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2020 Kansas State University Industrial Hemp Dual-Purpose and Fiber Trial

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2020 Kansas State University Industrial Hemp Dual-Purpose and Fiber Trial

Abstract

Hemp is a broad term used to describe the many varieties of *Cannabis sativa* L. that produce less than 0.3% tetrahydrocannabinol (THC). The crop is globally significant, but only recently was allowed to be grown again in the United States. There are many uses for industrial hemp, which include oil, seed, and fiber, and the market for industrial hemp is rapidly growing as more states are legalizing its production. The market for industrial hemp is expected to grow from $5.33 billion in 2020 to 15.26 billion (15.8%) by 2027 as it gains more popularity (Grand View Research 2021, Valuates Reports 2021). The main components driving the industrial hemp market is the demand for CBD, which provides potential health benefits and hemp fiber. Biofuel from industrial hemp is also expected to stimulate the market and demand for hemp in the future. Varieties have been selected for improved fiber and grain production that have numerous industrial uses. However, the data only exist from a single growing season (2019) regarding adaptability or production of these varieties in Kansas (Griffin et al., 2020). Hemp could be added to diversify a crop rotation and to provide new market opportunities for growers.

Keywords

fiber hemp, dual-purpose hemp, industrial hemp, hemp varieties, hemp trials

Cover Page Footnote

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2020 Kansas State University Industrial Hemp Dual-Purpose and Fiber Trial

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Introduction

Hemp is a broad term used to describe the many varieties of *Cannabis sativa* L. that produce less than 0.3% tetrahydrocannabinol (THC). The crop is globally significant, but only recently was allowed to be grown again in the United States. There are many uses for industrial hemp, which include oil, seed, and fiber, and the market for industrial hemp is rapidly growing as more states are legalizing its production. The market for industrial hemp is expected to grow from $5.33 billion in 2020 to 15.26 billion (15.8%) by 2027 as it gains more popularity (Grand View Research 2021, Valuates Reports 2021). The main components driving the industrial hemp market is the demand for CBD, which provides potential health benefits and hemp fiber. Biofuel from industrial hemp is also expected to stimulate the market and demand for hemp in the future. Varieties have been selected for improved fiber and grain production that have numerous industrial uses. However, the data only exist from a single growing season (2019) regarding adaptability or production of these varieties in Kansas (Griffin et al., 2020). Hemp could be added to diversify a crop rotation and to provide new market opportunities for growers.

In 2020, Kansans were allowed to apply for research licenses to grow industrial hemp for the second year. Limited data from the 2019 growing season demonstrated vast differences in growth and yield in south central Kansas. Therefore, controlled variety trials are necessary to determine which varieties are best adapted to the state. Currently, farmers in Kansas must rely on that single season's data combined with information generated from other states, which have vastly different growing conditions than Kansas. Variety selection is vital in hemp production considering latitude (day length) and length of growing season influence the planting date, number of days to harvest, and ultimately yield.

The objective of this study was to evaluate commercially available varieties of industrial hemp at two locations (Wichita and Manhattan) in Kansas.

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Methods

Wichita

Research plots were prepared at the Kansas State University John C. Pair Horticultural Center near Wichita, KS. The location is a flat sandy loam soil (Canadian-Waldeck fine sandy loam) averaging 32 inches of precipitation annually. The experimental plot was industrial hemp in 2019 and buffalograss for the previous 12 years. The plot was disked after the 2019 growing season and periodically through the winter to control volunteer hemp seedlings. Prior to planting in spring 2020, the plot was cultivated with a springtooth harrow. On June 3, 2020, 200 lb/a of nitrogen (46-0-0) was broadcast applied and then incorporated with a springtooth harrow. On June 5, 2020, 20 varieties of dual-purpose industrial hemp (Table 1) were seeded at a rate of 30 lb live seed/a (Figure 1). At the same time three varieties of fiber hemp were seeded at a rate of 60 lb live seed/a (Table 2). Experimental plots were 4.5 ft × 22 ft and seeded to a depth approximately 0.5 inch with a Hege 1000 drill outfitted with a Zero-Max gear box on 9-in. row spacing. The plot was irrigated with a Kifco Water Reel daily for the next 7 days. Approximately 0.25 inch of irrigation was applied per event to maintain a moist soil but to prevent any ponding of water. Seedlings were observed four days after planting.

