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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 either grain, fiber, or both (dual-purpose: both grain and fiber) markets, little information is available on hemp growth and water use in Kansas environments. Experiments were conducted at three locations representing the precipitation gradient across Kansas in 2022 to characterize hemp growth, nutrient uptake, and soil water depletion. One fiber and one grain variety were evaluated with and without fertilizer nitrogen at Manhattan, Haysville, and Scandia, KS. Both non-irrigated and fully irrigated plots were evaluated at Scandia. Soil water content and biomass accumulation were monitored in plots with full nitrogen fertilizer. Results from the 2022 season confirmed the benefit of nitrogen fertilizer. Although total biomass yield was similar for the two varieties, more of that yield was partitioned to grain in the grain variety and to stalks in the fiber variety. Nutrient uptake patterns were similar to those observed for hemp in previous years and documented in other crops. Nitrogen and potassium accumulation occurred at a faster rate than dry matter, and phosphorus accumulation lagged that of dry matter. Carbon accumulation closely followed total dry matter accumulation. The sum of net depletion of the soil profile water plus precipitation averaged 17.3 inches across the three locations in 2022, but some of the precipitation came in intense events that resulted in runoff. Relatively stable stalk yield coupled with more variable grain yield reveals hemp's 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 to produce either grain, fiber, or both. Unlike CBD production, which typically employs horticultural production systems,

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grain and fiber production systems typically employ practices like those used for many crops commonly grown in the Central Great Plains. 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 conducted near Haysville (37.5188, -97.3118) on Canadian-Waldeck fine sandy loams; Manhattan (39.1230, -96.6386) on a Wymore silty clay loam; and Scandia (39.8291, -97.8392) on Crete silt and silty clay loams. Normal precipitation for these locations is 34.5, 33.4, and 29.2 inches, respectively. A winter wheat cover crop was planted in October at Haysville; November 5, 2021, at Manhattan; and on April 15, 2022, at Scandia to provide uniform residue cover and suppress weed emergence. The wheat cover crop was terminated with glyphosate in April at Haysville, at boot stage on May 13 at Manhattan, and before jointing on May 20 at Scandia. Hemp was planted directly into the cover crop at Scandia on May 19, at Manhattan on May 23, and on June 15 after cultivation with a disk and springtooth harrow at Haysville. Hand weeding was required at all locations to remove weeds that emerged after planting.

Treatments 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 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-feet wide and 30- to 40-feet long and were replicated four times. The experiment at Scandia also included none and full irrigation as whole plots, with varieties and N rates randomized as subplots and sub-subplots, respectively.

Plots were planted with a Hege 1000 or Great Plains No-Till cone drill at a rate of 20 pure, live seeds (PLS) per square foot (871,200 PLS per acre) for the grain type and 30 PLS/ft^2 (1,306,800 PLS per acre) for the fiber type. Row spacing was 9 inches at Haysville, and 7.5 inches at Scandia and Manhattan. The different seeding rates correspond to recommendations for grain and fiber production systems. Seed was placed into moist soil at a depth of 0.5 to 0.75 inches. Nitrogen fertilizer was applied in standing hemp soon after emergence. 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 per acre as dry urea fertilizer (46-0-0).

Harvest data were collected from a 10.8 or 25 ft^2 area within each plot. Plant density was determined by counting the number of harvested plants. Harvest consisted of cutting plants at ground level. The entire sample was dried at 140°F for 7 days. At Manhattan and Scandia, after determining total dry biomass, plants were threshed with a belt thresher (ALMACO, Nevada, IA), stalks and grain were weighed, and the weight of flowers/leaves/branches was calculated by subtracting the sum of grain and stalks from total biomass. At Haysville, weights of only total biomass and threshed grain were determined, and stover (everything except grain) weight was calculated by subtracting grain from total biomass. Dry weights were converted to pounds per acre based on sample area.

Soil water content was measured only in subplots that received full N fertilizer. Measurements began after emergence and roughly every 14 days thereafter, with the last date coinciding with grain harvest. This resulted in eight sample dates at Manhattan, seven at Scandia, and six at Haysville. 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 at Manhattan. Tubes 6 feet in length were installed to a depth of 5.5 feet at Scandia and Haysville because previous work had indicated limited root development beyond that depth due to the dense, clay subsoil at Scandia and to the shallow water table at Haysville. Starting at a depth of 6 inches below the soil surface, water content was measured in 1-foot increments to either 4.5 or 8.5 feet. Field calibrations for the neutron probe for each location 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 ft^2. Samples were dried at 140°F to determine dry matter concentration, which was used 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. Data from plots of both varieties that received N fertilizer were pooled across all three locations after standardizing to percent of maximum. Sigmoidal models were fit to 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 $\alpha = 0.05$. Repeated measures of analysis of variance were used to compare soil moisture at different dates within each depth.

