.01$ ). This research emphasizes the importance of optimizing nitrogen (N) and variety selection to maximize yield potential under variable soil and climatic conditions in Missouri, while underscoring the need for site-specific nutrient management approaches to ensure sustainable hemp production.

## INTRODUCTION

Nitrogen (N) management in industrial hemp (*Cannabis sativa* L.) production remains difficult due to variations in soil properties, climatic conditions, and cultivar-specific nutrient demands. Nitrogen is essential for chlorophyll synthesis, enzymatic activity, and photosynthetic activity, and influences crop growth and yield (Campiglia et al., 2017). Previous studies have reported that N supply strongly affects hemp productivity (Aubin et al., 2015; Yang et al., 2021; Kaur et al., 2023). The optimal N rate varies significantly across different environments. Campiglia et al. (2017) observed a 35-40% increase in fiber yield when N rates increased from 0 to 110 lb ac<sup>-1</sup> under Mediterranean conditions, while Aubin et al. (2020) reported diminishing returns beyond 90 lb N ac<sup>-1</sup> for Canadian dual-purpose hemp cultivars.

Excessive N application usually delays flowering, enhances vegetative growth, and reduces fiber quality (Prade et al., 2011; Yang et al., 2021). In contrast, inadequate N supply limits canopy development and reduces grain and biomass accumulation.

Papastylianou et al. (2023) reported that AE and apparent N recovery efficiency in dual-purpose hemp increased up to 110 lb N ac<sup>-1</sup> but declined at higher rates due to reduced recovery and excess nitrate accumulation. Similarly, Vera et al. (2010) and Aubin et al. (2015) reported yield plateaus and declining efficiency beyond 110-135 lb N ac<sup>-1</sup>.

These findings highlight the complex interaction between variety, N, and environmental factors, suggesting that uniform fertilizer recommendations are impractical. Region-specific studies are needed to identify the agronomic optimum nitrogen rate (AONR) for maximizing yield and NUE under local soil and climatic conditions. Therefore, this study was conducted to evaluate the response of industrial hemp to five N rates across two locations in Missouri, having different soil properties and rainfall patterns, to determine optimum N rates and assess varietal responses under Missouri's production systems.

## MATERIALS AND METHODS

Field experiments were conducted in 2024 and 2025 at the University of Missouri's Lee Greenley Jr. Memorial Research Farm near Novelty, MO, and the Hundley-Whaley Extension and Education Center near Albany, MO. The dominant soil series at Novelty and Albany was Leonard silt loam and Grundy silt loam, respectively. The Leonard silt loam is a poorly drained soil with a slope ranging from 1% to 6%. The Grundy silt loam is somewhat poorly drained, with high runoff properties, and has a slope ranging from 2% to 5%.

The experiments were designed as a randomized complete block with a split-plot arrangement and four replications. The main plots were four industrial hemp varieties, including 'Puma', 'Yuma', 'Orion 33', and 'Futura 83'. The subplots included N application rates (0, 40, 80, 120, and 160 lb N ac<sup>-1</sup>) applied using SuperU<sup>®</sup> fertilizer source. The sub-plot size was 10 x 20 ft. Each plot had four rows of industrial hemp planted at a row spacing of 30 inches, with a seeding rate of 20 lb ac<sup>-1</sup> at Novelty and 40 lb ac<sup>-1</sup> at Albany in 2024. Seeding rate was 40 lb ac<sup>-1</sup> at both locations in 2025. Plant measurements included plant population, plant height, and stem diameter. At physiological maturity, hemp plants were hand-harvested from a 10-ft length of the second row in each subplot, and fresh biomass weights were recorded. Plants were threshed (ALMACO BT-14 belt thresher, Nevada, IA) to separate seeds from stalks. Subsamples of the stalks were air-dried to determine their moisture content and calculate the dry biomass yield. Seeds were dried, cleaned, and weighed to determine grain yield. The grain yields were adjusted to 8% moisture before data analysis. The data were analyzed using the GLIMMIX procedure in SAS, and means were compared at a significance level of  $p = 0.05$ . Nonlinear regression was performed using linear and Quadratic plateau models to fit grain yield responses to N using RStudio v4.5.1.

