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Summary

Some crop producers are considering hemp as an alternative to the typical crops grown in the region. Hemp is viewed as a crop to potentially access new markets. Two of those potential markets are hemp grain and fiber. Little information is available for this region about production management for hemp intended for those markets. Experiments were planted in 2020 at Manhattan, Haysville, and Colby, KS, to characterize plant growth, nutrient uptake, and soil water depletion. Results illustrated typical biomass and nutrient uptake patterns. Half of the total biomass was accumulated by 2,200 growing degree days (GDD), but accumulation continued until harvest at 4,200 GDD. Nitrogen (N) and potassium (K) accumulated more rapidly than dry biomass, with half of their total uptake at 2,000 and 1,700 GDD, respectively. Phosphorus (P) accumulation was similar to biomass accumulation. Hemp accumulated more than 7,000 pounds of dry biomass/acre that contained roughly 170 lb nitrogen, 13 lb of phosphorus, and 113 lb potassium/acre. Soil profile water was depleted by 4.3 to 6.9 inches during hemp growth with 11 to 18 inches of precipitation falling during the season. Some portion of the precipitation ran off before infiltrating the profile, and some may have drained through the rooting zone. These values represent data collected at only two sites and are only preliminary estimates. More information is needed from a wider range of growing conditions to better quantify biomass, nutrient accumulation, and soil water depletion by hemp.

Introduction

Hemp has garnered interest as a potential crop that is not constrained by the typical food, feed, and fuel market channels. Although much of the interest has been focused on the high-value cannabidiol (CBD) market, hemp varieties are available for the

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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 region. Unfortunately, little current information is available about hemp growth, nutrient uptake, and production techniques across the precipitation gradient that exists in Kansas. Our objective for this research was to characterize hemp growth, nutrient uptake, and soil water depletion at three locations representing the precipitation gradient across Kansas.

Procedures

Experiments were planted near Manhattan (latitude 39.1223, longitude -96.6382) 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 with 33.0, 33.2, and 20.3 inches of annual precipitation, respectively. The experiment at Colby included irrigation levels of 100% evapotranspiration (ET), 50% ET, and non-irrigated. All sites were tilled before planting to terminate existing vegetation and prepare a clean seedbed. The experiment at Colby failed to establish a sufficient stand and was abandoned.

Each experiment included two dual-purpose hemp varieties (Altair or Vega from Horizon Hemp Seeds, Willow Lake, SD; and NWG2730 or NWG452 from New West Genetics, Fort Collins, CO) as whole plots and two N fertilizer rates as subplots (0 and 180 lb N/acre). Whole plots were 30 feet wide and 35 feet long and were replicated four times in a randomized complete block experimental design. At Haysville, the fertilized subplots received granular urea (46-0-0) applied the day before planting. At Manhattan, the fertilized subplots received an application of UAN seven days before planting with a sprayer fitted with AIXR110VP nozzles (TeeJet Technologies, Grimes, IA). At Haysville, plots were planted with a Hege 1000 plot drill at a rate of 30 pounds of pure live seed per acre on a row spacing of 9 inches. At Manhattan, plots were planted with a Great Plains drill (Model 3P605NT Great Plains Manufacturing, Inc., Salina, KS) at a rate of 21 pure, live seed per square foot on a row spacing of 7.5 inches. At both locations, samples and data were collected from bordered rows within each plot.

Soil water content was measured in both 2019 and 2020. In 2019 at Haysville, soil cores 1 5/8-inch in diameter were obtained on July 23 and September 17 in 1-ft increments to a depth of five feet. Cores were weighed wet and after drying in 2019, and gravimetric water content was calculated as mass of water/mass of dry soil. Bulk density values determined in 2020 were used to convert gravimetric water content obtained in 2019 to volumetric water content. In 2020 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. 1 5/8 inch) 6 feet in length were installed in the field plots to a depth of 5.5 feet at Haysville. Tubes were 10 feet in length and installed to a depth of 9.5 feet at Manhattan. Starting at a depth of 6 inches below the soil surface, water content was measured in 1-foot increments to 4.5 feet at Haysville and 8.5 feet at Manhattan. Field calibrations for the neutron probe were used to calculate volumetric water content. Soil water content was measured in each subplot that received 180 lb N/acre roughly bi-weekly during the hemp growing season.

At Manhattan, hemp plants began to emerge on June 14, 2020, and produced acceptable stands. Hand weeding was used to control weeds that emerged after planting. The number of emerged plants was determined on June 26 by counting the number of plants in a sample area of 9.4 feet^2. Plants were also counted at grain harvest, and the percent of plant survival was calculated as (harvest plant density/emerged plant density) × 100. Because the two plant counts were taken from different areas within each plot, some values for plant survival exceeded 100%. Plant height was determined during the final days of grain fill after vegetative growth had ceased.

Biomass samples were collected from plots that had received 180 lb N/acre whenever soil water content was measured at both Haysville and Manhattan. 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/acre. Subsamples of dried biomass were submitted to the Kansas State University Department of Agronomy Soil Testing Laboratory for determination of nitrogen, phosphorus, and potassium concentrations. Sigmoidal models were fit to the observed data from both locations to illustrate the seasonal uptake patterns and to provide an estimate of total uptake for the entire season, given that significant leaf loss reduced biomass and nutrient values as grain fill progressed.

Harvest at both locations consisted of hand cutting plants at ground level from an area of 21.5 feet^2 within each plot. After drying, total dried biomass weight was determined, plants were stripped of their grain, and grain was passed through a seed blower for a final cleaning before the grain was weighed to estimate seed yield. Weight of the stover was calculated by subtracting the grain weight from the total biomass. The mass of 300 seeds was determined to facilitate calculation of seeds/pound. 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 $\alpha = 0.05$.

