Chapter 3
Industrial Hemp in the USA: A Brief Synopsis

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Abstract Industrial hemp has a long history of use in the U.S.A. Historically the crop was grown for fiber for home use as well as for ship cordage, rigging and sails, and this made the crop of strategic importance. The end of slavery, changing technologies, and other competing fibers all played roles in hemp's decline as an important commodity in the U.S.A., but prohibition through various federal legislation essentially created a 70-year hiatus for the crop. Changes in U.S. federal legislation have made hemp once again legal, and the crop is returning to production fields. However, this time around the majority of effort with the crop is for flowers production. Most regions of the country have seen rapid expansion of acres in hemp flower production, largely due to the potential returns significantly greater than possible with other commodity crops. Opportunities for other hemp products – i.e., grain and fiber – remain more restricted as processing capacity, particularly for fibers, is limited. However, regions such as the Mid-West and Great Plains are

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likely to be able to grow hemp grain in rotation with other crops given that this part of the U.S.A. has grain suitable infrastructure capable of handling hemp. Both long-term farmers and agricultural neophytes are engaging in efforts to grow hemp flowers, and it is likely that the market for cannabidiol (CBD) hemp growers will remain volatile over the next few years. Still-evolving Federal guidelines provides further uncertainty to these markets. Current production models rely on labor-intensive production, harvest and processing systems, and the application of technologies such as mechanization is likely to introduce significant changes in costs, value, and opportunity for this new industry. To date, research has largely focused on plant varieties and management. Efforts to address issues such as low seed vigor and seed shatter would likely have value across all hemp production systems. Research work also is being conducted on disease resistance and management, weed management and herbicide susceptibility. After a long interruption, U.S.A. efforts to improve industrial hemp are in the beginning stages of an exciting new chapter for this crop.

Keywords Hemp · Markets · Fiber · Grain · Cannabinoids

Abbreviations

CBD Cannabidiol
THC Δ9 Tetrahydrocannabinol

3.1 Introduction

Renaissance of an industrial hemp industry has been slower in the U.S.A. than in Europe and Canada, perhaps because of historic drug policies and the consequent cultural stigma associating all things *Cannabis* with recreational marijuana. Interestingly, people on opposite ends of the political spectrum found common ground in their efforts to legalize industrial hemp production in the U.S.A. At a state level, Colorado and Kentucky – which historically have had somewhat different attitudes towards recreational *Cannabis* – made some of the first efforts to push hemp forward. Former Kentucky Commissioner of Agriculture, James Comer, has told how his campaign platform to legalize hemp production allowed him to garner support both from rural conservatives as well as urban liberal voters during the early days of the hemp revival. The public's changing of opinions about industrial hemp may reflect more relaxed attitudes toward marijuana use for medicinal and recreational purposes, as well as a growing perception that hemp has potential as a renewable fiber, food, fuel, and pharmacological crop. Many claims surrounding the utility and sustainability aspects of hemp have yet to be borne out – it's really too early to tell. Much of the early (and continued) boosterism surrounding hemp was based on the idea that the crop may be grown multiple purposes and multiple

products. However, whether management for multiple outputs (i.e., for any combination of feed/food, fibers, and flowers) makes economic sense remains to be seen. Any multi-product system is likely to involve some level of tradeoffs and will require optimizing the product outputs on the basis of their value in the market. Anecdotal evidence also suggests that hype may be an important factor behind corporate production and market decisions. For example, recent U.S.A. research suggests kenaf (*Hibiscus cannabinus*) may be just as useful and more productive than hemp as a fiber crop. However, we know of a fiber processor capable of processing both fiber species that works with growers producing hemp – not because hemp produces the highest yields or quality, but because of the market's particular interest in (and demand for) the crop.

In the U.S.A., hemp is at an early stage as a crop in the marketplace, having only been legalized for production (outside of state research programs) with passage of the 2018 Farm Bill. As of this writing (spring 2019), only a few states remain holdouts with respect to legalizing hemp production. But what does "hemp production" really mean? There are significant regional differences as well as similarities in approach to hemp production across the U.S.A., and our purpose here is to provide some historical context and a brief synopses of the hemp systems we see developing on a regional basis as this "new" crop gains traction.

