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Biomass and Nutrient Accumulation by Dual-Purpose Hemp and Concurrent Soil Profile Water Depletion at Manhattan, KS, in 2021

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Biomass and Nutrient Accumulation by Dual-Purpose Hemp and Concurrent Soil Profile Water Depletion at Manhattan, KS, in 2021

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Summary

Hemp has garnered interest as a potential crop that is not constrained by the typical food, feed, and fuel market channels. Although hemp varieties are available for the production of either grain, fiber, or both (dual-purpose: both grain and fiber) markets, little research-based information is available on hemp growth and water use in Kansas environments. In 2019, Kansas State University researchers began conducting experiments to characterize hemp growth, nutrient uptake, and soil water depletion at three locations representing the precipitation gradient across Kansas. In 2021, one fiber and one grain variety were evaluated with and without fertilizer nitrogen. Soil water content and biomass accumulation were monitored in plots with full nitrogen fertilizer. Multiple plantings of the experiment at Haysville had to be abandoned because heavy rains soon after planting prevented successful stand establishment. The Colby experiment was abandoned because dry soils prevented successful stand establishment. Results from the experiment at Manhattan confirmed the benefit of nitrogen fertilizer, which roughly doubled total biomass yield. Although total biomass yield was similar for the two varieties, more of that yield was partitioned to grain in the grain variety, and stalks in the fiber variety. Nutrient uptake patterns were similar to those observed the previous year, with nitrogen and potassium accumulation occurring at a faster rate than dry matter, and phosphorus accumulation lagging that of dry matter. Carbon accumulation closely followed total dry matter accumulation. Hemp appeared to extract soil water to a depth of 5 feet because soil water content did not change at deeper depths. The sum of net depletion of the soil profile water plus precipitation was 14.64 inches, but some of the precipitation came in intense events causing a portion to run off. As an indeterminate species, hemp continues vegetative growth after flowering begins, increasing the probability that some grain will be produced even when resources are

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limited. Across three experiments conducted in Kansas in 2020 and 2021, stalk yields have varied by a factor of 1.5, and grain yields by a factor of 13.3. Relatively stable stalk yield coupled with more variable grain yield reveals hemp's potential ability to adjust growth to match the inconsistent growing conditions typical of Kansas.

Introduction

Although much of the interest in hemp has been focused on the high-value cannabidiol (CBD) market, varieties are available for the production of either grain, fiber, or both (dual-purpose: both grain and fiber) markets. Unlike CBD production, which typically employs horticultural production systems, grain and fiber production systems typically are more expansive and employ techniques similar to those used for many of the crops commonly produced in the Central Great Plains region. Our objective was to characterize growth, nutrient uptake, and soil water depletion for contrasting dual-purpose hemp varieties at three locations representing the precipitation gradient across Kansas. This information will support development of yield expectations and production practices in the state.

Procedures

Experiments were planted near Manhattan (39.1230, -96.6386) on a Wymore silty clay loam; Haysville (37.5188, -97.3118) on Canadian-Waldeck fine sandy loams; and Colby (39.3915, -101.0658) on a Keith silt loam. Normal precipitation for these locations is 33.0, 33.2, and 20.3 inches, respectively. The experiment at Haysville was planted on May 12, 2021, but heavy rains over the next five days crusted the soil and inhibited emergence. A second planting on June 8 also failed after a heavy rain three days later produced the same result. The experiment at Colby failed to establish sufficient stands due to lack of soil moisture and was also abandoned.

The experiment included two hemp varieties and two levels of nitrogen (N) fertilization. Varieties included one fiber type (Bialobrzeskie, International Hemp, Denver, CO) and one grain type (Henola, International Hemp, Denver, CO), although both can also be used as dual-purpose varieties. The experimental design was a randomized complete block with varieties as whole plots and N rates as subplots (none and full N fertilization). Whole plots were 30-ft wide and 55-ft long and were replicated four times.

The experimental site at Manhattan was in winter wheat the previous year and was managed without tillage. A spring-oat cover crop was planted in September of 2020 to provide uniform residue cover. Although the spring oats died over the winter, volunteer wheat survived and was terminated with glyphosate on April 12, 2021, before heading. A second application of burn-down herbicides was applied immediately before planting to terminate weeds that had emerged since the April herbicide application. Oat and volunteer wheat residue was left undisturbed in an attempt to suppress weed emergence in the hemp, but hand weeding was required to remove weeds that emerged after planting.

Plots were planted on June 4, 2021, with a Great Plains No-Till cone drill at a rate of 20 pure, live seeds (PLS)/square foot (871,200 PLS per acre) for the grain type and

30 pure, live seeds (PLS)/square foot (1,306,800 PLS per acre) for the fiber type. Row spacing was 7.5 inches. The different seeding rates correspond to recommendations for grain and fiber production systems, respectively (Williams and Mundell, 2018). Seed was placed into moist soil at a depth of 0.75 inches. Nitrogen and phosphorus fertilizers were applied to the soil surface on June 14, soon after emergence, to avoid reduction in hemp emergence observed in previous years when fertilizers were surface-applied before planting (Roozeboom et al., 2021). Fertilizer applications were made with a Gandy (Owatonna, MN) turf, drop spreader to achieve uniform distribution of the target rates. Nitrogen was applied to the full-rate plots at 130 lb/acre as dry urea fertilizer (46-0-0), and phosphorus was applied at a rate of 60 lb P_2O_5/acre as triple super phosphate (TSP, 0-45-0).