Results

Growing Season Weather

Uneven precipitation distribution was likely the factor that most limited hemp growth at Haysville and Manhattan in 2022 (Figure 1). Rainfall was adequate to excessive before and soon after planting, but dry periods occurred in July and August. Rainfall was more evenly distributed at Scandia. Growing degree day (GDD) accumulation exceeded normal at Haysville, was near normal at Manhattan, and lagged normal at Scandia. Roughly 4,000 to 4,500 GDD were required to reach harvest maturity at all locations, similar to previous years. Several days of maximum temperatures exceeding 100°F at Haysville likely caused additional stress to the hemp plants, but maximum temperatures seldom exceeded 100°F at Manhattan or Scandia. Minimum daily soil temperatures at the 2-in. depth exceeded 50°F for most of the growing season and were seldom less than 60°F.

Haysville

Although two of the four replications were abandoned due to poor stand establishment, data collected from the remaining two replications were informative (Table 1). Plant height was greater for the fiber-type variety (Bialobrzeskie). Nitrogen fertilizer increased total biomass yield, but the increase was greater for Henola than for Bialobrzeskie. Bialobrzeskie produced more stover than Henola, but nitrogen fertilizer did not have a significant effect. Grain yield ranged from 197 to 570 pounds per acre but was so variable that significant differences were not detected with only two replications. Later planting and high temperatures combined with limited rainfall likely limited growth, seed set, and seed fill.

Manhattan

Although harvest plant density was less than 165,000 plants per acre for all treatments, stands were relatively consistent and likely had little impact on yield differences (Table 2). Bialobrzeskie was taller than Henola at both rates of nitrogen fertilizer, but height of Bialobrzeskie increased by 45% with fertilizer compared to 28% for Henola. Nitrogen fertilizer more than doubled the biomass, stalk, and flowers/leaves/branches yield and nearly doubled grain yield. Henola produced roughly twice as much grain as Bialobrzeskie.

Scandia

Favorable rainfall distribution resulted in no significant effect of irrigation for plant height or any fraction of yield (Table 3). Stands were excellent for all treatments, averaging more than 250,000 plants per acre. Bialobrzeskie was 17 inches taller than Henola, and nitrogen fertilizer caused an average height increase of 10 inches across varieties and irrigation treatments. Although total biomass yield was similar for the two varieties, Bialobrzeskie produced more stalks, and Henola produced more grain. Nitrogen fertilizer increased yield of total biomass and stalks by 30%, flowers/leaves/branches by 41%, and grain by 18%. Nitrogen fertilizer resulted in a minimal grain yield increase for Bialobrzeskie, but caused a 26% increase in grain yield for Henola.

Biomass Accumulation and Soil Water Depletion

The rapid growth period started at about 1,500 GDD and continued through about 2,700 GDD (Figure 2). Half of the total dry biomass was accumulated by 2,150 GDD and 90% by 2,675 GDD. Total biomass accumulation averaged 5,000 lb/acre at harvest across the three locations. That total was partitioned to 48% stalks, 34% floral structures, and 18% grain.

Macronutrient accumulation (Figure 3) exhibited similar patterns to that presented for biomass. Carbon accumulation closely followed biomass aside from a slight lag during early growth. Nitrogen and potassium had nearly identical patterns with both accumulating more rapidly than dry matter. Phosphorus accumulation lagged dry matter accumulation and continued into seed filling. These patterns are similar to those reported for other crops and for hemp in previous years in Kansas.

Soil profile water content declined as the 2022 growing season progressed at all three locations (Figures 1, 4, 5, and 6). At Haysville (Figure 4) most soil water extraction occurred by mid-August. Soil water content declined during the growing season throughout the sampled profile to a depth of 4.5 feet. Total profile water loss, including additions from rainfall, was 9.3 inches. Relatively small, infrequent rainfall events after planting likely minimized runoff and percolation through the profile (Figure 1).