3.2 A Brief Historical Context for Hemp in North America

Hemp has a long history in North America, with the British colonists growing the crop along the Atlantic seaboard from Canada and New England to Georgia, southernmost of the 13 U.S. colonies. The crop largely was used for fiber for "homespun" cloth as well as for rope, but it was not particularly competitive with the European hemp grown and processed for high quality canvas given differences in production techniques and trade laws that prevented the shipping of finished products to Europe (Duvall 2014). Hemp production in the colonies was further constrained by the greater value of food and cash crops, particularly tobacco. Hemp traveled into the heartland as colonists moved beyond the Appalachian Mountains, and it would become a primary crop for setters in Kentucky and parts west. Ironically, one fiber industry supported another, as hemp largely was grown for rope and cordage to bundle and bale the cotton (*Gossypum hisrutum*) that was grown in Deep South states. During the U.S. Civil War, Midwestern states lost their market for hemp fibers, and following the war, freed men and women had little desire to return the labor of their enslavement. By the turn of the twentieth century, development of new technologies such as metal binding for cotton bales, the rise of steam- and fossil-fueled ships, and the availability of cheaper imported fibers were reducing the value and markets for hemp. Despite these changes, hemp was still considered a crop or strategic interest, and USDA research on the mechanization of hemp production began in a similar timeframe and lasted about two decades.

Early U.S. researchers identified the basic production practices to aid growers in successful production. Dewey (1902) reported low hemp production on poorly drained, infertile, and drought prone soils. In established stands, Dewey noted hemp's extensive taproot enabled soil water extraction from depths up to 3 m into the soil profile. Non-uniform and reduced stands were observed on heavy clay soils, which caused plants to branch and produce larger stems, resulting in harvest difficulties and reduction of fiber quality. In 1919, Haney reported seeding hemp between May 10 and May 20 in North Dakota, depending on spring conditions with emphasis on soils having sufficiently warmed to promote rapid emergence and stand establishment. Haney (1919) also noted hemp in thick stands could be competitive with weeds, including perennial grasses and thistles, depending on establishment timing. Haney (1919) stated, "Trials of hemp have proven satisfactory and with the machinery that has been developed recently makes this an important and valuable crop."

Although significant strides were made in plant breeding and mechanization during this time (Wright 1918; Dewey 1928), such progress was insufficient to keep the crop within the good graces of those politicians who were bent on outlawing the hemp as a psychoactive plant material. Despite opposition from the American Medical Association, the U.S. government passed the Marihuana Tax Act (MTA) in 1937, placing cultivation of all *Cannabis* under the U.S. Treasury Department's control (USDA 2000). This measure effectively constrained hemp production in the U.S.A., but concerns over lost access to cheap foreign fibers during World War II led the U.S. government to support a "Hemp for Victory" campaign in which several thousand farmers were recruited to grow the crop (Johnson 1999). Following the war, hemp production rapidly declined in the face of cheaper imported materials and the development of synthetic fibers. By the time the Controlled Substances Act made all *Cannabis* a Schedule I drug, opportunity to grow the crop was already out of reach for farmers, and it would remain so for over 30 more years, when the Agriculture Act of 2014 opened the possibility of research with hemp in the U.S.A.

The Farm Act of 2014 authorized U.S. states to define pilot research programs for the cultivation of industrial hemp, and several embraced the opportunity to initiate research into hemp cultivation and passed legislation authorizing industrial hemp pilot programs. Although this poised those states to become producers of industrial hemp – providing healthy hempseed oil and fiber for textiles, insulation and other uses – there was no foundational knowledge of hemp cultivation or infrastructure in place to initiate a hemp industry. However, based on historic cultivation of hemp, there was and is great potential to incorporate hemp grain, fiber, and CBD crops into rotation with field crops and vegetables into U.S. agriculture, allowing farmers to diversify their production and improve sustainability.

3.3 Renaissance of Hemp in the U.S.A – Regional Variations on a Theme

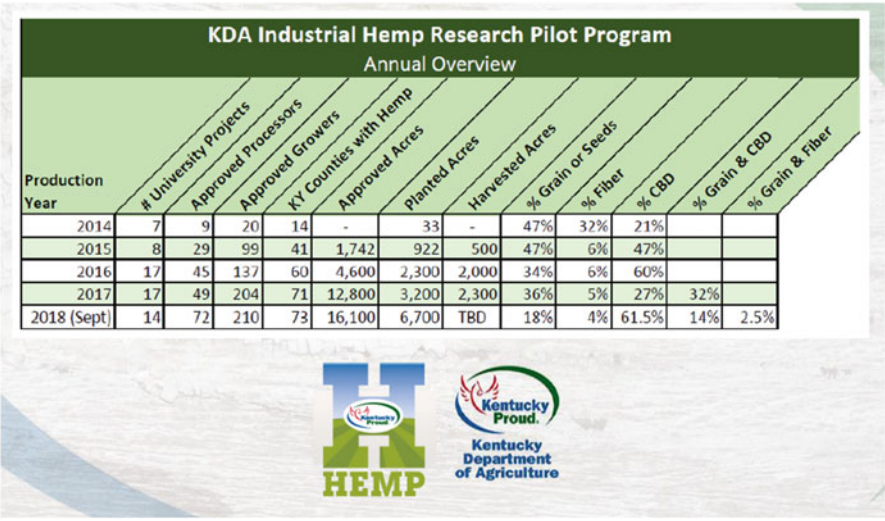
Following what was essentially a 70-plus-year absence in production, industrial hemp (*Cannabis sativa* L.) is again being grown across the U.S.A. Previously published research regarding agronomic guidelines for industrial hemp production in the United States are severely dated and limited – and new uses for the crop are changing the research needs. Initial university research trials and efforts from state-pilot programs have thus begun the process of defining the basic agronomic guidelines for hemp production that will aid in successful crop commercialization. While we will highlight efforts from various regions of the U.S.A., we start with the specific case of Kentucky, both because it was an early leader in the country's hemp production efforts and because that state's experiences have been common for many states that have followed.