Plant density and harvest data were collected from a 10-ft length of four, bordered rows (25 ft^2) in each plot. Emerged plants were counted in late June and again at harvest. Plant survival (%) was calculated as (harvest plant density/June plant density) × 100. Plant height was determined during the final days of grain fill after vegetative growth had ceased. Harvest consisted of hand cutting plants at ground level from the entire 25-ft^2 sample area within each plot. The entire sample was dried at 140°F for 7 days. After drying, total biomass weight was determined, plants were stripped of their grain, and the stalks were weighed. The grain sample was passed through a series of screens and then passed through a seed blower for a final cleaning before the grain was weighed to determine grain yield. Weight of flower parts was calculated by subtracting grain + stalk weight from total biomass. The mass of 300 seeds was determined to facilitate calculation of harvested seed size (seeds/lb).

Soil water content was measured only in subplots that received full N fertilizer. Measurements began after emergence (11 days after planting) and every 5 to 14 days thereafter, with the last date coinciding with grain harvest. This resulted in nine sampling dates during the 2021 growing season. Soil water content was measured by neutron thermalization with a 503 DR Hydroprobe Moisture Gauge (CPN International, Inc., Martinez, CA) using a count duration of 16 seconds. Access tubes of standard type 6061-T6 aluminum tubing (o.d. 1⅝ inch) 10 feet in length were installed in the field plots to a depth of 9.5 feet. Starting at a depth of 6 inches below the soil surface, water content was measured in 1-foot increments to 8.5 feet. Field calibrations for the neutron probe were used to calculate volumetric water content.

Biomass samples were collected from the same plots whenever soil water content was measured. All above-ground material was clipped from a sample area of 9.4 $feet^2$. Samples were dried at 140°F to determine dry matter concentration, which was used along with the sample area to convert mass of fresh biomass to mass of dry biomass per acre. Samples were analyzed for nutrient concentration at the Kansas State University Department of Agronomy Soil Testing Laboratory. Nutrient accumulation at each sample date was calculated as the product of dry biomass and nutrient concentration. Sigmoidal models were fit to the observed biomass and nutrient data to illustrate seasonal biomass and nutrient accumulation.

Data were subjected to analysis of variance using the SAS GLIMMIX procedure to determine least square means and mean separations for each response variable at α =

0.05. Repeated measures of analysis of variance were used to compare soil moisture at different dates within each depth.

Results

Growing Season Weather

Although conditions were generally favorable for hemp growth, temperature extremes and uneven rainfall distribution likely adversely affected vegetative growth in June and seed fill in August (Figure 1). Growing degree day (GDD) accumulation in 2021 exceeded Normal, especially in June and again late in the season (Figure 2), but only about 4,000 GDD were required to reach harvest maturity compared to about 4,500 GDD in 2020 (Roozeboom et al., 2021). Maximum temperatures exceeded 100°F for a few days in mid-June and again in late August (Figure 1). In both cases, warm temperatures coincided with periods of limited rainfall. May precipitation was greater than Normal, but only 0.03 in. of precipitation was received during the first 23 days of June. Consequently, hemp emergence and early growth depended almost entirely on stored soil moisture. Although July precipitation of 4.89 in. was greater than Normal (4.20 in.), 3.86 in. was associated with one rainfall event, likely resulting in substantial runoff. August rainfall (3.1 in.) was slightly less than Normal (3.9 in.). Minimum daily soil temperatures at the 2-in. depth exceeded 60°F during the entire growing season and were less than 70°F for only the first two days after planting (Figure 2).

Plant Establishment, Survival, and Height

Variety was the only factor to affect plant density, which is expected given that the fiber-type variety (Bialobrzeskie) was seeded at a rate 50% greater than that of the grain-type variety (Henola) in accordance with recommendations for each production system (Table 1). Plant survival was near 100% for both varieties at both N rates. Late-emerging plants likely contributed little to stalk or grain yield. Although Bialobrzeskie was taller than Henola, the two varieties responded differently to addition of N. Both varieties were similar in height with no N. Bialobrzeskie was 48% taller with N fertilizer, whereas Henola was only 26% taller with N fertilizer.

Yield and Yield Fractions

Variety and N fertilizer affected the different yield fractions differently (Table 2). Total biomass production was similar for both varieties at either level of N fertilization, but doubled with N fertilizer. In line with each variety's market type, Bialobrzeskie produced more stalks, and Henola produced more grain and floral structures. Fertilization with N resulted in significantly more total biomass, stalks, flower parts, and grain, which had larger seed.