Changes in soil water content in the top 1.5 to 2 feet of the soil profile at Manhattan (Figure 5) were similar to changes observed at Haysville. However, at Manhattan, subsurface depths increased in water content during the season compared to the initial reading on June 16. Eventually, the profile lost water to a depth of 2.5 feet through the course of the growing season. At depths of 4.5 feet and below, soil water content was greater at the end of the growing season than at the beginning, likely due to downward movement of soil water not extracted by the hemp crop. Total change in soil profile water content, including inputs from precipitation, was 22.2 inches. Several rainfall events greater than 1 inch likely resulted in significant runoff (Figure 1). Soil moisture readings taken on July 27, soon after a 2.88-inch rainfall, indicated that surface soil moisture had returned to levels similar to the initial readings (Figure 5).

Soil water content at Scandia was nearly identical in non-irrigated and irrigated plots at the first two sample dates before any irrigation was applied (Figure 6). However, at subsequent sample dates, soil water decline was greater in the non-irrigated plots than in the irrigated plots. The entire sampled profile to a depth of 4.5 feet became drier in both sets of plots as the season progressed. Total soil water loss, including reductions in soil profile water content and inputs from precipitation and irrigation, was 17.2 inches in the non-irrigated plots and 21.0 inches in the irrigated plots. Relatively even rainfall distribution and several events totaling more than 1 inch likely resulted in runoff (Figure 1). Volumetric soil water content near the surface never became less than 0.20 (non-irrigated) or 0.25 (irrigated) in./in. (Figure 6) compared to 0.10 in./in. at Haysville and Manhattan at the end of the season (Figures 4 and 5).

Results from these experiments and similar experiments conducted in 2019 through 2022 illustrate hemp's responsiveness to nitrogen fertilizer and soil water supply. The nutrient accumulation data can quantify the potential nutrient demand of the crop, which will inform soil fertility recommendations. Biomass, stem, and grain yield results combined with soil water content data form the basis for understanding the relationship between water supply and the different economic fractions of crop yield. Taken together, this information will support ongoing efforts to refine hemp production management recommendations for the range of environments where hemp is likely to be grown in Kansas.

Acknowledgments

Funding support was provided from the Kansas Department of Agriculture.

Table 1. Field performance of two hemp varieties grown with two rates of nitrogen fertilizer at Haysville, KS, in 2022

Factor	Level	Harvest plant density	Height		Total biomass		Stover†		Grain
		plants/a	inches		----- lb/acre -----				
Variety	Type								
Bialobrzeskie	Fiber	143662	35	a‡	2132		1856	a	276
Henola	Grain	195391	24	b	2048		1588	b	455
Nitrogen	lb/acre								
None	0	149864	28		1897	b	1624		269
Full	130	189189	31		2283	a	1820		462
Interaction									
Variety	lb N/acre								
Bialobrzeskie	0	139616	35		2008	b	1812		197
Bialobrzeskie	130	147709	36		2256	a	1901		355
Henola	0	160112	21		1787	c	1436		341
Henola	130	230669	26		2310	a	1740		570

† Total biomass less grain.
‡ Values within a column followed by the same letter are not different at $\alpha = 0.05$.

Table 2. Field performance of two hemp varieties grown with two rates of nitrogen fertilizer at Manhattan, KS, in 2022

Factor	Level	Harvest plant density	Height		Total biomass		Stalks		Flowers, leaves, branches		Grain	
		plants/a	inches		----- lb/acre -----							
Variety	Type											
Bialobrzeskie	Fiber	159212	42	a†	1515		754		617		145	b
Henola	Grain	148975	36	b	1580		603		676		302	a
Nitrogen	lb/acre											
None	0	149629	33	b	905	b	368	b	385	b	153	b
Full	130	158558	45	a	2190	a	989	a	907	a	294	a
Interaction												
Variety	lb N/acre											
Bialobrzeskie	0	164221	35	c	951		447		406		99	
Bialobrzeskie	130	154203	50	a	2079		1061		828		190	
Henola	0	135036	32	c	859		289		365		207	
Henola	130	162914	41	b	2300		917		987		397	

† Values within a column followed by the same letter are not different at $\alpha = 0.05$.