Between-row weed control was done once by hand approximately three weeks after planting. Weeds were managed between the plots with a walk-behind self-propelled garden tiller. In the absence of rainfall, the plot was irrigated with 1 inch of precipitation weekly until plants were approximately 2-ft tall. No irrigation was applied after that.

Harvest began on August 11, 2020, and proceeded as individual varieties matured. The determination to harvest a variety was made when approximately 75% of the grain was mature. Two 1.0 m^2 sub-plots were chosen randomly for harvest in each experimental plot. For grain yield, the terminal female inflorescence (Figure 2) and primary lateral female inflorescence were removed from the plant and placed in paper bags, and air-dried for 7 days at 80°F and 45% relative humidity. Once dried, grain was manually threshed then separated from the chaff using an in-house seed separator often referred to as a 'zig-zag seed cleaner.' Plants within each sub-plot were cut at the soil surface for data collection. Data collected included: plant count per sub-plot, plant height (measured from the soil surface to the point where the female inflorescence was removed from the plant), stem caliper (measured at the soil line), and stem dry weight. Dry weight was obtained after drying samples in a forced air drying oven at 160°F for four days.

Fiber varieties were harvested after the grain harvest was complete. Similarly, two 1 m^2 sub-plots were randomly chosen for harvest in each fiber experimental plot. Plants within each sub-plot were cut at the soil surface for data collection. Data collected included: plant count per sub-plot, plant height (measured from the soil surface to the end of the terminal inflorescence), stem caliper, and whole plant dry weight.

The experimental design for the dual-purpose varieties was a randomized complete block design with 20 varieties. Two subsamples per plot were harvested and the experiment was replicated four times. Data were subjected to ANOVA and means separated by Fishers Protected LSD. An identical experimental design and analysis was employed for the three fiber varieties.

In addition to the previously mentioned data, on August 14, 2020, the terminal 8 in. of five plants selected at random were collected from each variety of three replications. These samples were air-dried similarly to the grain samples. The plant material was then analyzed for THC and cannabidiol (CBD) content at the K-State Olathe Post-Harvest Physiology Laboratory using standard laboratory techniques for such analysis. Data were subjected to ANOVA and means separated by Fisher's protected LSD.

Manhattan

A similar experiment was conducted comparing 18 hemp varieties at the K-State Research and Extension Ashland Bottoms Research Farm (latitude 39.1223, longitude -96.6382) in Manhattan, KS. Plots were 6-ft wide and 25-ft long. Nitrogen fertilizer was applied at a rate of 180 lb/a with a sprayer fitted with streamer bars. On June 8th, prior to planting, emerged weeds were terminated with glufosinate and clethodim.

Plots were planted the same day with a Great Plains No-Till cone drill at a rate of 914,760 pure, live seeds per acre. Plots consisted of 9 rows spaced at 7.5 inches with samples and data collected from the center, bordered rows in each plot.

Seedling emergence was observed on June 14th and the stands were determined to be acceptable. Hand weeding was used to control weeds that emerged after planting. First bud dates were determined by visual inspection. The number of emerged plants was determined on June 26th by counting the number of plants in a sample area of 9.4 ft^2. Plants were also counted at harvest, and the plant survival (%) was calculated as (harvest plant density/emerged plant density) × 100. Harvest consisted of hand cutting plants at ground level from an area of 21.5 ft^2 within each plot. The entire sample was dried for one week. After drying, total 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 determine 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/lb.

The experimental design was a randomized complete block design with 18 varieties replicated four times. Data were subjected to analysis of variance using SAS GLIMMIX procedure to determine least square means and mean separations for each response variable at $\alpha = 0.05$.

Results and Discussion

Wichita

The growing season of 2019 can be summarized as favorable for hemp growth (Figure 4). The summer was warm without any extended high temperatures, and occasional precipitation was helpful without flooding or hail events. The first hemp planting was successful and good stands were established. Experimental plots with good germination and rapidly growing seedlings were able to outcompete weeds. Varieties with low germination or overall short stature quickly were overcome with grassy weed infestation.