Biomass Accumulation and Soil Water Depletion

Given the lack of difference in total biomass at harvest, data from plots of both varieties that received N fertilizer were pooled to characterize dry biomass and nutrient accumulation by hemp in 2021 (Figures 3 to 8). Although the rapid growth period started at about 1,500 GDD, as it had the previous year (Roozeboom et al., 2021), its duration was shorter, lasting only until about 2,400 GDD compared to 3,000 GDD in 2020. Half of the total dry biomass was accumulated by 1,960 GDD in 2021 compared to

2,200 in 2020. In 2021, 90% of total dry matter had accumulated by 2550 GDD (early August) compared to 3,320 GDD (mid-August) in 2020. Total biomass accumulation totaled about 4,200 lb/acre at harvest. That total was partitioned with 56% as stalks, 19% as floral structures, and 25% as grain.

Macronutrient concentrations were generally high early in the season and became diluted as the plants accumulated carbon (Figures 4 and 5). Phosphorus concentrations did not follow this pattern as closely and varied little after a decline after the first sample date when plants were still seedlings. Both nitrogen and potassium followed a reverse sigmoid pattern, starting at a plateau over the first three to five sample dates, declining rapidly during the period of rapid dry matter accumulation in the middle of the growing season, and reaching a lower plateau during seed filling.

Macronutrient accumulation (Figures 6 to 10) exhibited similar patterns to those reported for biomass and for macronutrient accumulation in the previous year's experiments (Roozeboom et al., 2021). Carbon accumulation (Figure 6) closely followed biomass (Figures 3 and 10). Nitrogen (Figure 7) and potassium (Figure 9) had nearly identical patterns with both accumulating more rapidly than dry matter (Figure 10). Phosphorus accumulation continued into seed filling (Figure 8) and lagged dry matter accumulation (Figure 10). These patterns of nutrient accumulation are similar to those reported for both corn (Abendroth et al., 2011) and sorghum (Roozeboom and Prasad, 2016).

Soil profile water content generally declined as the 2021 growing season progressed (Figures 1 and 11). Exceptions occurred in the upper part of the profile in late June and mid-July after large precipitation events. Soil moisture content declined rapidly in late July when the hemp plants had established nearly full canopy, and precipitation totaled only 0.39 in. over 22 days. Hemp appeared to extract soil water to a depth of 5 feet, with no difference in soil water content at deeper depths on any sample date.

The net depletion of soil profile water from the first to last sample dates was 6.14 inches with 8.5 inches of precipitation during the same period. Some fraction of the precipitation that came in large and/or intense events likely ran off and failed to enter the profile. As a result, summing soil water depletion and precipitation would overestimate water use by the hemp (i.e., transpiration from the plants plus evaporation from the soil surface).

Combining the 2021 results with those from previous years begins to create a picture of hemp productivity and soil water extraction in a range of environments in Kansas. As with all crops, hemp biomass, stalk, and grain yields varied in response to the interaction of temperatures, water supply, and nutrient availability. Although greater biomass production generally resulted in greater grain yield, harvest index (grain yield/total biomass yield) varied between 0.07 and 0.40 depending on variety, environmental conditions, and N fertilizer. The lowest harvest index values occurred when no N fertilizer was applied. When N fertilizer was applied to grain-type varieties, harvest index values fell between 0.29 and 0.43, with the larger values associated with more favorable growing conditions and larger grain yields. Similar to most crops (Kemanian et al., 2007), as temperatures, water, and nutrients became more limiting, a smaller fraction of hemp's total production was allocated to the grain, reducing harvest index. The fact that hemp is an indeterminate species, with continued vegetative growth after flowering begins, increases the probability that some grain will be produced even when resources are limited, especially in situations when a water limitation is relieved by precipitation after flowering (Spaeth et al., 1984; Vega et al., 2001). Because stalks are generally produced before grain, stalk yield was somewhat less sensitive to resource availability. Across the three experiments conducted in Kansas in 2020 and 2021, stalk yields varied by a factor of 1.5, and grain yields varied by a factor of 13.3. Results from additional environments are needed to obtain a complete picture of how hemp responds in Kansas growing conditions.

Acknowledgments

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Table 1. Plant density, survival, and height for two hemp varieties grown with two rates of nitrogen fertilizer at Manhattan, KS, in 2021

Factor	Level	Plant density June		Plant density Harvest		Plant survival†	Height	
		------------ plants/acre ------------				--- % ---	--- inches ---	
Variety	Type							
Bialobrzeskie	Fiber	328,225	a‡	330,403	a	101	62	a
Henola	Grain	222,592	b	228,009	b	104	53	b
Nitrogen fertilizer	lb/acre							
None	0	277,695		279,002		103	49	b
Full	130	273,121		280,309		103	67	a
Interaction								
Variety	lb N/acre							
Bialobrzeskie	0	342,817		334,977		99	50	c
Bialobrzeskie	130	313,632		325,829		104	74	a
Henola	0	212,573		223,027		107	47	c
Henola	130	232,611		234,789		102	59	b

† Calculated as (Harvest plant density/June plant density) × 100.
‡ Values within each set of comparisons within a column followed by the same letter are not different at $\alpha = 0.05$. If no letters follow a set of means, the P-value was > 0.05 for that factor or interaction.