Results

Growing Season Weather

Temperatures and precipitation were generally favorable for hemp growth (Figure 1). Maximum temperatures did not exceed 100°F at any point in the growing season, fluctuating between 79°F and 97°F at Haysville and 74°F and 97°F at Manhattan. Minimum temperatures exceeded 50°F until late seed fill in early September at both locations. Roughly 4,500 GDD accumulated from planting in early June to harvest in mid-September at both locations (Figure 2). Precipitation before planting assured adequate soil profile moisture at planting at both locations (Figure 1). No precipitation occurred from seven days before planting until 13 days after planting at Haysville, but emergency sprinkler irrigation facilitated emergence. Timely precipitation events during most of the growing season prevented moisture-deficit stress. Periods of roughly 14 days without substantial precipitation occurred in August at both locations. Similar dry periods in September likely had little impact on productivity because harvest was already underway by mid-September.

Plant Establishment and Survival

Variety and nitrogen fertilizer influenced several measures of stand establishment, survival, and growth (Table 1). The two varieties had similar plant stands, but N fertilizer influenced plant density at harvest at both locations. The significant variety × nitrogen interaction revealed that fewer plants of NWG452 survived during the growing season with full nitrogen fertilizer at Manhattan. Nitrogen fertilizer sources, timing, and rates require further investigation. Altair was significantly shorter than NWG2730 at Haysville, and Vega was significantly shorter than NWG452 at Manhattan. Nitrogen fertilizer did not affect plant height at Haysville, but the average height of both varieties was greater with full N fertilizer at Manhattan. NWG2730 had greater stem diameter than Altair, and full nitrogen fertilizer resulted in greater stem diameter than no fertilizer treatment at Haysville.

Grain and Stover Yield

Variety and nitrogen fertilizer significantly affected biomass yields, but effects differed with location (Table 2). At Haysville, NWG2730 had greater total biomass yield than Altair; and at Manhattan, Vega produced more total biomass than NWG452. However, in both locations, the Horizon Hemp variety (Altair or Vega) had a greater fraction of that biomass as grain compared to the variety from New West Genetics: 40% for Altair and 37% for Vega compared to 24% for NWG2730 and only 7% for NWG452. So little grain was harvested from NWG452 at Manhattan that its total biomass yield was less than for Vega even though it produced significantly more stover. Full nitrogen fertilizer resulted in greater grain yield at both locations and greater total biomass yield at Manhattan, but had no significant influence on stover yield at either location. Evidently, enough N was supplied for vegetative growth from residual soil N pools and/or mineralization, but N was limited for grain production without N fertilizer. Seed size was greater for Altair at Haysville and Vega at Manhattan compared to NWG2730 and NWG452, respectively. This differential was enhanced with full N fertilizer at Manhattan. Averaged over varieties, nitrogen fertilizer had no effect on seed size at either location.

Biomass and Nutrient Accumulation and Soil Water Depletion

Data were pooled for the two varieties and two locations to characterize dry biomass and nutrient concentration and accumulation by hemp in 2020 (Figures 3 - 8). After slow accumulation during the seedling stages, dry biomass accumulated rapidly from 1,500 to 3,000 GDD (Figure 3). Half of the estimated total dry biomass had accumulated by 2,200 GDD (mid-July), and 90% had accumulated by early grain fill at 3,320 GDD (mid-August). Measured dry biomass was greatest from 3,000 to 3,700 GDD but declined during grain fill due to leaf loss. Estimated total accumulation averaged 7,445 lb/acre across the two locations.

Macronutrient concentration in hemp biomass declined as the season progressed, but the patterns were different for nitrogen, phosphorus, and potassium (Figure 4). Nitrogen concentration approached 5% of dry biomass in the seedling stages, but leveled out at roughly 2% later in the growing season. Phosphorus concentrations were more variable than for the other nutrients at every sample date and declined only marginally during the growing season. Potassium concentrations approached 4% of dry biomass in the seedling stages and declined linearly until late seed fill when concentrations averaged 1% to 1.5%.

Nitrogen and potassium accumulated more rapidly than dry biomass, but phosphorus accumulated in a pattern similar to dry biomass (Figures 5 - 8). Half of the nitrogen had been taken up by 2,000 GDD (Figure 5). Estimated total nitrogen uptake averaged 170 lb/acre across both varieties at both locations. Estimated total phosphorus uptake was 16 lb/acre (Figures 6 and 8). Potassium uptake was more rapid than it was for nitrogen, with half of the total accumulated by 1,700 GDD (early July). Estimated total uptake of potassium was 113 lb/acre. Both nitrogen and phosphorus fertility are likely to be important management factors for hemp grain and fiber production, and potassium may become important in fiber production systems.

Soil profile water content generally declined as the 2020 growing season progressed (Figures 1, 9, and 10). At Haysville, exceptions to the pattern occurred in the top foot or two of the profile as measured on August 11 and September 14 (Figure 9). Precipitation events of more than one inch on August 10 and 29 and September 9 (Figure 1) were able to recharge the top-most foot of the profile as crop water usage likely slowed as plants approached maturity, and accumulation of biomass slowed (Figure 3). At Manhattan, soil water content was slightly greater on June 30 compared to June 17, reflecting relatively little crop water usage in the seedling stages compared to the 3.5 inches of precipitation received between the two sample dates (Figure 1). Soil water content in the top foot of the profile was substantially greater at the last two sample dates, reversing the continuous drying trend since late June (Figure 10). Aside from the near-surface recharge previously mentioned, soil below actively growing hemp was drier to a depth of 5 feet at Haysville and 6.5 feet at Manhattan at the end of the growing season compared to early in the season (Figures 9 and 10). The net depletion of soil profile water from the first to last sample dates was 6.9 inches at Haysville and 4.3 inches at Manhattan. Haysville received 10.9 inches, and Manhattan received 18.0 inches of precipitation during the same period. Some fraction of 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).