Growth and yield were highly influenced by variety in this experiment (Table 3). Varieties NWG 452, Vega, Anka, and Altair had good germination with more than 240,000 plants/a. These varieties were sufficiently dense to suppress weed competition for the growing season. Hlesia, NWG 2730, and Helena also produced good stands of vigorous plants with more than 178,000 plants/a that suppressed weed competition satisfactorily. The remaining varieties had fewer than 170,000 plants per acre and weed suppression was inconsistent to unacceptable. It should be noted that Fedora 17, Felina 32, and Rigel, while having fewer plants/a, were taller than many varieties with similar plant densities. These varieties did have acceptable weed suppression suggesting plant height (or early season vigor) as well as plant density influenced weed suppression. Varieties with poor plant densities and less height had the greatest weed infestations. Helena was the tallest and produced the greatest stem dry weight, but NWG 2730 was statistically similar in stem dry weight and height. NWG 452 was the only other variety to produce greater than 4,000 lb/a stem dry weight. Altair and Anka were the only other varieties in the study to yield greater than 3,000 lb/a stem dry weight. Plant height also varied greatly among the varieties. There were similarities between stem dry weight and height. Helena and NWG 2730 were the tallest, but NWG 452 and Anka were less than 8 in. shorter. These four varieties, along with Altair and Bialobrezskie, were the only varieties among the 20 evaluated to average greater than 39 in. in height. Stem caliper was the last growth parameter measured. Helena, NWG 730, and USO 31 had the greatest stem diameter. Felina 32 and Bialobrezskie were the only other varieties to have stem caliper of 1 cm or greater. Only three varieties yielded greater than 2,000 lb/a grain. X-59 yielded the highest grain weight. Henola and Vega were the other two varieties with high yields. Interestingly, neither X-59 nor Henola had very high stand establishment, stem dry weight, height, or caliper. Vega did have a good stand establishment, but stem dry weight, height and caliper were only average for the 20 varieties. Of the varieties that had good germination and produced sufficiently dense plant stands to suppress weeds, Altair, Vega, and NWG 2730 also produced high grain yields. Some varieties that produced good grain yields, surprisingly had low plant stands that were weed-infested. More research is needed to investigate methods for producing dense stands capable of outcompeting weeds that also yield abundant grain.

In general, fiber varieties were more vigorous (growing faster and ultimately taller) than the dual-purpose varieties (Table 4) and successfully prevented weed infestation. There were no differences between the varieties for plants per plot or any of the growth measurements. Stand density ranged from approximately 213,000 (Fibranova) to 270,000 (Jinma) plants/a. Neither variety yielded 5 tons of stem dry weight per acre. However, Eletta Campana was close (9,890 lb/a). Plant height and stem caliper were similar among the varieties. Cannabinoid content was low in all varieties. However, Jinma did have less CBD and higher THC content than the others.

The quantity of CBD in the inflorescence was impacted by variety (Table 5). However, none of the varieties produced enough CBD to be commercially viable. THC content was similar among the varieties and all were below 0.2%.

No significant pest populations were observed during the growing season. As the grain matured, small birds and a flock of turkeys were frequently observed visiting the plot.

Manhattan

Stand establishment varied widely depending on the variety. Bialobrzeskie had the lowest establishment (89,443 plants/a) (Table 6) while Vega had the highest establishment (333,832 plants/a). Population counts for the remaining varieties ranged between 100,000 and 300,000 plants/a.

Harvest stand establishments and percent of plant survival also varied greatly depending on variety. The variety with the lowest harvest population was Canda (69% survival) with 69,295 plants/a, whereas Vega had the highest population (126% survival) with 333,832 plants/a (Table 6). In general, varieties with higher harvest population produced more pounds of grain per acre. Additionally, varieties with higher plant populations in June also had higher plant populations at harvest. Percent survival was calculated based on stand establishment but counts were not taken in the same exact area of the plot each time, causing some of the survival percentages to be greater than 100%. NWG 2730 had the lowest plant survival (54%) while Hlukhovskii 51 had the highest plant survival (131%) (Table 6).