Table 2. Biomass fraction yield and seed size of two hemp varieties grown with two rates of nitrogen fertilizer at Manhattan, KS, in 2021

Factor	Level	Total biomass	Stalks	Flower parts	Grain	Seed size
		------ lb/acre	------	------	------	- seeds/lb -
Variety	Type					
Bialobrzeskie	Fiber	3,383	2,091 a†	603 b	689 b	45,747
Henola	Grain	3,404	1,717 b	708 a	980 a	46,965
Nitrogen fertilizer	lb/acre					
None	0	2,281 b	1,277 b	456 b	548 b	48,034 a
Full	130	4,506 a	2,531 a	855 a	1,121 a	44,678 b
Interaction						
Variety	lb N/acre					
Bialobrzeskie	0	2,290	1,421	428	442	48,306
Bialobrzeskie	130	4,475	2,761	779	936	43,188
Henola	0	2,271	1,133	483	655	47,762
Henola	130	4,538	2,300	932	1,306	46,167

† Values within a column followed by the same letter are not different at $\alpha = 0.05$.
If no letters follow a set of means, the *P*-value was > 0.05 for that factor or interaction.

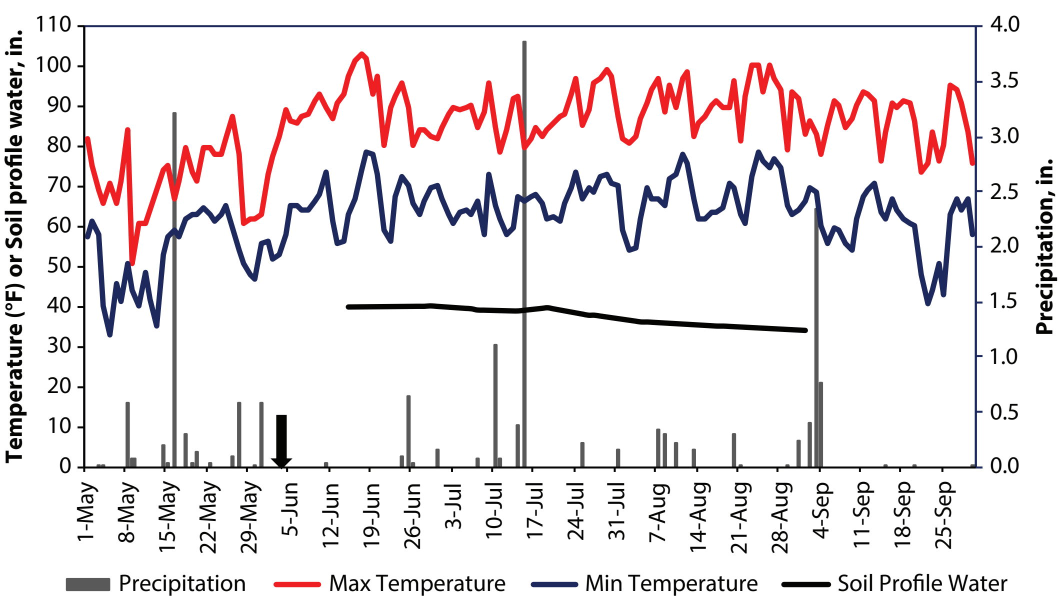

Figure 1. Daily maximum and minimum temperatures, precipitation, and soil profile water content to a depth of 9 feet during the industrial hemp (*Cannabis sativa*) 2021 growing season at Manhattan, KS. Planting date is indicated by the arrow. Temperature and precipitation data were obtained from the Kansas State University Mesonet weather station located on-site (mesonet.k-state.edu).