Table 3. Field performance of two hemp varieties grown with two rates of nitrogen fertilizer with and without irrigation at Scandia, KS, in 2022

Factor	Level	Harvest plant density	Height		Total biomass		Stalks		Flowers, leaves, branches		Grain	
		plants/a	inches		------------------- lb/acre						--------------------	
Irrigation	Inches											
None	0	268983	60		4911		2610		1302		999	
Full	6.05	252975	62		5222		2744		1350		1128	
Variety	Type											
Bialobrzeskie	Fiber	232066	70	a†	5156		3094	a	1220		842	b
Henola	Grain	289892	53	b	4977		2261	b	1432		1285	a
Nitrogen	lb/acre											
None	0	270943	56	b	4402	b	2327	b	1099	b	976	b
Full	130	251015	66	a	5731	a	3028	a	1552	a	1151	a
Interaction												
Variety	lb N/acre											
Bialobrzeskie	0	255480	65		4466		2684		965		817	c
Bialobrzeskie	130	208653	75		5846		3503		1475		868	c
Henola	0	286407	48		4338		1969		1234		1136	b
Henola	130	293377	58		5615		2552		1630		1434	a

† Values within a column followed by the same letter are not different at $\alpha = 0.05$.

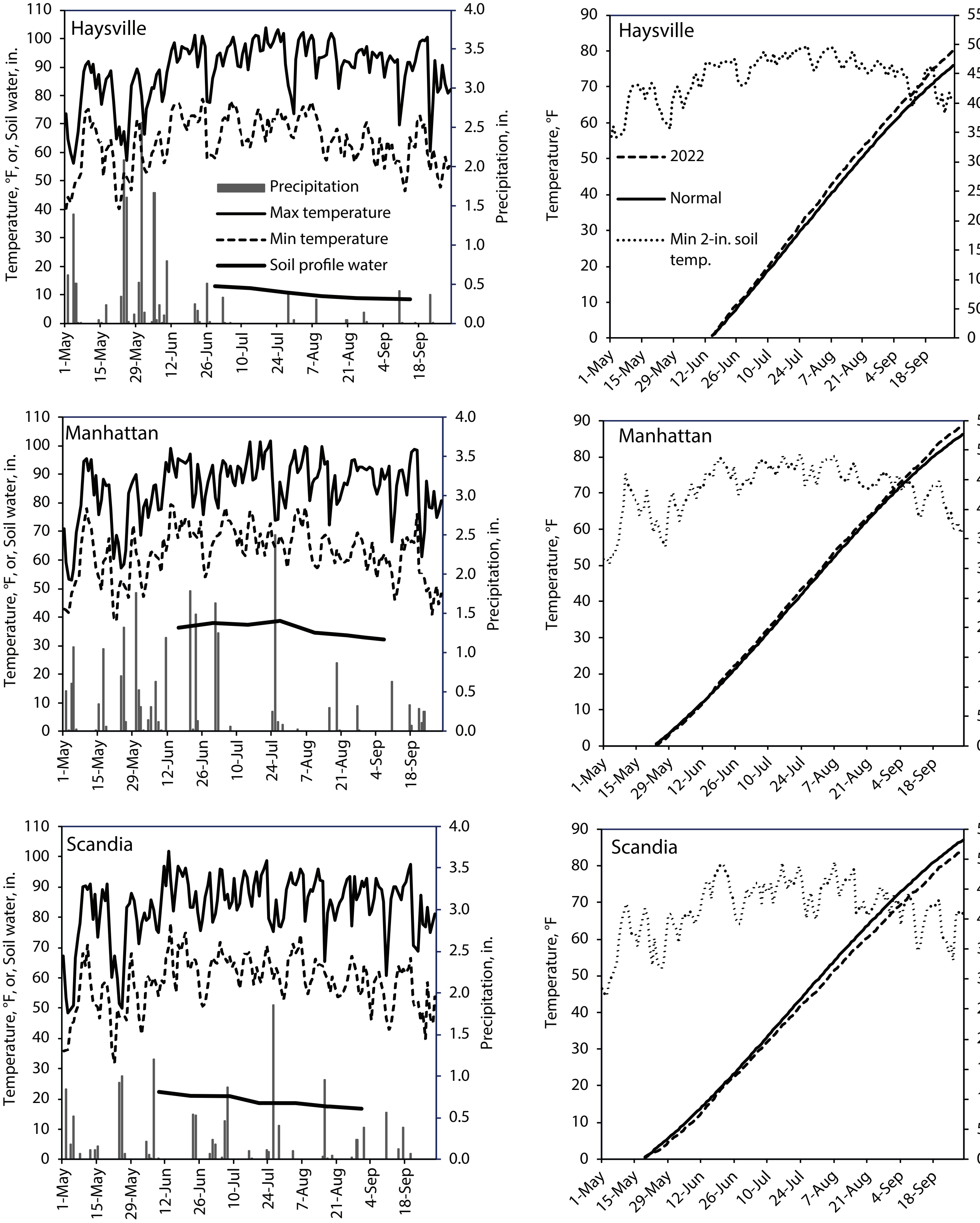

Figure 1. Daily maximum and minimum temperatures, precipitation, and soil profile water content (left) and cumulative growing degree days (average daily temperature minus 33.8°F, summed from planting date) and minimum 2-inch soil temperatures (right) in 2022 at Haysville, Manhattan, and Scandia, KS (mesonet.k-state.edu).

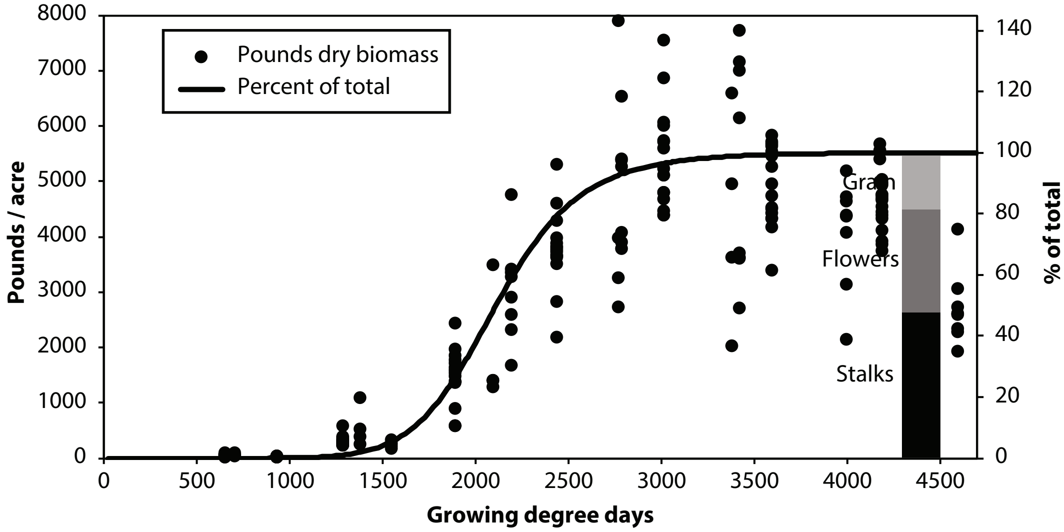

Figure 2. Dry biomass accumulation and partitioning to harvest fractions for hemp at Haysville, Manhattan, and Scandia, KS, in 2022. Pounds per acre was standardized across locations. The sigmoidal model illustrating accumulation as percent of total assumes no late-season losses.

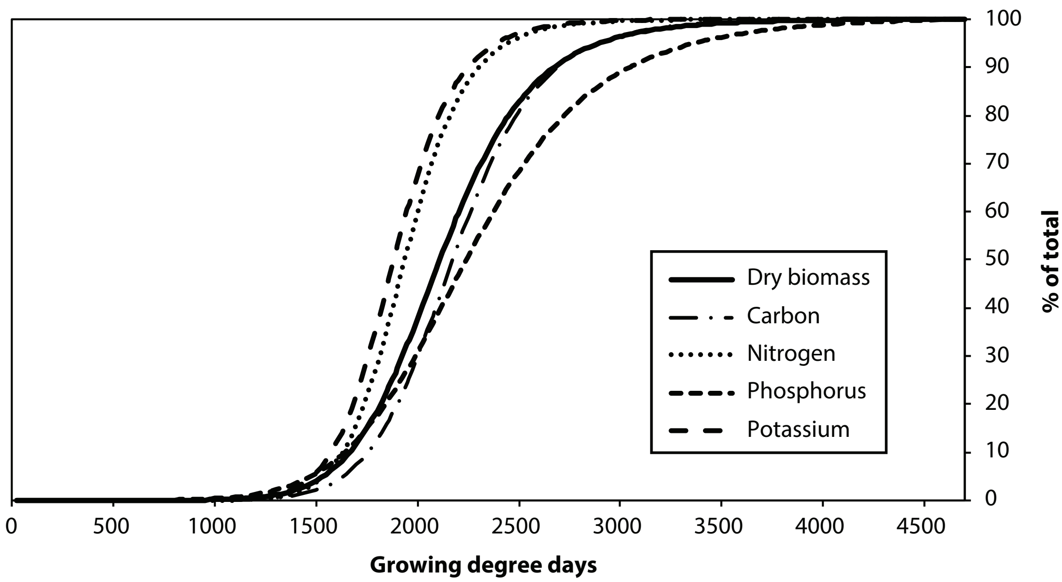

Figure 3. Dry biomass and macronutrient accumulation by hemp at Haysville, Manhattan, and Scandia, KS, in 2022. Sigmoidal models for each were fit to data that had been standardized across locations.