The determination of first bud and harvest date were key to which varieties would arrive at maturity the quickest. The varieties that were the quickest to form buds were CFX-1 and Katani, which took 19 days from planting to first bud (Table 6). The variety latest to bloom was NWG 2730 with a first bud date of July 11, which is 33 days after planting. The remaining varieties' first bud date clustered around 184th day of the year, which is the end of June and beginning of July and is about 22-28 days after planting. The variety with the earliest harvest date was Vega on August 28 (81 days after planting). The variety last to harvest was NWG 2730 on September 28 (112 days after harvest) (Table 6). All other varieties had similar harvest dates. Varieties that were harvested earlier produced more pounds of grain per acre. Also, varieties that had an earlier harvest date arrived at first bud sooner.

Hemp variety strongly influenced yield (Table 7). Altair had the greatest total plant biomass (5,442 lb/a), and Canda had the lowest total biomass (2,832 lb/a). Varieties with greater total biomass also produced more stover and had a higher percent survival. The variety with the lowest grain yield was NWG 452, while Vega had the largest. Grain yields of the remaining varieties were similar and all were within approximately 200 pounds of each other. CFX-1 produced the least amount of stover, and Hlesia had the most. The tallest variety was NWG 2730 (76 in.) and Katani was the shortest (32 in.). Varieties that were shorter tended to produce more grain per acre, while taller varieties produced more stover, arrived at first bud later, and had a later harvest date.

This was the second year of industrial hemp research in Kansas and there is a great need for further variety and production-based research. There is much variation among the varieties evaluated. Planting date, rainfall, and temperatures greatly influence plant productivity. This growing season was well suited for hemp production, but variety evaluations under more adverse conditions will be important. In our trial, planting occurred in early June. With a limited number of days to grow before the summer solstice and decreasing day length, many of the varieties failed to achieve the anticipated height and possibly yielded less grain than they would have if they were taller with more branching. Research to investigate planting date, fertility, and water requirements will be planned for the future.

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The authors wish to thank Horizon Hemp Seed, Legacy Hemp, New West Genetics, and Schiavi Seed for generous donation of seed, and the Kansas Department of Agriculture for collaborative support throughout the project.

Table 1. Variety, percent germination, and origin information for dual-purpose industrial hemp (*Cannabis sativa*) planted in 2020

Variety name	Germination, %*	Source
Altair	91	Horizon Hemp Seeds/UniSeeds
Anka	92	Horizon Hemp Seeds/UniSeeds
Bialobrezskie	77	Bija Hemp
CFX-1	90	Hemp Genetics International
CRS-1	94	Hemp Genetics International
Fedora 17	83	Schiavi Seed
Felina 32	84	Schiavi Seed
Hlukauskii 51	92	Fiacre Enterprises
Helena	65	Schiavi Seed
Henola	81	Bija Hemp
Hlesia	89	Fiacre Enterprises
Hliana	87	Fiacre Enterprises
Joey	57	Parkland Industrial Hemp Growers
Katani	93	Hemp Genetics International
NWG 2730	93	New West Genetics
NWG 452	93	New West Genetics
Rigel	72	Horizon Hemp Seeds/UniSeeds
USO 31	60	Schiavi Seed
Vega	86	Horizon Hemp Seeds/UniSeeds
X-59	80	Legacy Hemp

*From pre-plant germination tests.

Table 2. Variety, percent germination, and origin information for fiber industrial hemp (*Cannabis sativa*) varieties planted at the Kansas State University John C. Pair Horticultural Center (Wichita) in 2020

Variety name	Germination, %*	Source
Eletta Campana	58	Schiavi Seed
Fibranova	66	Schiavi Seed
Jinma	64	Sunstrand

*From pre-plant germination tests.