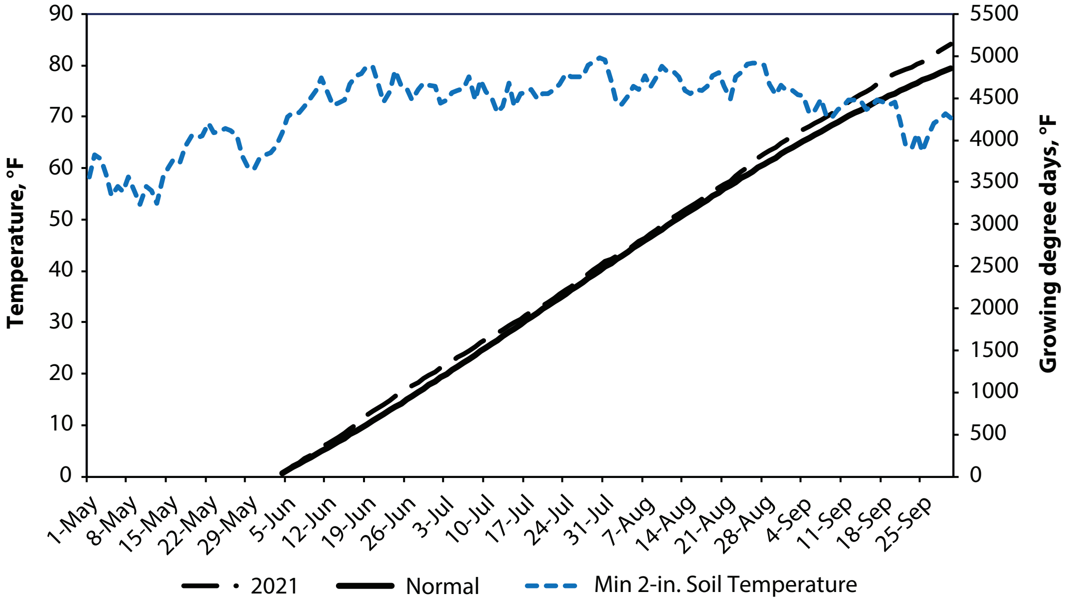

Figure 2. Normal (1980-2010) and 2021 growing degree day accumulation at Manhattan, KS. Growing degree days calculated as average daily temperature minus 33.8°F, summed from 2021 planting date.

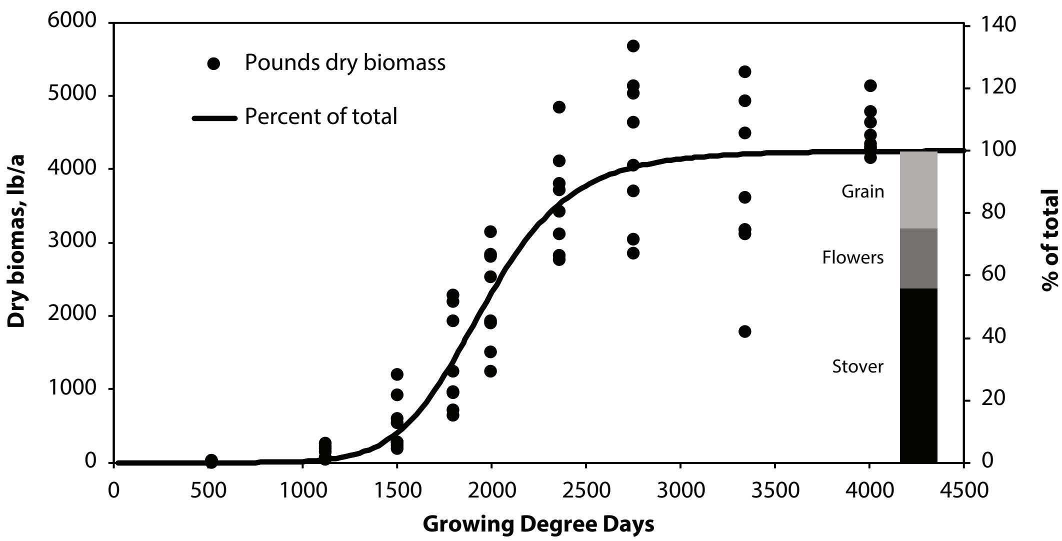

Figure 3. Dry biomass accumulation and partitioning to harvest fractions for hemp at Manhattan, KS, in 2021. The sigmoidal model illustrating accumulation as percent of total assumes no late-season losses.

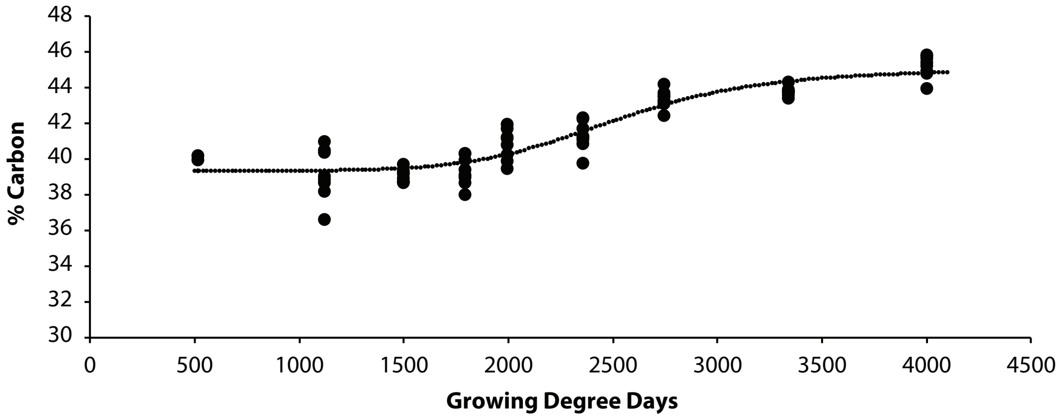

Figure 4. Carbon concentration of hemp dry biomass from seedling stage through harvest at Manhattan, KS, in 2021.