3.3.1 Hemp in Kentucky and the Southeast

In the spring of 2014, the Kentucky Department of Agriculture (KDA), then led by Commissioner James Comer, began work towards the establishment of a pilot research program with industrial hemp under the provisions of the newly passed Farm Bill. Being a brand-new initiative on all levels, there were several bumps in the road as those efforts moved forward. However, through the efforts of KDA and several universities, hemp was planted across the state in 2014. While the quality of the scientific data derived from these initial efforts was limited, the experiences gained at all levels, *i.e*. administrative and agronomic, were extremely valuable, enabling the program to move forward efficiently and effectively.

In 2015, much more work (both in numbers of farms and acres) was conducted on private lands than by university researchers. The KDA administrators of the pilot research program considered and deduced that under the language of the Farm Bill, research efforts involving marketing must inherently also involve both the ability of farmers to sell to processors, and for processors to sell goods to the public. Hence, a renewed hemp industry in Kentucky was underway in earnest. At that point in time, there was one very striking difference in industry efforts relative to subsequent and current efforts. A slight majority of total interest focused on fiber and grain, with a slight minority of the efforts focused on cannabinoid production (Fig. 3.1).

However, from 2016 to today, the majority of efforts have focused on "flower" production for cannabinoid-based products and relatively very small efforts towards fiber and/or grain. By 2019, there were 1075 applicants to the KDA hemp program; 1009 of which applied to focus on cannabinoid production (93% of all applicants).



KDA Industrial Hemp Research Pilot Program
Annual Overview

Production Year	# University Projects	Approved Processors	Approved Growers	KY Counties with Hemp	Approved Acres	Planted Acres	Harvested Acres	% Grain or Seeds	% Fiber	% CBD	% Grain & CBD	% Grain & Fiber
2014	7	9	20	14	-	33	-	47%	32%	21%		
2015	8	29	99	41	1,742	922	500	47%	6%	47%		
2016	17	45	137	60	4,600	2,300	2,000	34%	6%	60%		
2017	17	49	204	71	12,800	3,200	2,300	36%	5%	27%	32%	
2018 (Sept)	14	72	210	73	16,100	6,700	TBD	18%	4%	61.5%	14%	2.5%

Fig. 3.1 Data from the Kentucky Department of Agriculture industrial hemp pilot research program 2014–2018

Similar responses have occurred in other states across the U.S.A., with larger numbers of people getting into the business of hemp production, whether they know anything of crop production or not. Interest is driven by the perceived potential profit from cannabinoid production, which has attracted a very large and diverse group of program participants. Data in Fig. 3.2 indicates that in Kentucky in 2017, average yields and average prices for the crop clearly favored cannabinoid production relative to fiber and grain by highly significant amounts. This potential has created a real interest in cannabinoid agriculture by life-long, highly successful farmers alongside those who literally have never cultured a crop of any kind before. The diversity of interest is staggering, as is the likely potential range of success and failure.

Although a lone southern state (Mississippi) currently holds out against hemp production, other states in the Southeast that have engaged in hemp production have seen similar patterns of interest and exponential increases in production efforts as occurred in Kentucky. E.g., Virginia went from a handful of producers growing hemp in 2018 for university research to over 750 registered growers with over 7500 registered acres in 2019 – almost all for flowers. Interestingly, those states that historically had hemp industries (particularly in the Southeast and mid-Atlantic regions of the U.S.A.) were more aggressive in developing hemp research (and then full-scale production) programs. Many of these same states also have had a long tradition of tobacco production. Until very recent times, tobacco was produced on very small family farms as well as large, corporate operations. Once it was established that tobacco's consumption and use could contribute to negative health outcomes, the federal government slowly removed support for the crop, which