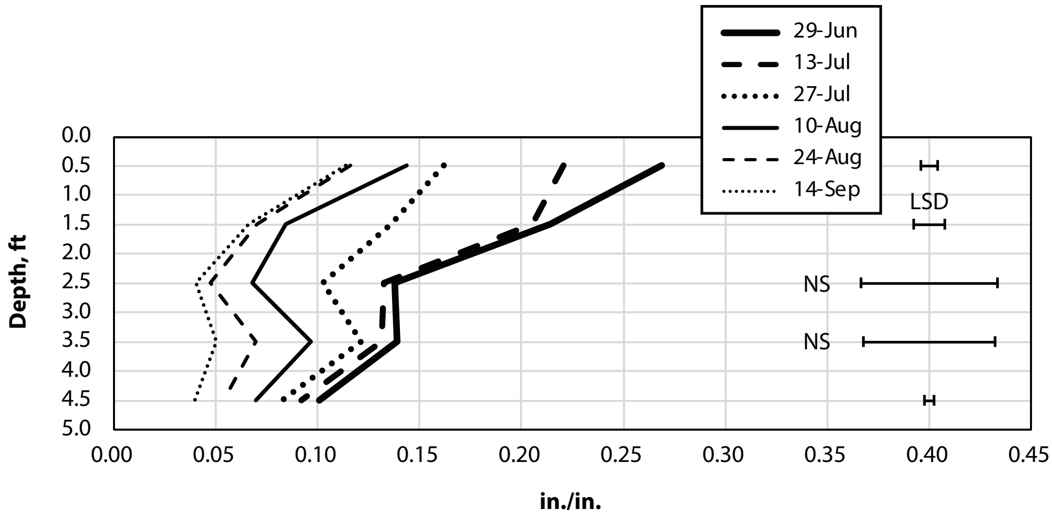

Figure 4. Volumetric water content at five depths in the soil profile at six dates during the hemp growing season at Haysville, KS, in 2022. The LSD bars indicate least difference in soil water content required to be significant at each depth; NS indicates no difference between dates at that depth.