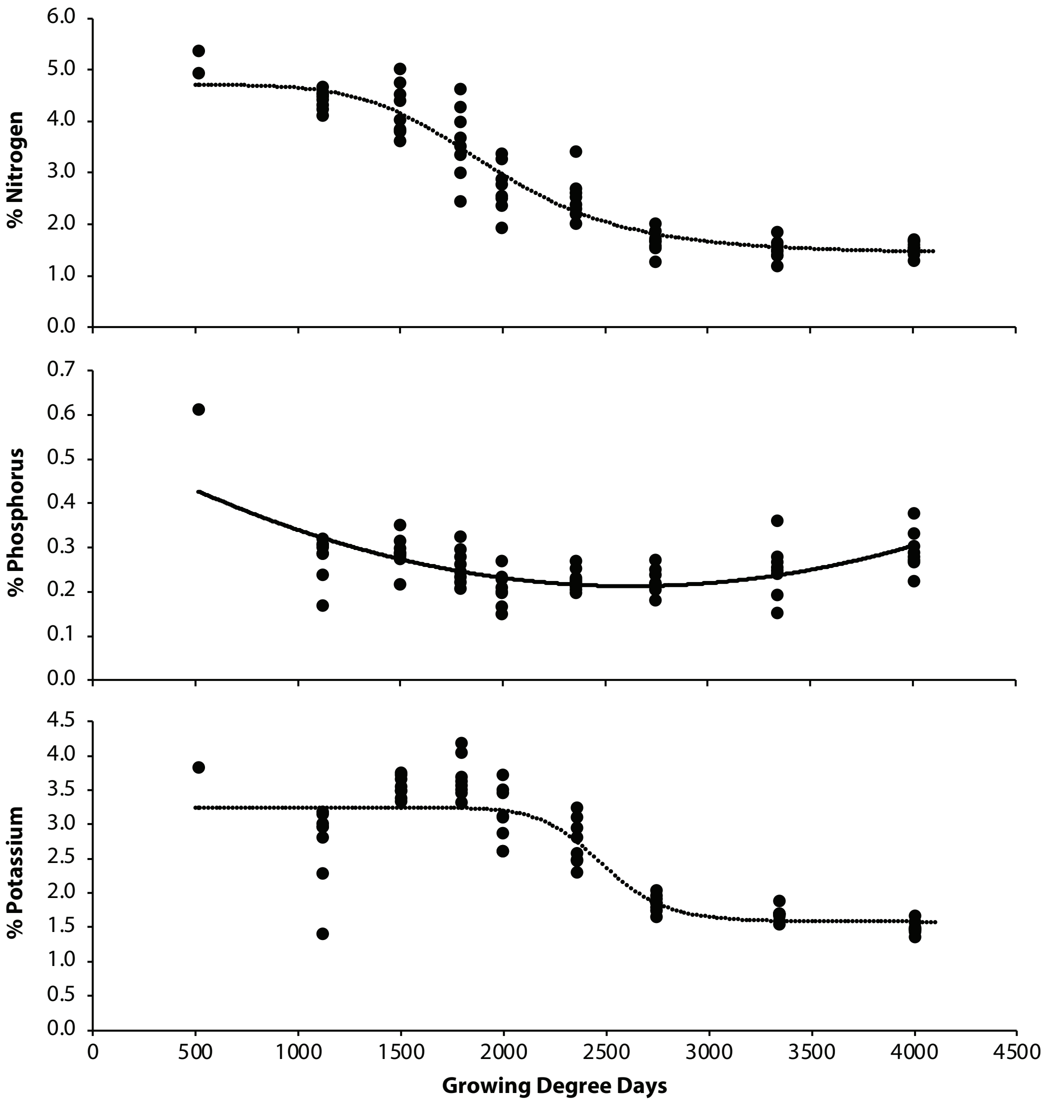

Figure 5. Macronutrient concentration of hemp dry biomass from seedling stage through harvest at Manhattan, KS, in 2021.

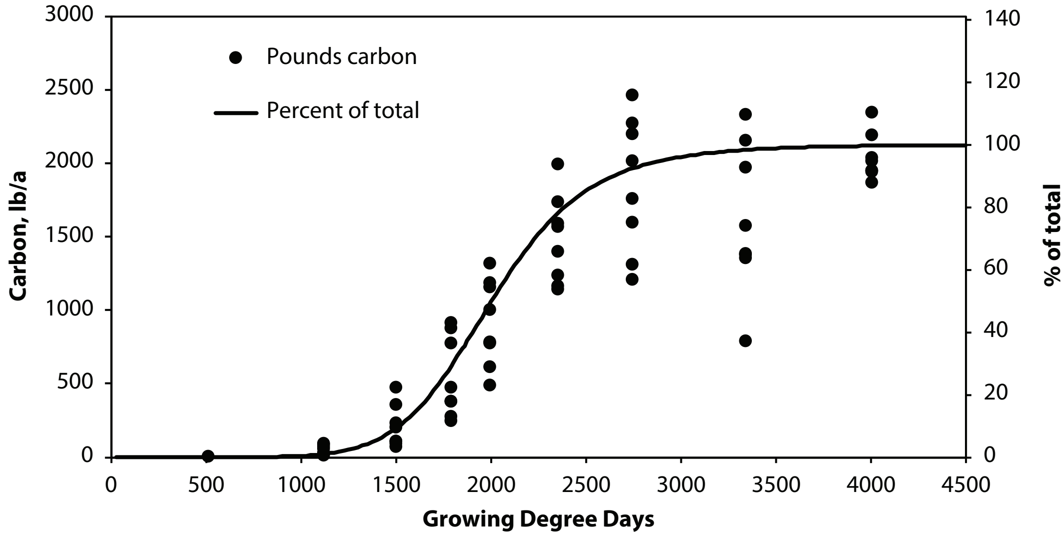

Figure 6. Carbon accumulation of hemp at Manhattan, KS, in 2021. The sigmoidal model illustrating accumulation as percent of total assumes no late-season losses.