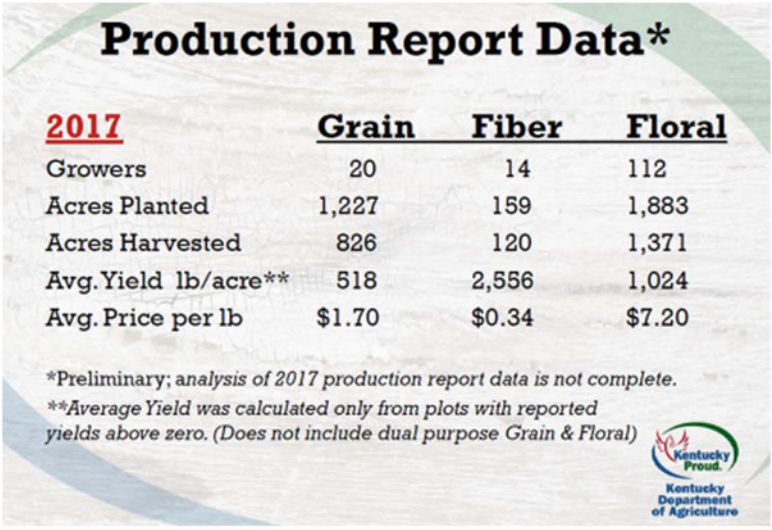


Fig. 3.2 Average yield and price data provided by participants in the 2017 Kentucky industrial hemp pilot research program. (Source: Kentucky Department of Agriculture)

inevitably led to very large reductions in production. As tobacco acres across the region have declined, many growers and politicians have come to view hemp as a means to revitalize their flagging agricultural economies and rural communities. We will return to this tobacco connection in a subsequent consideration of flower production models.

3.3.2 Hemp in the Mid-Atlantic and New England States

As in other colonies, hemp production in the Mid-Atlantic and New England historically and primarily was for household use and generally less important than flax as a household fiber (Dewey 1914). New England in particular has a history tied to hemp through its shipping industries which manufactured cordage for ropes – but much of the raw material likely was imported. Despite the demand for naval stores, government incentives, experimentation with hemp in early settlements, and the desire of New England farmers to have an agricultural staple, hemp never became a major crop in New England, and local production never met the demands of New England shipyards (Bidwell and Falconer 1941). The failure of hemp to achieve staple crop status in New England has been attributed to the crop's being outcompeted by grain crops for a limited supply of fertile land in the region (Bidwell and Falconer 1941).

New England's land constraint has relevance today, and in a modern context, hemp production in the region is almost entirely driven to CBD production. Although currently it is not legal in all states. Industrial hemp may be grown for commercial and research purposes in Vermont, Maine, Massachusetts, and Rhode Island. As of 1 February 2019, hemp cannot be grown commercially in New Hampshire and Connecticut, although feasibility studies have been enacted in both states and special permissions have been given to research universities (National Conference of State Legislatures 2019). No official production statistics of hemp in recent years have been published by the USDA. A publication by the Congressional Research Service, *Hemp as an Agricultural Commodity*, reports national statistics for industrial hemp in the US and Canada in the 1990s and 2000s. While there is data for Canada and US imports, only 2016–2017 acreage data by state is presented. From 2016 to 2017, the number of acres in production in Maine increased from 1 to 30, and in Vermont from 180 to 575 (Johnson 2013). Official state data of registered growers and acreage in Vermont indicate 427 registrations and 2711 acres in production in the 2018 growing season (Clithero 2018). The State of Rhode Island's Department of Business Regulation records four state-approved industrial hemp licenses on their website as of 24 May 2019 (State of Rhode Island 2019). For 2019, all states have reported a significant increase in registrants and potential acres of hemp to be grown. In Vermont as of April 2019, there were currently 300 farmers registered to plant 4500 acres of hemp (Vermont Agency of Agriculture 2019). The Vermont Agency of Agriculture reports that over 90% of acreage will be planted with intended use for CBD. As of May 2019, Massachusetts reported issuing 77 licenses for growing and processing hemp. It is projected that 430 acres of hemp will be grown primarily for flower production for the CBD market. In Maine, there were 143 licensed growers planning to produce 2150 acres of hemp in the 2019 growing season. An informal regional survey from 2019 indicates about 90% of farmers are primarily interested in CBD production, with a majority growing 10 or fewer acres. A significant majority (58%) of these producers were in their first year in the hemp industry.