Above-average precipitation was received at Haysville before planting and in the first part of the growing season in 2019 (Figure 11). July was relatively dry, but precipitation became more regular in August and September. Soil water was depleted by a total of 3.36 inches from July 23 through September 17. A total of nine inches of precipitation was received during that period, and 17.3 inches from planting to harvest. Soil water was depleted more at depths from 1.5 to 3.5 feet, compared to the 0.5 and 4.5 depths (Figure 12).

These initial results illustrated that hemp could be grown successfully in northeast and south-central Kansas. Hemp accumulated biomass and nutrients in patterns similar to those for other non-legume crops, implying that fertility management should be similar to that used for those crops as well. Soil water depletion results indicated that hemp was able to access soil water from depths of more than six feet. As with any crop grown in the region, adequate time for soil profile moisture recharge should be built into rotations to minimize soil moisture deficits for succeeding crops.

Table 1. Plant density, survival, and height for two hemp varieties grown with two rates of nitrogen fertilizer at Haysville and Manhattan, KS, in 2020

Location Factor	**June**		**Harvest**		**Plant survival**†		**Height**		**Stem diameter**	
	----------- plants per acre -----------				-------- % --------		------------------ inch ------------------			
Haysville										
Variety										
New West Genetics NWG-2730			166,680	a			57	a	0.04	a
Horizon Hemp Altair			171,233	a			34	b	0.03	b
Nitrogen fertilizer										
0 lb N/acre			206,896	a			45	a	0.03	b
180 lb N/acre			131,017	b			46	a	0.04	a
Manhattan										
Variety										
New West Genetics NWG-452	281,668	a‡	272,124	a	98	a	74	a		
Horizon Hemp Vega	279,365	a	292,862	a	105	a	52	b		
Nitrogen fertilizer										
0 lb N/acre	296,789	a	314,358	a	108	a	61	b		
180 lb N/acre	264,264	a	250,627	b	95	a	65	a		
Interaction§										
Variety, Nitrogen										
NWG-452, 0 lb N/acre					112	a				
NWG-452, 180 lb N/acre					83	b				
Vega, 0 lb N/acre					103	a				
Vega, 180 lb N/acre					106	a				

† Calculated as Harvest/June plant density; June and Harvest plant counts were conducted in different areas within each plot, so values do not reflect true plant survival.

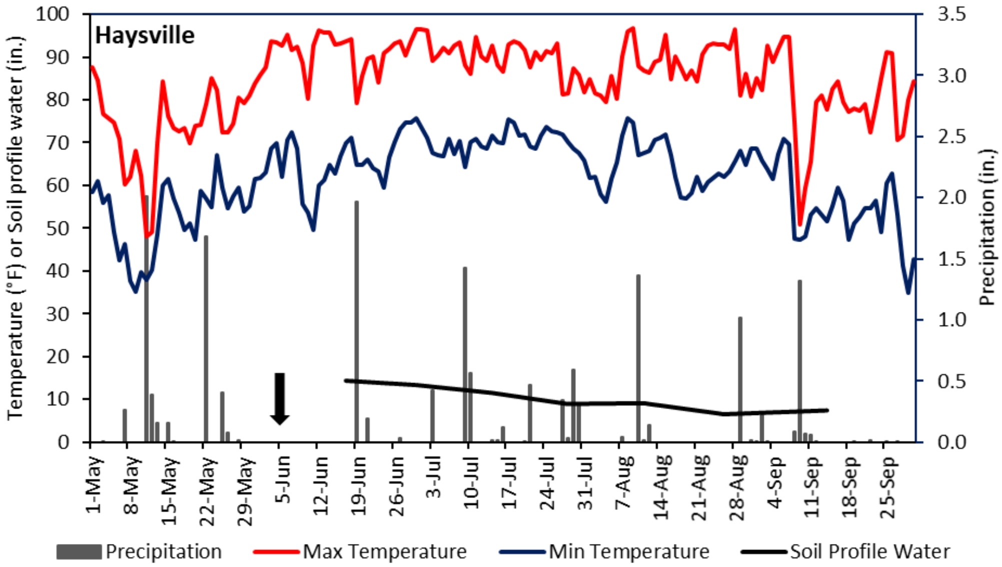
‡ Values within set of comparisons within a column followed by the same letter are not different at $\alpha = 0.05$.

§ Interaction means are presented only for significant variety × nitrogen interactions.

Table 2. Biomass and grain yield and seed size of two hemp varieties grown with two rates of nitrogen fertilizer at Haysville and Manhattan, KS, in 2020

Factor Level	Total biomass		Stover		Grain		Seed size	
	-------------------- pounds per acre				---------------------		seeds per lb	
Haysville								
Variety								
New West Genetics NWG-2730	5,180	a[†]	3,912	a	1,268	a	40,277	a
Horizon Hemp Altair	3,609	b	2,178	b	1,431	a	27,579	b
Nitrogen fertilizer								
0 lb N/acre	4,008	a	2,898	a	1,110	b	35,216	a
180 lb N/acre	4,782	a	3,192	a	1,590	a	32,640	a
Manhattan								
Variety								
New West Genetics NWG-452	3,429	b	3,188	a	241	b	48,540	a
Horizon Hemp Vega	3,881	a	2,447	b	1,433	a	35,376	b
Nitrogen fertilizer								
0 lb N/acre	3,345	b	2,683	a	663	b	42,869	a
180 lb N/acre	3,964	a	2,952	a	1,012	a	41,047	a
Interaction[‡]								
Variety, Nitrogen								
NWG-452, 0 lb N/acre							47,821	a
NWG-452, 180 lb N/acre							49,259	a
Vega, 0 lb N/acre							37,917	b
Vega, 180 lb N/acre							32,835	c

[†] Values within a column followed by the same letter are not different at $\alpha = 0.05$.
[‡] Interaction means are presented only for significant variety × nitrogen interactions.