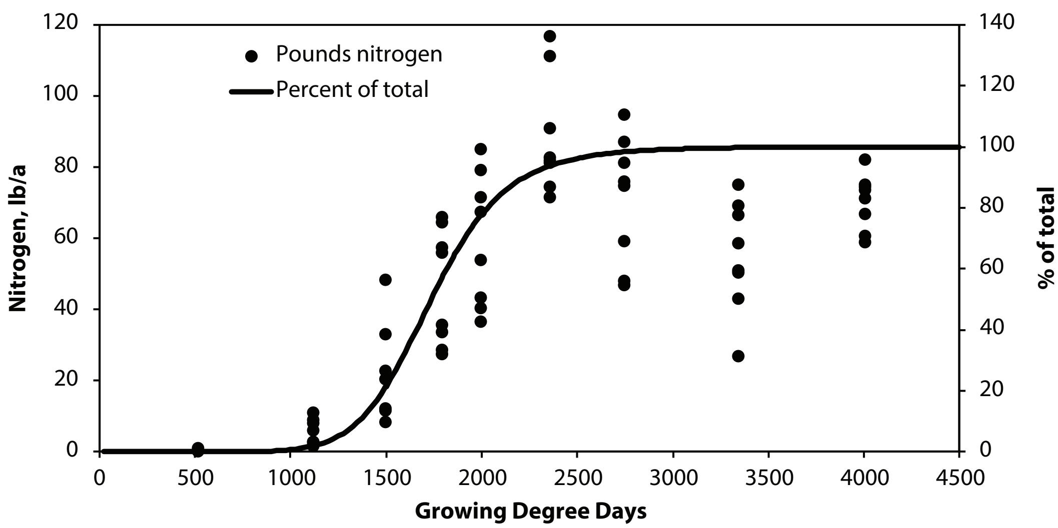

Figure 7. Nitrogen accumulation of hemp at Manhattan, KS, in 2021. The sigmoidal model illustrating accumulation as percent of total assumes no late-season losses.

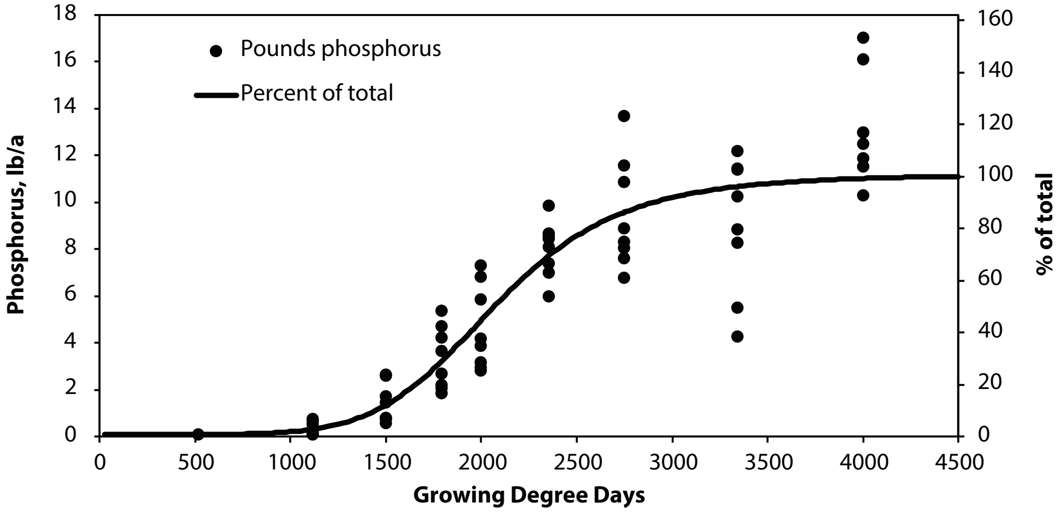

Figure 8. Phosphorus accumulation of hemp at Manhattan, KS, in 2021. The sigmoidal model illustrating accumulation as percent of total assumes no late-season losses.