In the Mid-Atlantic, New York has perhaps been one of the most aggressive of states at promoting industrial hemp. Following initial authorization of hemp research (2014) New York modified and greatly broadened the scope of its pilot program in 2016. The first licenses under this program were issued to several institutions of higher education, although a few pioneering growers also obtained their licenses. The first hemp crop, totaling approximately 30 acres, was planted in 2016. New applications for hemp farming were encouraged in 2017 and the state took a unique approach by granting funds to Cornell University to engage farmers in hemp cultivation. About 1700 ac of the dual-purpose grain/fiber hemp cultivar 'Anka' was grown across 24 different farms. This project was aimed at demonstrating full field-scale cultivation of industrial hemp on farms across the state to attract pioneer producers and de-risk grower and processor participation in hemp enterprises. Through one season of hemp cultivation on a relatively large scale, these farmers gained the most basic knowledge about the logistics, agronomics, and economics of industrial hemp, while stimulating interest among farmers to expand the hemp

enterprise. New York's approach also was novel in that farmers were compensated $350 per planted acre and they were not required to harvest the fields. Due to the lateness of initiating this project and delays in importing seed from Canada, the earliest fields were planted on July 10, 2017 and very few of the fields even achieved maturity. By late 2017, the limits on hemp growers' licenses were removed and licenses were issued to just over 100 applicants, most of whom were interested in growing CBD-rich cultivars. In early 2018, the application procedure for growing CBD-rich cultivars was closed until early December 2018, when it was reopened for a month to allow more than 200 new applications. At the start of the 2019 growing season, there are close to 300 licensed hemp growers and the application process was reopened indefinitely.

The first hemp production in New York was for grain to be used for food products and hempseed oil for personal care products. Early food products that were marketed include culinary hempseed oil, hemp-based pasta and flour mixes, and hemp baby green salad mixes. The 2018 growing season was dominated by production of CBD-rich hemp cultivars in a horticultural system in fields of 5–20 acres with a total of approximately 2200 acres across the state. The 2019 growing season will also be predominantly represented by production of CBD-rich cultivars, and the acreage is likely to expand significantly across the state and in larger fields on average.

3.3.3 Hemp in the Mid-West and Great Plains

Hemp production on the Great Plains (and the rest of the U.S.A.) may benefit from historical research. Although many early hemp boosters proclaimed hemp capable of growing with few nutrients on difficult soils and with no pest or weed challenges, these advocates would do well to review existing literature from the region. During the previous century, Wilsie et al. (1944) showed that heavy Canada thistle (*Cirsium arvense* L. Scop.) and quackgrass [*Agropyron repens* (L.) Beauv] infestations in Iowa occurred when establishment was slow or in hemp stands that were poor. Soil moisture and temperature, fertility, and seed quality also were shown to be important factors influencing stand establishment. Seeding rate did not affect yield, but was influenced fiber percentage with higher fiber percentage from the higher seeding rate (Wilsie et al. 1944). Seeding date recommendations were between 5 and 20 May for hemp produced in Iowa. Robinson (1943) recommended planting hemp after small grains and before corn (*Zea mays* L.). Better hemp performance was noted when the previous crop was a legume rather than non-legume grass crops such as oat (*Avena sativa* L.) and sorghum (*Sorghum bicolor* L.), primarily due to the legume's nitrogen contribution to the subsequent hemp crop. Excessive nitrogen reduced fiber quality because of high interplant competition and self-thinning of stands to low levels that resulted in short plants with thick stems (Howard et al. 1946). Howard et al. (1946) noted greater hemp yield at higher nitrogen levels, but a reduced stem breaking

Fig. 3.3 Varietal evaluation for grain and fiber crops is a critical component of research programs aimed at re-establishing industrial hemp as a viable row crop. (Source: Burton Johnson)

strength at soil nitrogen levels of 80 lbs./acre. Howard stated nitrogen fertility should maximize yield and fiber quality.

Current field research in the U.S.A. and Canada is engaged in redefining basic production guidelines due to changes in technology, cultivars, regulations, and markets. Hemp cultivars in Canada and the U.S.A. must not contain more than 0.3% THC in plant tissue. Hemp THC concentrations largely are determined by genotype, but climatic conditions during the growing season can also influence THC level (Small et al. 2003). This presents challenges for developing varieties that both are suitably productive over large regions and consistently below 0.3% THC.

As should be apparent, much of the work from Plains states is viewed through the lens of traditional row-crop production systems and early work has focused varietal evaluation (Fig. 3.3). Hemp grain and dual-purpose varieties used in the region are primarily from Canadian seed companies Hemp Genetics International Inc. and Parkland Industrial Hemp Growers, given the similarity in climatic and latitudinal conditions, although a "homegrown" company, New West Genetics, is in the process of releasing U.S.-bred varieties developed in Colorado. Grain yields in North Dakota research trials primarily with Canadian varieties have averaged about 1270 lb/acre, with better yields at lower plant densities.