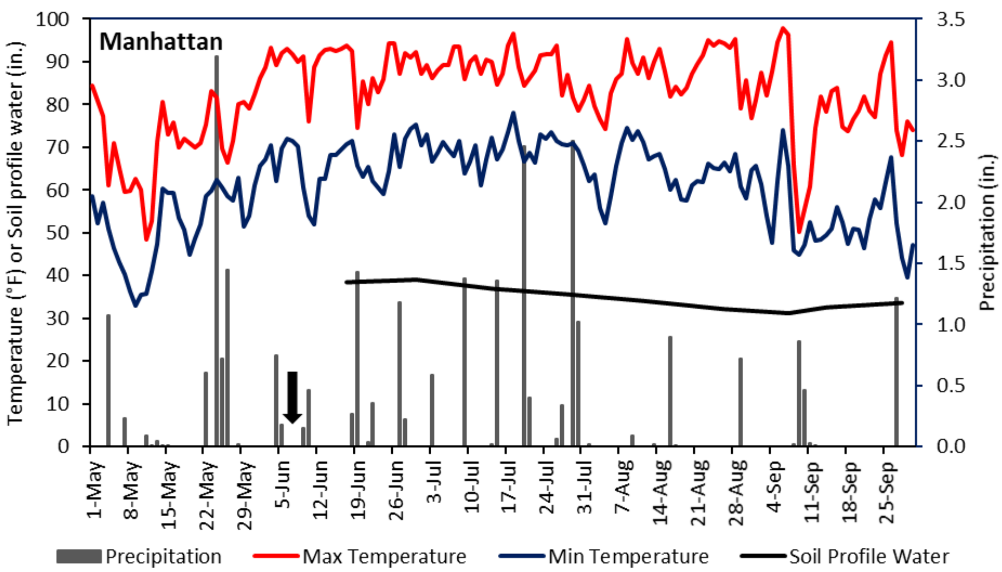


Figure 1. Daily maximum and minimum temperatures and precipitation and soil profile water content to a depth of five feet at Kansas State University John C. Pair Horticultural Center (Haysville - top) and nine feet at Ashland Bottoms (Manhattan - bottom) during the industrial hemp (*Cannabis sativa*) growing season of 2020. 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).

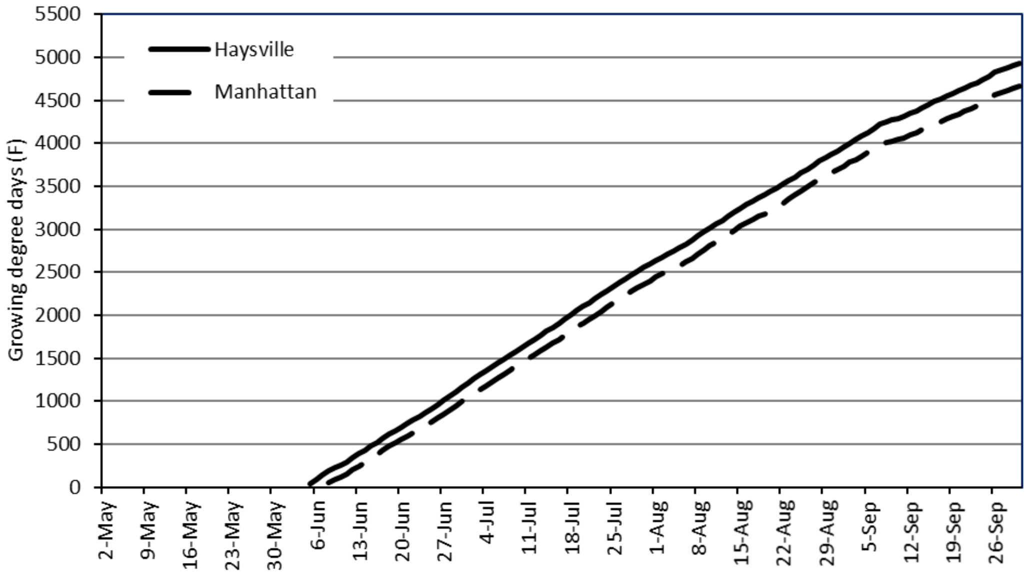


Figure 2. Growing degree day accumulation at Haysville and Manhattan, KS, in 2020. Growing degree days were calculated as average daily temperature – 33.8°F summed from planting date.