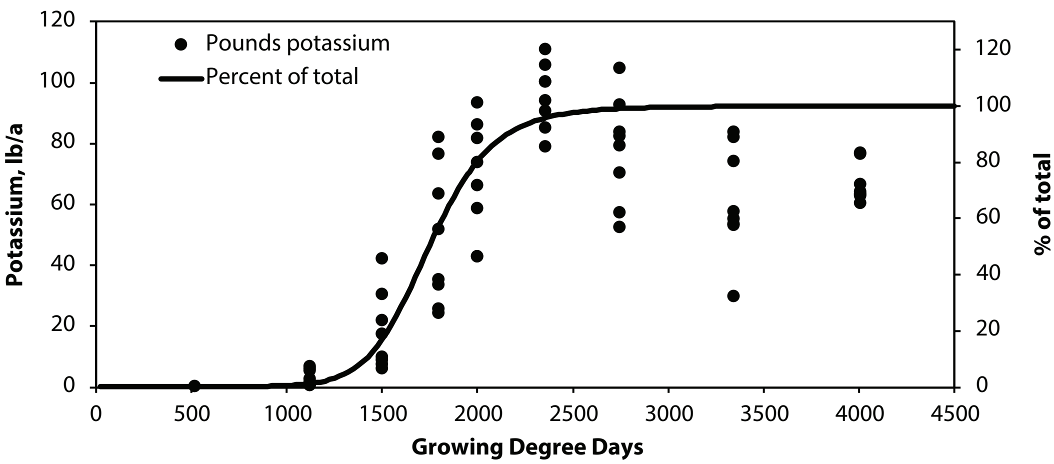

Figure 9. Potassium accumulation of hemp at Manhattan, KS, in 2021. The sigmoidal model illustrating accumulation as percent of total assumes no late-season losses.

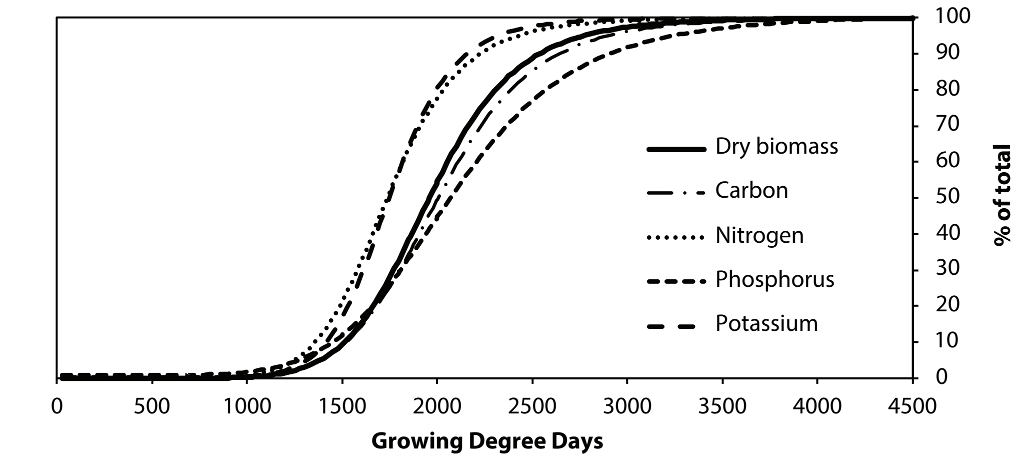

Figure 10. Dry biomass and macronutrient accumulation of hemp at Manhattan, KS, in 2021.

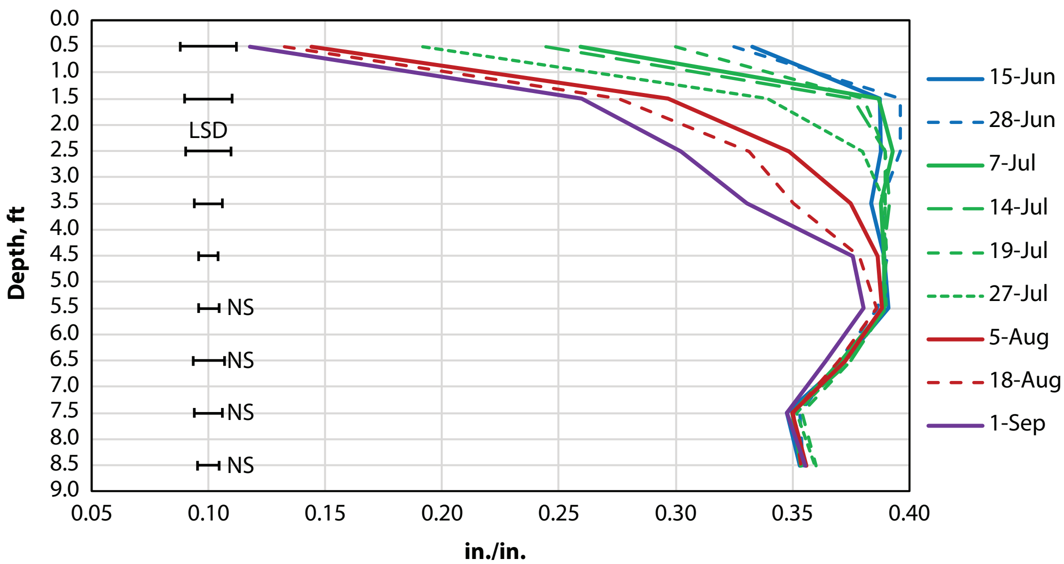

Figure 11. Volumetric water content (in./in.) at nine depths in the soil profile at nine dates during the hemp growing season at Manhattan, KS, in 2021. The LSD bars indicate least significant difference in soil water content at each depth; NS indicates no significant differences in soil water content among the sample dates at those depths.