In North Dakota's initial hemp pilot-program with the Department of Agriculture, five producers planted a total of 70 acres of hemp. An in-state point of sale was

available for producers to contract grain at $0.90/lb, and producer yields ranged from 400 to 1100 lbs/acre. This generated net returns higher than mainstream commodity crops such as wheat (*Triticum aestivum*), corn (*Zea mays*), and soybean (*Glycine max*). Producer interest increased to 35 growers and slightly more than 3000 acres in 2017 with grain prices down from 2016 to the $0.65/lb. range. However, the crop was still more profitable, considering higher input costs and declining grain prices for traditional crops. Lower grain prices and higher seed costs in 2018 discouraged what would have been record-breaking production near 10,000 acres by 55 producers. Instead, 28 growers grew approximately 2800 acres, with a grain value of $0.45/lb. Market prices, market size, and market type are in developmental stages and have not outpaced progress when compared with advances on the agronomy side of hemp production. Successful commercialization requires both processes to evolve together with market demand directing the scale of agronomic production. We consider this in a brief look at current market conditions in Sect. 3.4.

3.3.4 Hemp in the Western States

Western states have been early leaders in the *Cannabis* industry, largely from a willingness to buck Federal regulations surrounding the production of recreational marijuana. Many of the current hemp varieties used for CBD production have been bred from marijuana strains grown in states such as Oregon and Colorado, which were leaders in legalizing recreational use. (We use the industry term "strain" here rather than "cultivar," given that the more exacting protocols for cultivar development found in the commercial crop industry are rarely applied to hemp.) Interestingly, tensions between hemp and marijuana communities have arisen in states such as Oregon, because marijuana growers fear the effects of cross-pollination from hemp fields. Pollination would lower the value of the marijuana crop if fertilized, and the subsequent genetics of the new seed would likely have lower expression of psychoactive THC. This is leading many marijuana growers to move their production indoors.

Like other states, large increases in grower numbers and have accompanied the enthusiastic rush to get into the hemp business. However, experience from these states may also serve as a precautionary tale, as marijuana growers in Oregon have seen significant drop in prices as production in the state has far outpaced demand. Many of these growers are now moving to the production of CBD-rich hemp strains.

3.4 Markets

At the time the 2014 Farm Bill was signed, market demand for hemp-based feedstocks along with market-ready products already existed in the U.S.A. At that point, a number of companies were purchasing imported hemp materials in order to

manufacture and market hemp-based goods. Of course, at that time there were no hemp farmers or primary processors from whom to purchase U.S.-produced materials. The products included fiber-based packaging materials, food products from grain and hempseed oil, and personal care products incorporating hempseed oil. Interest remains in domestically producing both grain and fiber for such uses, although some regions may be better prepared to meet consumer need. In the Great Plains, grower interest has focused on grain production because the infrastructure and a local market already exists. The 2018 U.S. Farm Bill, which allowed interstate movement of hemp grain further supported this by opening market opportunities beyond the confines of state borders. Grain markets currently are more limited in volume, however, and opportunities to scale up will likely require consumer education about the healthful qualities of hemp seed in order to increase demand. The Great Plains also would be well-suited to fiber production, but few fiber processors currently exist and are typically some distance from growers. Those growers interested in collecting hemp straw following grain production also would face the added penalty of grain crops having less stem yield, with fibers of lower quality. These factors, coupled with the fact that fiber value is relatively low, make for a difficult positive net return. As markets for this fiber do not readily exist, producers often end up burning the hemp stalks since they are a nuisance in the field in terms of residue management. If fiber value was slightly greater than costs associated with baling stalks, producers might be inclined to bale instead of burn. This would have many positive effects on soil health, ecosystem services, and reducing carbon dioxide emissions.

Production of actual fiber cultivars will also be well-suited to the Mid-West and portions of the Great Plains, but processing remains a limitation. Where fiber processors are in operation and have developed a local grower base, fiber processing is more competitive with traditional row crops. Long-term, questions about global competitiveness also must be addressed for both grain and fiber production if the U.S.A. is to be competitive with as countries such as China, that have more mature production and processing capacity.

3.4.1 Hemp Flowers – What Goes Up Must Come Down?

Given the limitations in the grain market and the lack of processors for fibers, it should not be surprising that as hemp comes on line, nearly all the interest and efforts for its development have been with flower production systems. Of course, as noted above this is not just a system interest, but a function of the existing economic reality (see Fig. 3.2). Indeed, many hemp enthusiasts have been known to express that their initial (and long-term) interests in hemp were and are for its potential environmental benefits as a fiber and food crop for all manner of sustainable bioproducts. . .but that they grow flowers to pay today's bills.

One of the oddest aspects of the phenomenal growth in the flowers market is that there are so many hemp program participants who expect this market to continue as

it exists today, perhaps even in perpetuity. Many participants simply have no concept that a crop which provides such huge profits per acre will soon be produced at such high levels that supply of the product will far exceed any demand, thus resulting in a significant drop in the value of the crop. In other words, there are many participants that have no actual experience in production agriculture or familiarity with the basic concepts of agricultural economics and/or commodity agriculture. Or course, even our observation here assumes that an agricultural production model of some form will win out. However, efforts are afoot to develop laboratory methods to synthesize cannabinoids, and should they prove economically viable, labor-intensive flowers production would likely be limited to sales into specialty markets.