Table 3. 2020 K-State John C. Pair Horticultural Center (Wichita) dual-purpose industrial hemp (*Cannabis sativa*) variety trial harvest data

Variety	Stand (plants/a)	Stem DW (lb/a)	Height (in.)	Caliper (cm)	Grain Yield (lb/a)	Plant Yield (g/plant)
Altair	244430 bc	3115 cd	39 de	0.74 fghi	1776 abcd	3.4 ghi
Anka	267093 ab	3568 bc	49 c	0.82 efgh	1369 cdef	2.5 hi
Bialobrezskie	76890 gh	2483 de	42 d	1.00 bcd	1290 def	9.7 bc
CFX-1	109670 fgh	731 hi	18 kl	0.63 ij	1584 cde	7.3 bcde
CRS-1	163088 def	1420 gh	26 ij	0.63 ij	1991 abc	5.5 defgh
Fedora 17	151352 def	2562 de	34 fgh	0.87 cdef	1696 bcde	5.4 defghi
Felina 32	127476 efg	2846 cde	38 def	1.03 bc	1296 def	6.5 cdefg
Hlukauskii 51	169968 def	2922 cde	35 efg	0.82 efgh	1250 def	3.3 ghi
Helena	178062 cde	4800 a	56 a	1.14 ab	1411 cdef	3.6 fghi
Henola	168349 def	2409 de	33 fgh	0.83 defgh	2288 ab	6.6 cdefg
Hlesia	198296 cd	2316 e	33 fgh	0.68 ghi	1276 def	2.9 hi
Hliana	53419 h	1191 gh	26 ij	0.83 efgh	901 f	7.2 bcde
Joey	55847 h	881 ghi	22 jk	0.98 bcde	1765 abcd	15.9 a
Katani	83365 gh	439 i	14 l	0.56 j	1549 cde	8.4 bcd
NWG 2730	184537 cde	4529 a	55 ab	1.20 a	1672 bcde	4.5 efghi
NWG 452	319297 a	4244 ab	50 bc	0.84 defg	1209 def	2.1 i
Rigel	106432 fgh	2246 ef	35 efg	0.86 cdef	1503 cdef	6.9 bcde
USO 31	47348 h	1545 fg	29 hi	1.04 ab	1070 ef	10.1 b
Vega	280447 ab	2268 ef	32 ghi	0.66 hij	2000 abc	3.5 fghi
X-59	127476 efg	1008 ghi	20 k	0.75 fghi	2380 a	9.7 bc
Significance	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$	$P < 0.0008$	$P < 0.0001$

Means within a column followed by the same letters are not significantly different.
Data are a mean of four replications. DW = dry weight.

Table 4. 2020 K-State John C. Pair Horticultural Center (Wichita) industrial hemp (*Cannabis sativa*) fiber variety trial harvest data and cannabinoid content

Variety	Stand (plants/a)	Stem DW (lb/a)	Height (in.)	Caliper (cm)	CBD (%)	THC (%)
Eletta Campana	246858	9890	98	1.66	1.04 a	0.03 b
Fibranova	213674	9210	96	1.28	0.87 a	0.02 b
Jinma	272353	8783	94	1.15	0.10 b	0.33 a
Significance	NS ($P < 0.08$)	NS ($P < 0.76$)	NS ($P = 0.73$)	NS ($P < 0.34$)	$*P = 0.01$	$*P < 0.01$

Means within a column followed by the same letters are not significantly different.
Data are a mean of four replications.
DW = dry weight. CBD = cannabidiol. THC = tetrahydrocannabinol. NS = not significant.

Table 5. 2020 K-State John C. Pair Horticultural Center (Wichita) dual-purpose industrial hemp (*Cannabis sativa*) variety trial cannabidiol (CBD) and tetrahydrocannabinol (THC) analysis

Variety	CBD (%)	THC (%)
Altair	0.66 cdef	0.05
Anka	0.89 bcde	0.02
Bialobrezskie	0.95 bcd	0.10
CFX-1	0.59 def	0.01
CRS-1	1.03 bcd	0.03
Fedora 17	1.32 b	0.04
Felina 32	1.08 bc	0.13
Hlukauskii 51	0.05 g	0.00
Helena	0.76 cdef	0.02
Henola	0.89 bcde	0.03
Hlesia	0.04 g	0.00
Hliana	0.05 g	0.00
Joey	0.65 cdef	0.19
Katani	1.94 a	0.07
NWG 2730	1.08 bc	0.09
NWG 452	0.59 def	0.07
Rigel	0.66 cdef	0.03
USO 31	0.36 fg	0.01
Vega	0.45 efg	0.03
X-59	0.72 cdef	0.01
Significance	*$P < 0.0001$	NS $P < 0.09$

Means within a column followed by the same letters are not significantly different.
Values are a mean of 3 replications.