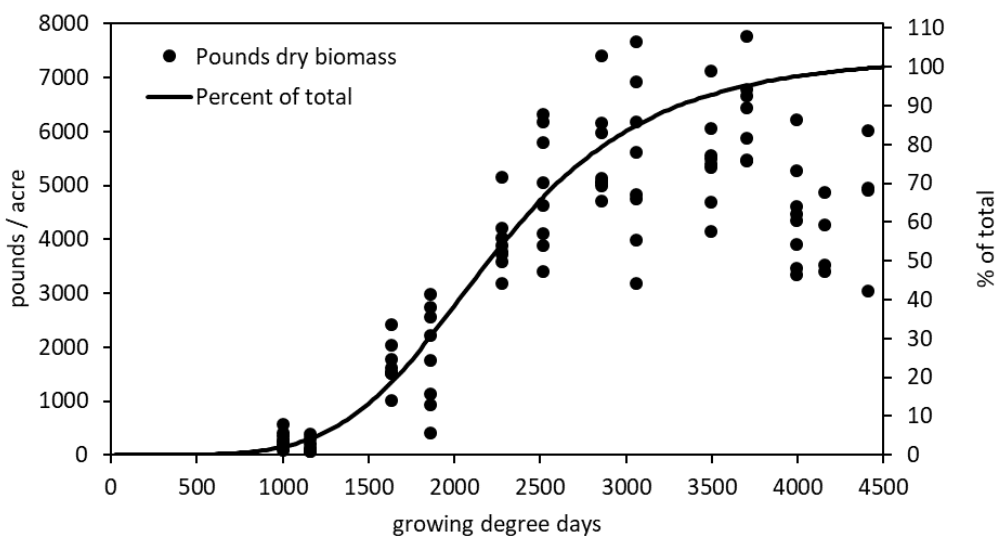


Figure 3. Dry biomass accumulation of hemp at Haysville and Manhattan, KS, in 2020. The sigmoidal model illustrating accumulation as percent of total assumes no late-season dry biomass loss.

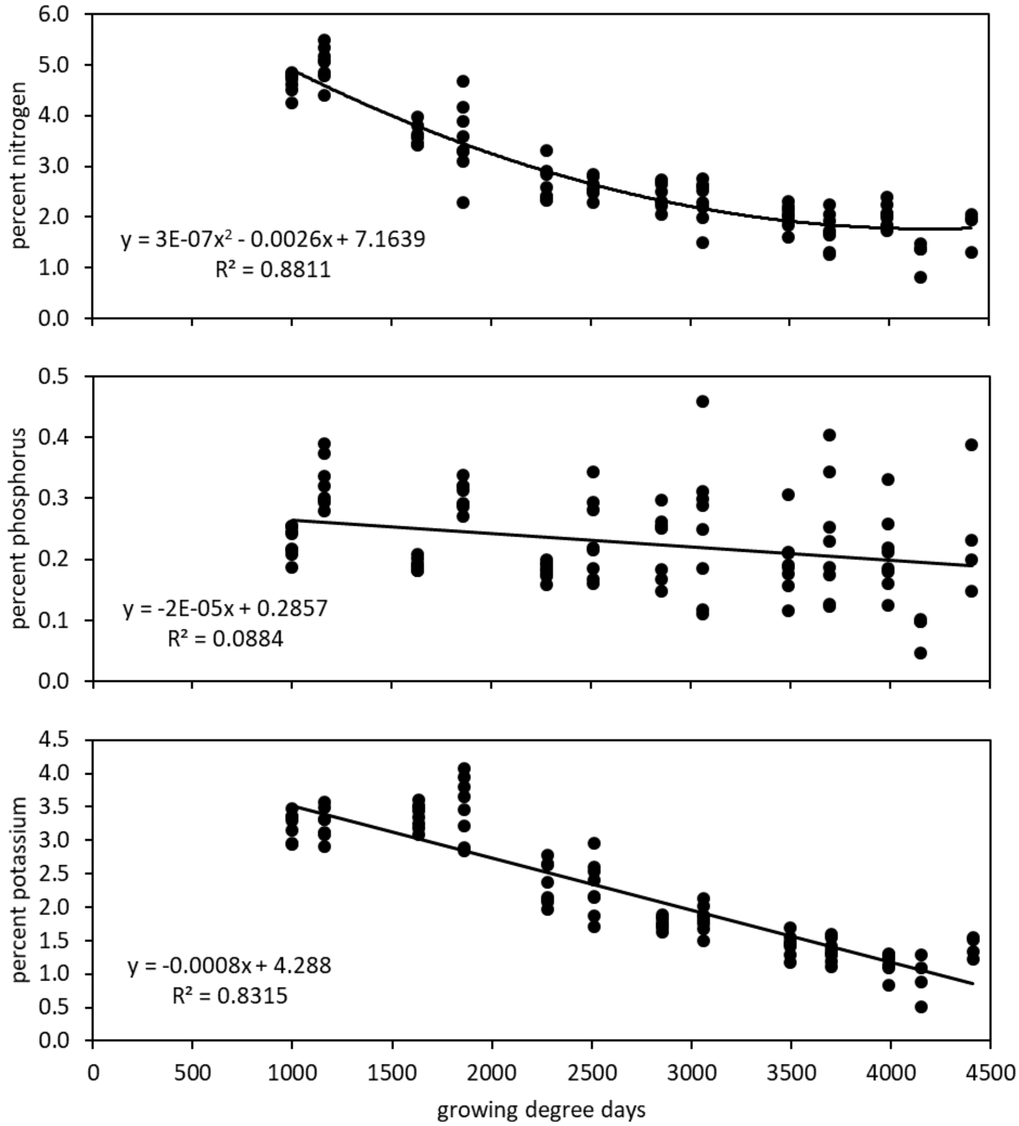


Figure 4. Macronutrient concentration of hemp dry biomass from seedling stage through harvest at Haysville and Manhattan, KS, in 2020.