Complicating this entire scenario is continued ambiguity regarding the ultimate regulatory framework under which cannabinoids will be managed by the U.S. Food and Drug Administration (FDA). Passage of the 2018 Farm Bill provided several very positive changes for the continued evolution of a U.S. hemp industry. Hemp as defined in the Bill was removed from the definition of marijuana within the Controlled Substances Act, thus making it legal within the purview of an approved hemp program. The new Farm Bill also provided that extracts from legal hemp were also removed from the definition of marijuana. Lastly and very importantly, the Bill contained language that provided full oversight and regulatory authority of the cannabinoids to the FDA. The Bill was signed into law on 20 December 2018, and on that same day, the Commissioner of the FDA released a statement acknowledging the new legal status of hemp, but also called for science-based, clinical research in support of utilizing cannabinoids in essentially any type of product available to the public. Despite the as-of-yet unknown regulatory status of the cannabinoids, individuals and entities continue to make multi-million-dollar investments in infrastructure to grow, process, extract, formulate, and sell cannabinoid products both in brick and mortar stores and across the internet. This has created a gold-rush mentality to meet a perceived public demand for cannabinoid products, such that it is literally controlling the evolution of the entire hemp industry today. Efforts in fiber and/or grain production are miniscule compared to efforts in cannabinoid production; rarely even considered at any significant level. Additionally, capital investments in infrastructure to process fiber and/or grain crops are a mere fraction of investments towards the cannabinoid market. This is true all across the U.S.A. at present.

How long will this evolution continue? Logic would dictate until the price of cannabinoids is affected by supply exceeding demand. At that time, it could be most likely that the price of the molecules from that point forward will fit more closely within a typical, commodity-based economic model. However, it is still possible that the FDA could decide to regulate cannabinoids such that broad-acre production in outdoor systems might not be feasible. If the ultimate regulatory framework continues to tightly control cannabinoids at any level as is the case today (e.g., Epidiolex®), and if that classification is enforced by federal agencies, then production would almost surely be similar to other horticultural crops where quality control and predictability of yields would be greatly increased by indoor production models; such parameters are unachievable by outdoor production models. Other examples

would include recreational and medical forms of *Cannabis*, the values of which easily support high-input, indoor production systems. We further explore these aspects of production in the next section.

3.5 Flower Production Models

One very important and as-of-yet unanswered question in hemp farming is which production model will be most cost-efficient? When considering hemp grain and/or fiber, we can immediately know that on an industrial scale, these will be standard row crops cultured almost entirely by mechanical means. There are several reasons for this simple conclusion. First and foremost, the value of hemp grain and fiber today will not support production by higher-input models. We know that hemp grain and/or fiber can be profit-competitive with normal commodity crops like corn and soybeans. Any increases in input costs that might reduce profit potential from hemp would push farmers to grow a more profitable crop in support of their business. When considering 100s or 1000s of acres, just a small difference in input costs and/or income per acre will make a huge difference in gross farm income. Farmers will generally make wholly business-based or profit-based decisions when choosing crops. We have definitely noted exceptions to this premise as hemp has become more widely distributed, but when push comes to shove, farmers will almost certainly rely on their business skills to estimate profits from potential crops, evaluate the agronomic benefits/costs of their decision, and choose the most appropriate crop accordingly. We should also note that consumer demands for artisan, craft, and locally produced hemp grain and fiber-products will be a factor. The value of these products will be much higher than for industrial products, thus justifying potentially higher-input production models in support of the final product (e.g., produced organically with higher human inputs).

Hemp grown for cannabinoids today is nearly always produced by much higher input production models than the standard, highly mechanized, broad-acre row crops. Early adopters of cultivation of CBD-rich cultivars of hemp in most states have been biased toward specialty crop growers, since they have expertise and equipment for cultivation in raised beds with plastic mulch. Surprisingly, these growers often have a leg up on former marijuana growers who could not apply these techniques to illicit (marijuana) grow systems.

In the “plasticulture” model, plants generally are started from seed or clonally propagated from cuttings. Seeds may be considered more robust than clones and generally are cheaper, but they have the disadvantage of being less uniform and perhaps having males – which need to be eliminated. In either model, the plants are typically started in greenhouses or controlled environments then transplanted to the field, typically at planting spacing of 1200–2000 plants per acre. This horticultural approach to hemp cultivation had heavy labor requirements for harvest, drying and post-harvest processing of plant material (Fig. 3.4). Examples of existing models

Fig. 3.4 Current cannabinoid production models typically involve growing hemp under intensive management, often using drip irrigation under plastic film which is used both to conserve moisture and provide weed control. A relatively new planting (left) on wide intra- and inter-row spacing fills in over the course of the growing season. Photo on right shows the plants at mid-season. (Source: Jabari Byrd)

include either tobacco or tomato production systems, both of which require extremely high inputs relative to row crops.