## RESULTS AND DISCUSSION

**Plant Population:** In 2024 at Novelty, control (0 lb N ac<sup>-1</sup>) produced the highest population, statistically comparable to 40 and 80 lb N ac<sup>-1</sup>. Futura 83 had the highest plant population, which was significantly higher than Yuma and Puma (Table 1). At Albany, plant population was affected only by variety in 2024, and Futura 83 had the

highest plant population among all other varieties (Table 2). In 2025, N did not affect plant population at either location. , 'Puma' had the best establishment of other varieties at Novelty (Table 3). The plant population did not vary significantly by variety or N at Albany in 2025 (Table 4).

**Plant Height:** In 2024 and 2025, Puma and Yuma varieties produced the tallest plants at Novelty, whereas Puma reached to maximum height at Albany in both years. Plant height increased with N rate and was maximum at 120 lb N ac<sup>-1</sup> at Novelty in 2024. Maximum height was observed at 160 lb N ac<sup>-1</sup> at Novelty and 80 lb N ac<sup>-1</sup> (statistically similar to 120 & 160 lb N ac<sup>-1</sup>) at Albany in 2025.

**Stem Diameter:** Yuma produced the thickest stems at Novelty, while Puma and Yuma had bigger stem diameters at Albany in 2024 and 2025 (Tables 1-4). A significant variety x N interaction was observed at Novelty in 2024, where 'Puma' and 'Yuma' showed maximum stem thickness at 120-160 lb N ac<sup>-1</sup> (data not presented). N application increased stem thickness up to 160 lb N ac<sup>-1</sup> at Novelty in 2024 & 2025 (Table 1 & 3) and 80 lb N ac<sup>-1</sup> at Albany in 2025 (Table 4).

**Biomass and Grain Yield:** In 2024 at Novelty, the highest biomass yield was recorded at 120 lb N ac<sup>-1</sup>, statistically similar to 80 lb N ac<sup>-1</sup>, while 160 lb N ac<sup>-1</sup> reduced biomass yield. Puma produced the highest biomass at Novelty, about 50% greater than Futura 83 and Orion 33 in 2024. At Albany, Puma, Yuma, and Futura 83 had similar biomass yields, with 'Orion 33' yielding about 50% less biomass in 2024. In 2025, variety and N significantly influenced biomass yield at both locations. At Novelty, Puma and Yuma produced the highest biomass yield, and the highest biomass yield was recorded at 160 lb N ac<sup>-1</sup> (Table 3). At Albany in 2025, maximum biomass was recorded at 120 and 160 lb N ac<sup>-1</sup>, which was greater than the non-treated control but statistically comparable to the 40 and 80 lb N ac<sup>-1</sup>. Puma again outperformed all varieties in biomass production by giving 2–3 times more biomass yield than 'Futura 83' and 'Orion 33' (Table 4).

In 2024, grain yield increased with N up to 120 lb ac<sup>-1</sup> at Novelty (Table 1). At Albany, Futura 83 had higher grain yield, nearly double to Orion 33 in 2024 (Table 2). In 2024, Linear Plateau (LP) provided a good fit ( $R^2 = 0.59$ ) compared to QP ( $R^2 = 0.58$ ), defining the agronomic optimum nitrogen rate (AONR) near 120 lb N ac<sup>-1</sup> at Novelty. The yield at AONR was 1,621 lb ac<sup>-1</sup> at Novelty in 2024. Fiber-type varieties ('Puma' and 'Yuma') did not produce grains due to late maturity in Missouri. In contrast, grain yield showed no significant response to N fertilization at Albany (Figure 1b). Both the LP and QP models exhibited very low coefficients of determination ( $R^2 < 0.01$ ), suggesting that the N rate had a minimal influence on grain yield.

In 2025, grain yield was significantly affected by N at Novelty (Table 3). Yield increased with N rate, reaching a maximum of 704 lb ac<sup>-1</sup> at 160 lb N ac<sup>-1</sup>, about five times higher than the control and double to the yield obtained at 80-120 lb N ac<sup>-1</sup>.

Models did not converge for the 2025 data.

**Table 1.** Main effects of variety and nitrogen rate on plant population, height, stem diameter, aboveground biomass, and grain yield at Novelty in 2024. Means within a column followed by different letters are significantly different at  $\alpha = 0.05$ . Underlined p-values indicate significant fixed effects.