Table 6. 2020 industrial hemp dual-purpose variety trial data from Manhattan; bud and harvest dates, early (June) and end of season (harvest) plant density, and plant survival

Variety	First bud		Harvest		June		Harvest		Plant survival†	
	------------- day of year		-------------		-------------- plants per acre		--------------		-------- % --------	
Altair	183	ed‡	249	dec	276,461	bac	300,954	ba	115	a-d
Anka	185	cb	259	bac	159,139	fde	150,351	gh	98	a-d
Anka-U	184	cbd	258	bdc	295,046	a	237,223	bdc	80	c-f
Bialobrzeskie	184	ced	259	bac	89,443	g	107,231	igh	115	bac
Canda	181	e-h	259	a-d	98,736	fg	69,295	i	69	ef
CFX-1	179	h	245	de	195,149	dec	129,486	igh	68	ef
CRS-1	180	fgh	242	e	202,118	b-e	232,165	b-e	117	bac
Henola	185	cbd	249	dec	211,411	bdc	230,142	b-e	108	a-e
Hlesia	184	cbd	249	dec	199,795	dec	209,909	c-f	135	a
Hliana	184	ced	251	b-e	101,059	fg	111,783	igh	117	bac
Hlukhovskii 51	183	fed	263	ba	119,645	feg	153,259	fgh	131	ba
Joey	182	d-f	247	de	104,544	fg	84,975	ih	90	b-d
Katani	179	h	242	e	224,189	a-d	162,869	feg	73	edf
NWG 2730	193	a	272	a	210,540	bcd	110,898	igh	54	f
NWG 452	187	b	271	dec	240,451	bac	150,730	fgh	67	ef
Rigel	184	ced	248	dec	228,835	bac	255,432	bc	123	ba
Vega	184	ced	241	e	284,592	ba	333,832	a	126	ba
X-59	180	gh	252	b-e	195,149	dec	169,445	d-g	93	a-e

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

Table 7. 2020 industrial hemp dual-purpose variety trial yield and height data from Manhattan

Variety	Total biomass		Grain		Stover		Height	
	------------------------ pounds per acre ------------------------						------- inches -------	
Altair	5,442	a[†]	1,576	bac	3,866	ba	64	ed
Anka	4,286	bc	1,082	fe	3,204	b	73	bc
Anka-U	4,450	bac	1,086	fde	3,364	ba	68	dc
Bialobrzeskie	4,951	ba	1,020	fe	3,931	ba	74	ba
Canda	2,832	e	1,008	fe	1,824	e	55	igh
CFX-1	3,067	ed	1,394	a-d	1,673	e	37	kj
CRS-1	3,691	edc	1,537	bac	2,154	de	43	j
Henola	5,085	ba	1,638	ba	3,447	ba	55	ih
Hlesia	5,397	a	1,355	b-e	4,042	a	60	e-h
Hliana	4,081	bcd	967	fg	3,114	bc	60	e-h
Hlukhovskii 51	4,455	bac	1,008	fe	3,447	ba	62	d-g
Joey	3,000	ed	1,249	c-f	1,751	e	56	f-i
Katani	3,446	edc	1,506	bac	1,939	e	32	k
NW G2730	3,359	ed	714	hg	2,645	dc	76	a
NW G452	2,955	e	453	h	2,502	dce	74	bac
Rigel	4,907	ba	1,387	bdc	3,520	ba	62	edf
Vega	4,918	ba	1,747	a	3,171	bc	50	i
X-59	3,713	edc	1,576	bac	2,137	de	39	j

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

Figure 1. Hege 1000 grain drill for planting hemp variety plots.

Figure 2. Female inflorescence with grain ready to harvest.

Figure 3. Higher seeding rate of fiber varieties ensures straight stems with little branching.