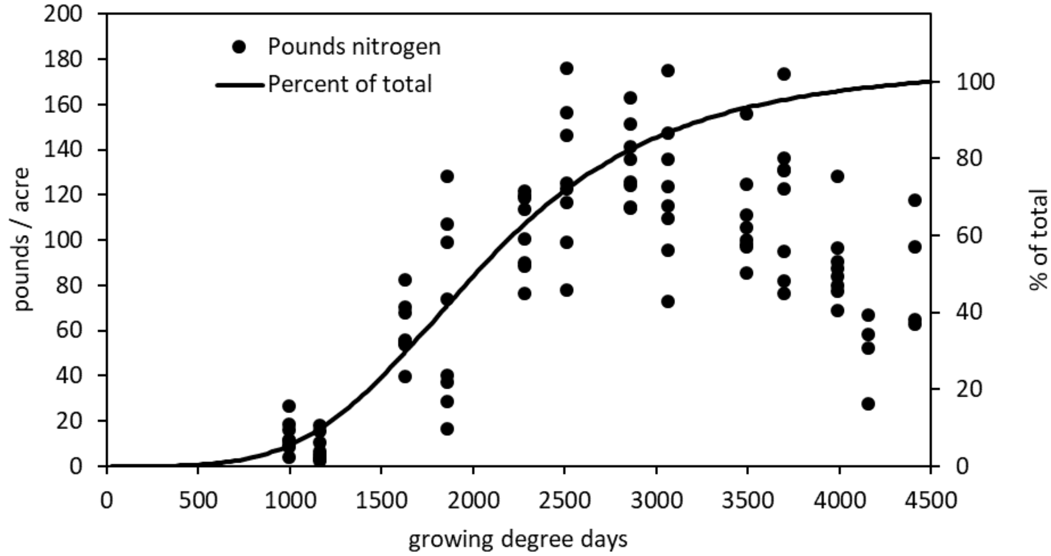


Figure 5. Nitrogen accumulation of hemp at Haysville and Manhattan, KS, in 2020. The sigmoidal model illustrating accumulation as percent of total assumes no late-season nitrogen loss.

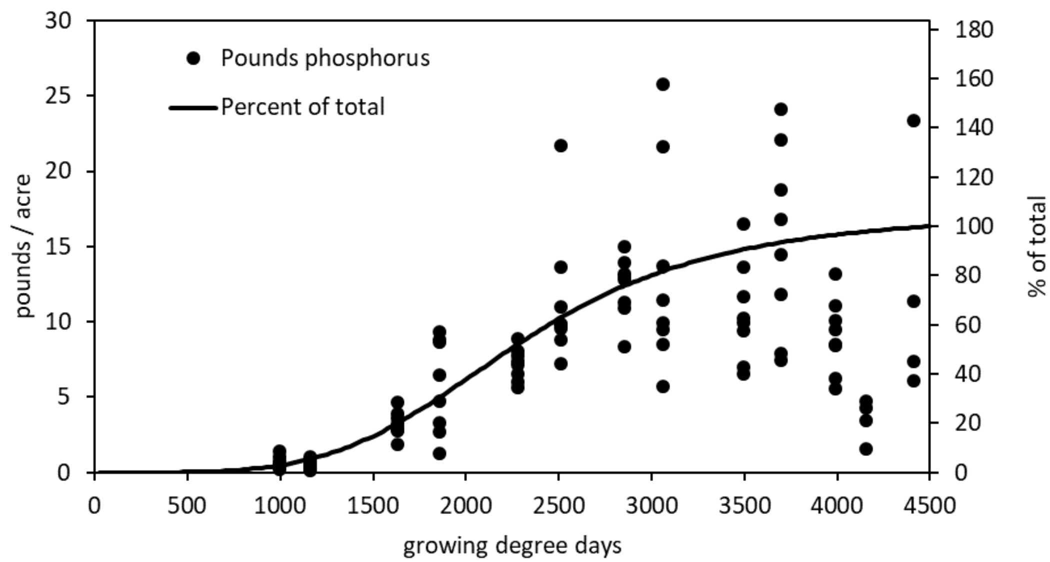


Figure 6. Phosphorus accumulation of hemp at Haysville and Manhattan, KS, in 2020. The sigmoidal model illustrating accumulation as percent of total assumes no late-season phosphorus loss.

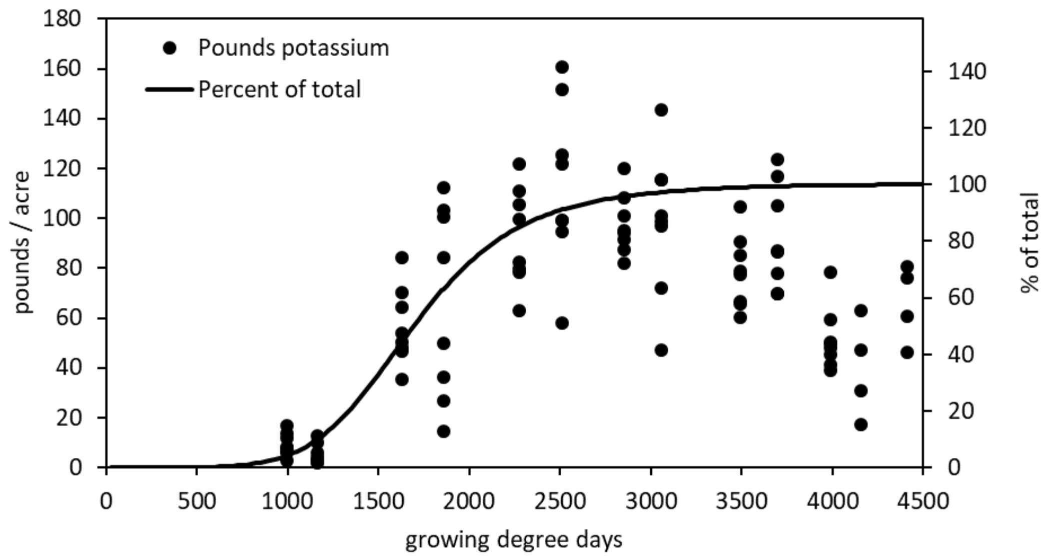


Figure 7. Potassium accumulation of hemp at Haysville and Manhattan, KS, in 2020. The sigmoidal model illustrating accumulation as percent of total assumes no late-season potassium loss.