Variety	N rate	Plant Population	Plant height	Stem diameter	Aboveground Biomass	Grain yield
	lb ac <sup>-1</sup>	Plants ac <sup>-1</sup>	in	mm	lb ac <sup>-1</sup>	lb ac <sup>-1</sup>
Futura 83		117394 a	37 b	8.5 c	6134 c	1316
Orion 33		109989 a	32 c	7.6 c	4855 d	1153
Puma		62257 b	52 a	15.7 b	10421 a	-
Yuma		40075 c	51 a	17.4 a	9070 b	-
	0	96304 a	39 c	9.5 d	5402 c	723 c
	40	89329 ab	42 b	11.9 c	7768 b	994 bc
	80	84670 ab	44 ab	12.7 bc	8056 ab	1212 b
	120	75413 bc	45 a	13.3 b	9221 a	1623 a
	160	66429 c	44 a	14.6 a	7655 b	1619 a
Source of Variation		-----P-values-----				
Variety		<u>&lt;.0001</u>	<u>&lt;.0001</u>	<u>&lt;.0001</u>	<u>&lt;.0001</u>	0.0910
N		<u>0.0018</u>	<u>&lt;.0001</u>	<u>&lt;.0001</u>	<u>&lt;.0001</u>	<u>&lt;.0001</u>
N*variety		<u>0.3031</u>	<u>0.6053</u>	<u>0.0494</u>	<u>0.9260</u>	<u>0.0341</u>

**Table 2.** Main effects of variety and nitrogen rate on plant population, height, stem diameter, aboveground biomass, and grain yield at Albany in 2024. Means within a column followed by different letters are significantly different at  $\alpha = 0.05$ . Underlined p-values indicate significant fixed effects.

Variety	N rate	Plant Population	Plant height	Stem diameter	Aboveground Biomass	Grain yield
	lb ac <sup>-1</sup>	Plants ac <sup>-1</sup>	in	mm	lb ac <sup>-1</sup>	lb ac <sup>-1</sup>
Futura 83		48134 a	45 c	16.2 b	8835 a	1015 a
Orion 33		37272 b	49 ab	13.4 c	5782 b	569 b
Puma		29403 bc	51 a	28.6 a	11469 a	-
Yuma		24829 c	48 bc	28.4 a	10887 a	-
	0	37026	47	21.9	9232	777
	40	37571	48	20.0	9179	739
	80	36209	49	21.6	9882	827
	120	35209	48	22.8	8142	943
	160	28533	47	21.8	9783	673
Source of Variation		-----P-values-----				
Variety		<u>&lt;.0001</u>	<u>0.001</u>	<u>&lt;.0001</u>	<u>0.0004</u>	<u>0.0004</u>
N		0.2291	0.5564	0.0521	0.8092	0.6242
N*variety		0.6659	0.3935	0.5801	0.5349	0.2970

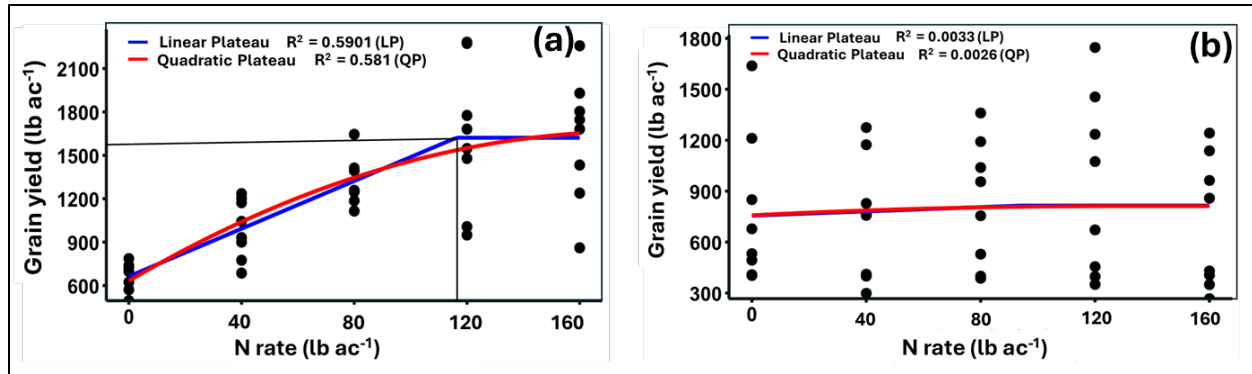
**Table 3.** Main effects of variety and nitrogen rate on plant population, height, stem diameter, aboveground biomass, and grain yield at Novelty in 2025. Means within a

column followed by different letters are significantly different at  $\alpha = 0.05$ . Underlined p-values indicate significant fixed effects.