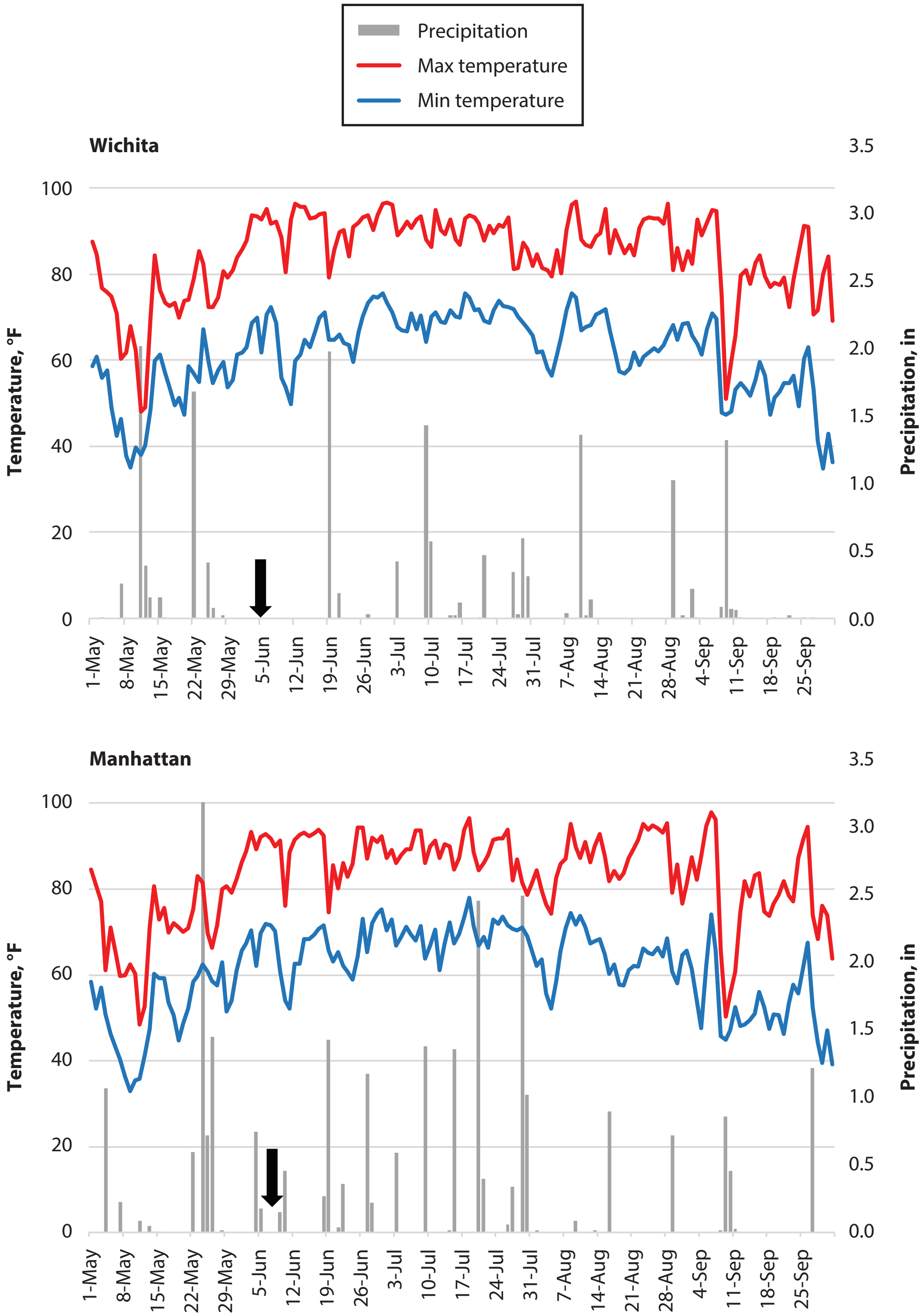

Figure 4. Daily maximum and minimum temperatures and precipitation at the Kansas State University John C. Pair Horticultural Center (Wichita - top) and Ashland Bottoms (Manhattan - bottom) during the industrial hemp (*Cannabis sativa*) growing season of 2020. Planting date is indicated by the arrow. Data were obtained from the Kansas State University Mesonet weather station located on site (mesonet.k-state.edu).