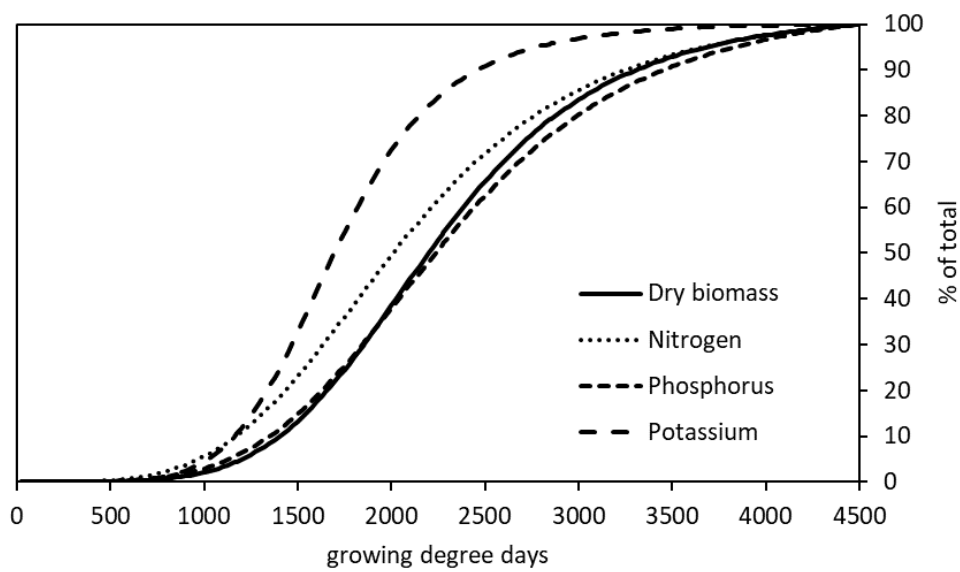


Figure 8. Dry biomass and macronutrient accumulation of hemp at Haysville and Manhattan, KS, in 2020.

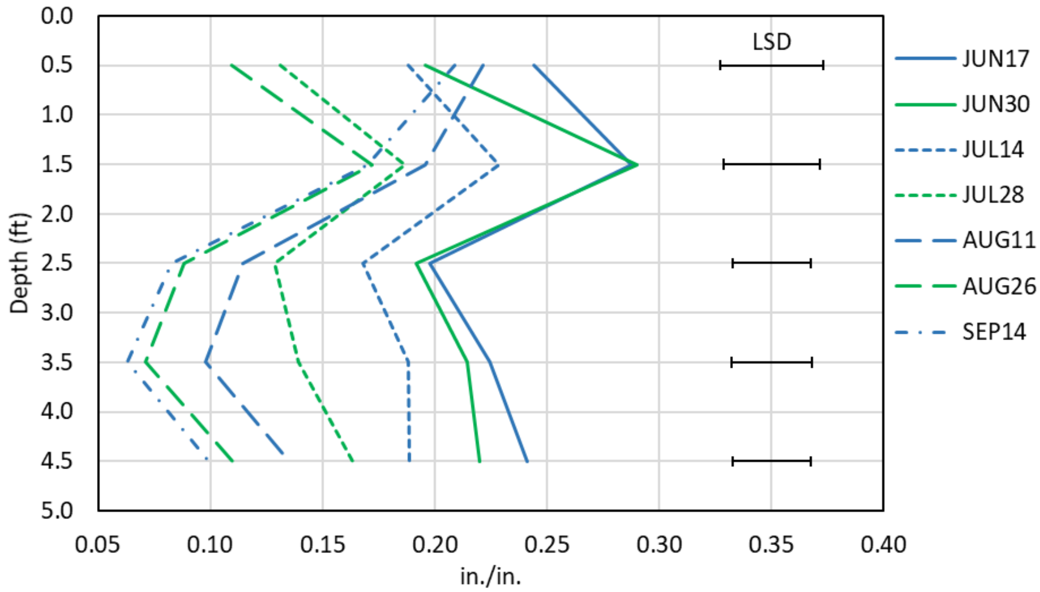


Figure 9. Volumetric water content (in./in.) at five depths in the soil profile at seven dates below hemp grown at Haysville, KS, in 2020. LSD = least significant difference. $\alpha = 0.05$.

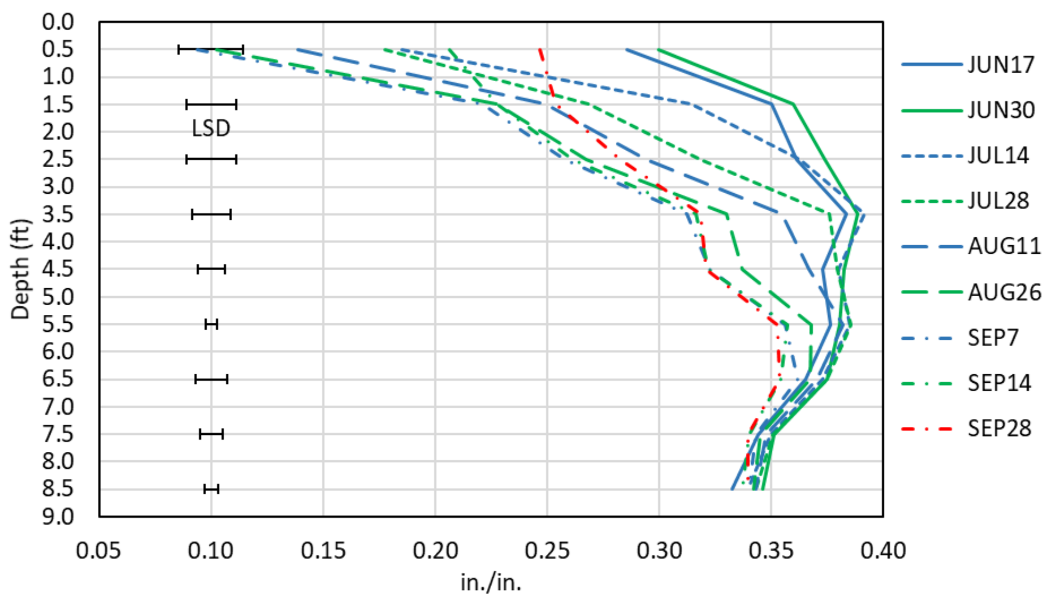


Figure 10. Volumetric water content (in./in.) at nine depths in the soil profile at nine dates below hemp grown at Manhattan, KS, in 2020. LSD = least significant difference.