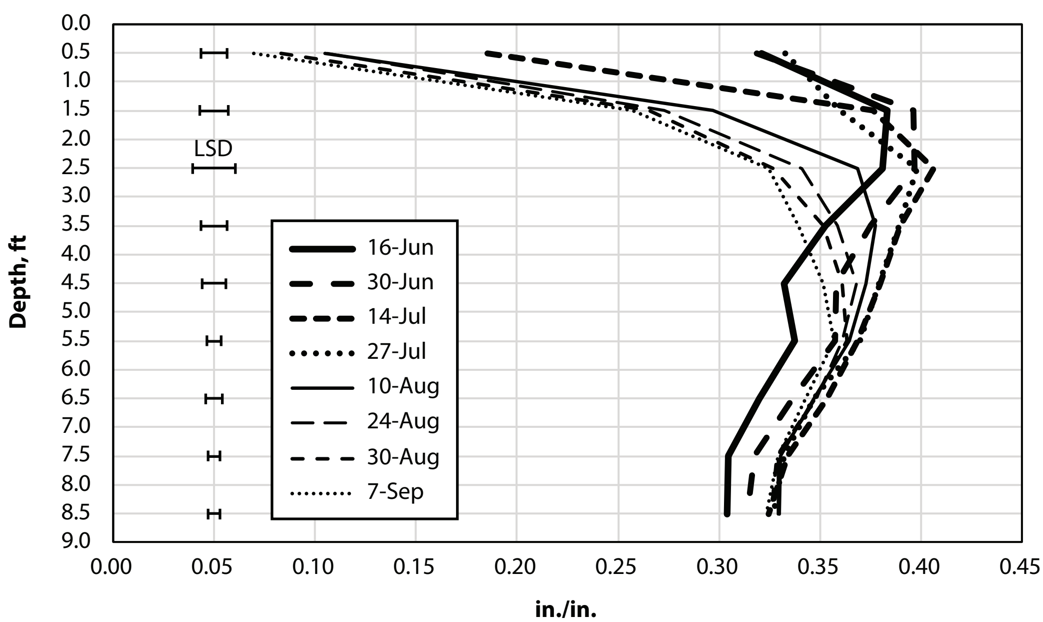

Figure 5. Volumetric water content at nine depths in the soil profile at eight dates during the hemp growing season at Manhattan, KS, in 2022. The LSD bars indicate least difference in soil water content required to be significant at each depth.

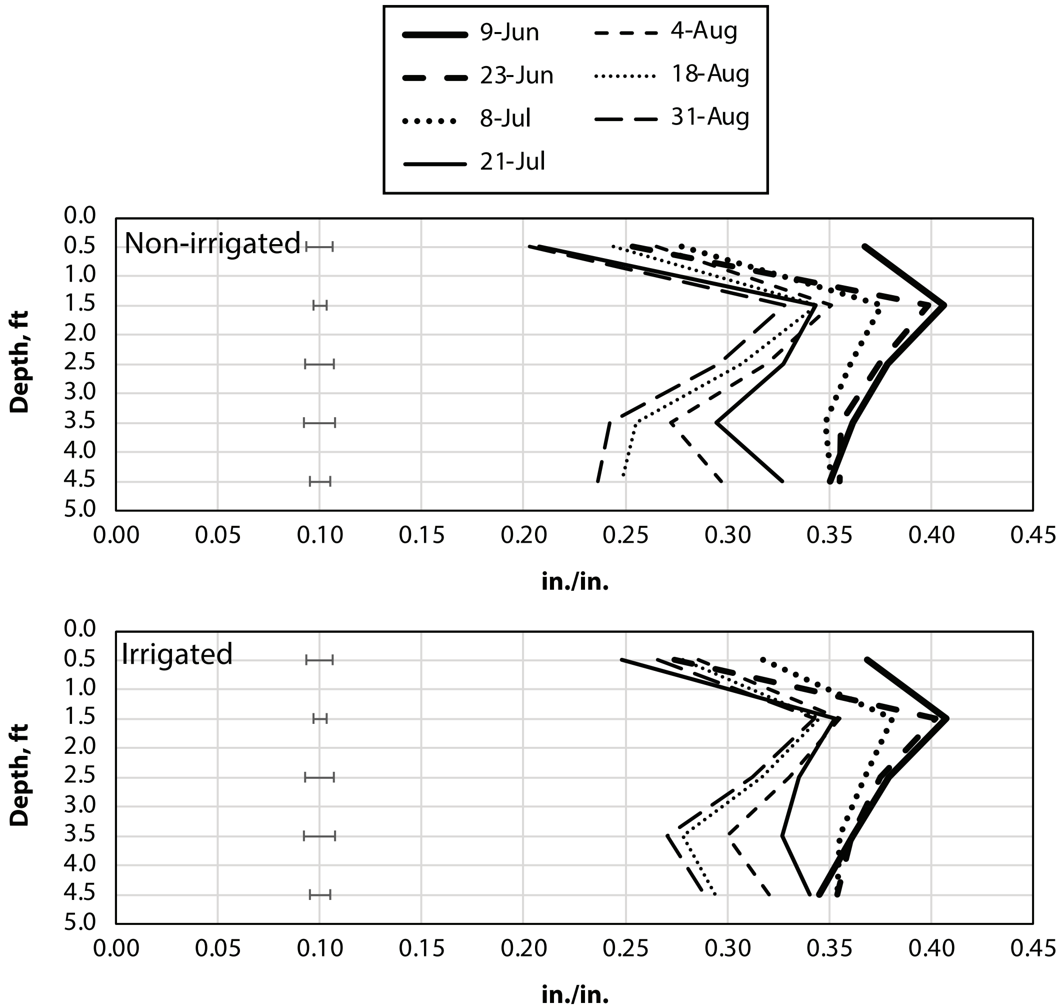

Figure 6. Volumetric water content at five depths in the soil profile at seven dates in non-irrigated (top) and irrigated (bottom) conditions during the hemp growing season at Scandia, KS, in 2022. The LSD bars indicate least difference in soil water content required to be significant at each depth.