<b>Variety</b>	<b>N rate</b>	<b>Plant Population</b>	<b>Plant height</b>	<b>Stem diameter</b>	<b>Aboveground Biomass</b>	<b>Grain yield</b>
	<b>lb ac<sup>-1</sup></b>	<b>Plants ac<sup>-1</sup></b>	<b>in</b>	<b>mm</b>	<b>lb ac<sup>-1</sup></b>	<b>lb ac<sup>-1</sup></b>
Futura 83		83417 b	76 a	6.7 bc	3698 bc	390
Orion 33		54885 c	61 b	5.1 c	2636 c	301
Puma		122839 a	84 a	8.4 ab	6791 a	-
Yuma		40293 c	78 a	10.1 a	5168 ab	-
	0	71329	53 c	4.7 c	1771 c	137 c
	40	72963	61 c	5.7 c	2359 c	168 bc
	80	71874	77 b	8.1 b	4852 b	368 b
	120	75686	82 b	8.2 b	5742 b	351 b
	160	84942	99 a	11.3 a	8143 a	704 a
Source of Variation		-----P-values-----				
Variety		<u>&lt;.0001</u>	<u>0.0007</u>	<u>&lt;.0001</u>	<u>&lt;.0001</u>	0.1741
N		0.5889	<u>&lt;.0001</u>	<u>&lt;.0001</u>	<u>&lt;.0001</u>	<u>&lt;.0001</u>
N*variety		0.1975	0.4692	0.7377	0.4547	0.7520

**Table 4.** Main effects of variety and nitrogen rate on plant population, height, stem diameter, aboveground biomass, and grain yield at Albany in 2025. Means within a column followed by different letters are significantly different at  $\alpha = 0.05$ . Underlined p-values indicate significant fixed effects.

<b>Variety</b>	<b>N rate</b>	<b>Plant Population</b>	<b>Plant height</b>	<b>Stem diameter</b>	<b>Aboveground Biomass</b>	<b>Grain yield</b>
	<b>lb ac<sup>-1</sup></b>	<b>Plants ac<sup>-1</sup></b>	<b>in</b>	<b>mm</b>	<b>lb ac<sup>-1</sup></b>	<b>lb ac<sup>-1</sup></b>
Futura 83		51375	59 c	6.7 b	3326 b	266
Orion 33		65050	55 c	5.3 b	2498 b	238
Puma		61855	96 a	11.9 a	8582 a	-
Yuma		33106	80 b	12.5 a	5042 b	-
	0	46101	48 b	6.3 b	2079 b	76
	40	49335	63 b	8.5 ab	4750 ab	214
	80	52998	87 a	10.7 a	4764 ab	242
	120	64977	85 a	10.2 a	6763 a	319
	160	50820	80 a	9.7 a	5955 a	407
Source of Variation		-----P-values-----				
Variety		0.0652	<u>&lt;.0001</u>	<u>&lt;.0001</u>	<u>0.0002</u>	0.7286
N		0.7180	<u>&lt;.0001</u>	<u>0.0042</u>	<u>0.0334</u>	0.1260
N*variety		0.9679	0.4803	0.3578	0.6216	0.9243



**Figure 1.** Relationship between nitrogen (N) rate and grain yield of industrial hemp at Novelty (a) and Albany (b) in 2024, fitted using Linear Plateau (LP) and Quadratic Plateau (QP) models.

## CONCLUSION

Our results demonstrated clear varietal and N rate differences in industrial hemp growth and yield under Missouri conditions. Nitrogen significantly enhanced plant growth up to 160 lb N ac<sup>-1</sup> at Novelty and 80-120 lb N ac<sup>-1</sup> at Albany. Nitrogen application at a rate higher than 160 lb ac<sup>-1</sup> may result in increased growth and yield at Novelty. Among the tested cultivars, Puma and Yuma consistently produced the tallest plants, thickest stems, and highest biomass, while 'Futura 83' excelled in grain yield across both locations and years. Puma and Yuma performed best for fiber and biomass production, whereas Futura 83 proved most suitable for grain yield. Adopting moderate N rates within the identified optimum range offers a balanced strategy for maximizing yield potential and nitrogen efficiency across Missouri's diverse growing environments.

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