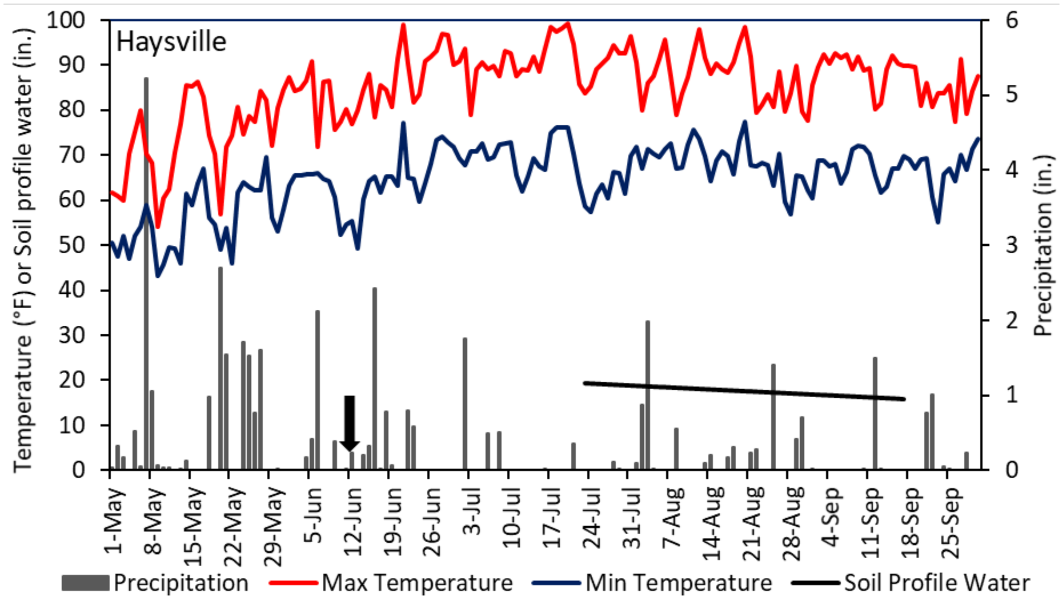


Figure 11. Daily maximum and minimum temperatures and precipitation and soil profile water content to a depth of five feet at Kansas State University John C. Pair Horticultural Center (Haysville) during the industrial hemp (*Cannabis sativa*) growing season of 2019. Planting date is indicated by the arrow. Temperature and precipitation data were obtained from the Kansas State University Mesonet weather station located on-site (mesonet.k-state.edu).

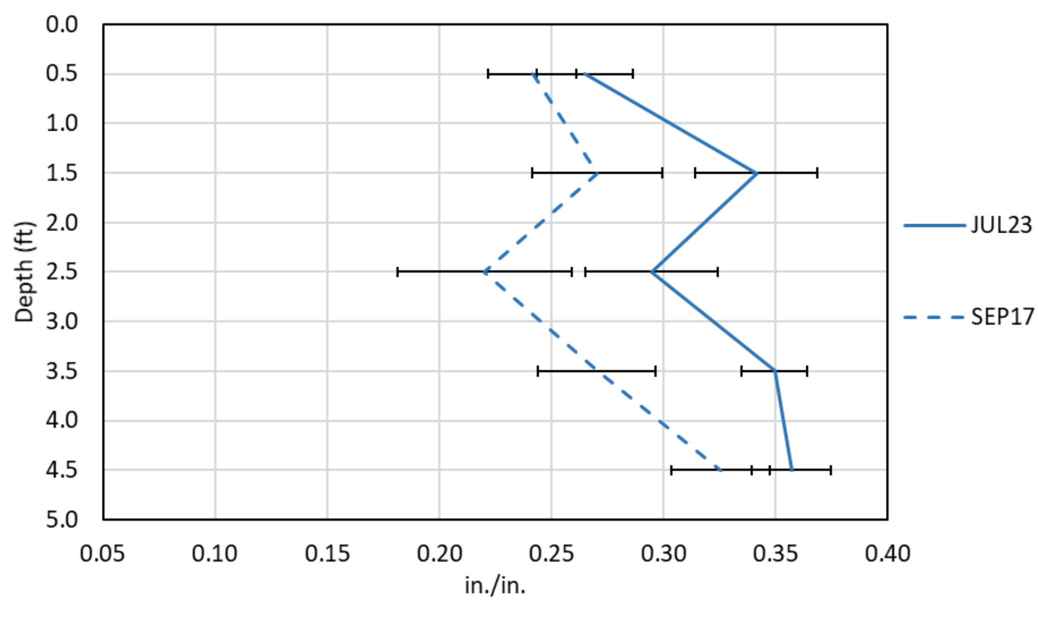


Figure 12. Volumetric water content (in./in.) at five depths in the soil profile at two dates below hemp grown at Haysville, KS, in 2019. Error bars indicate standard deviation.