Interestingly, when considering hemp, there's no science behind the usage of these high-input models for cannabinoid production. Rather, growing single female plants while maintaining an unfertilized state (not pollinated) is purely anecdotal from marijuana production systems. The scientific literature is still very poor regarding cannabinoid production (e.g., the effects of pollination alone on CBD yields). New research will address these questions post-haste, but until then, the CBD world is depending on the anecdotal production systems of old. It should be noted here that the value of the CBD molecule today more than validates just about any production model one could possibly dream up, but as mentioned above, this must be a temporary economic condition. Once an equilibrium of supply and demand are met or supply grossly exceeds demand, the price will adjust accordingly which will certainly impact the desire or need for increasing cost efficiencies.

In addition to production, harvest systems are likely to undergo significant transformation in the next few years. The current model of labor-intensive hand harvest (Fig. 3.5) is already being challenged by mechanization more typical of grain or forage systems. In grain-type systems, combines have been modified (Fig. 3.6) to collect both seed and chaff, which may have value for extraction Equipment is being used to bale or chop the hemp plants, and in some cases the material is harvested wet then wrapped in plastic to ensile. While these production methods are likely to greatly lower labor inputs, it remains to be seen how the effective these models will be, given the potential increase in processing and extraction costs if the harvested material is of low cannabinoid concentration and quality.

Fig. 3.5 Current hemp production systems involve labor-intensive hand harvest (top). Many producers currently hang plants in barns to dry (bottom), which adds to the labor and cost of production. (Source: John Fike)

Fig. 3.6 This combine has been modified by placing a bin underneath to collect hemp chaff which comes from around the seed grain and could potentially be suitable for extraction. (Source: John Fike)

3.6 Research Needs

Research will be central to the advancement of hemp production in the U.S.A., and indeed, the development of state-based industrial hemp research programs was central to the first (2014) Farm Bill. Most of the initial work conducted by universities involved cultivar appraisal and agronomics of grain or fiber production. While these issues are still of interest, they likely will be a lower priority for most regions of the U.S.A. under the current market climate of high flower demand. Regardless of production system, variety development and evaluation and agronomic management practices are some of the first issues that come to mind for growers. As well, fertility, suitable herbicides and pest control often loom large on their minds.

Given the semi-domesticated nature of the plant, improvement in a few agronomic traits could go a long way in improving the productivity and sustainability of hemp production systems. For example, hemp seed is prone to shatter and also subject to geminating on the stalk (Fig. 3.7). The shatter issue further complicates harvest by forcing producers to gather in hemp seed at elevated moisture and before they are all ripe. Reducing shatter to support greater seed harvest at maturity will be important for increasing grain yield and also for lowering the energy required to dry the crop.

Fig. 3.7 Hemp germinating on the stalk following a period of high humidity and wet weather. (Source: Josh Ellinger)

Across hemp types, poor seedling vigor can be a problem. This may be less of an issue in fiber production systems that rely on high seeding rates, because when growing in concert, the many seeds push together to get out of the soil. Lower seeding rates used in grain production systems may be inadequate to do this, particularly if seeding depth has not been well controlled or if the soils have a texture that is prone to crusting. This may have environmental consequence as well, as the general recommendation is to plant hemp in finely tilled fields. Thus, improving seed vigor to improve standability – and to increase the success of no-till establishment – is an important area of effort.

There is limited information about hemp susceptibility to insect pressures, although some preliminary research suggests that arthropods cause minimal damage to plants. This understanding may be premature, however, given that for many states, statewide and regional assessments of disease and arthropods are in their early stages. Certainly, empirical observations indicate species such as corn earworm (*Helicoverpa zea*) and several armyworm (*Spodoptera*) species consume hemp seedheads (Fig. 3.8), and there is some indication that injury from these assaults to

Fig. 3.8 Corn earworm (*Helicoverpa zea*) consuming industrial hemp grown for flowers (left) and fall armyworm (*Spodoptera frugiperda*) consuming hemp grown for grain (right). (Source: John Fike)

Fig. 3.9 Bud rot in the flowers of a CBD-rich hemp plant. (Source: John Fike)

the plant promotes the onset of fungal diseases such as bud rot (*Botrytis* spp.; Fig. 3.9). Efforts to compile information about the most common pests for industrial hemp that growers face and what damage they may cause the crop is critical to formulating best management practices for mitigating pests and to disseminate that information to farmers.

Improving plant disease resistance and determining best management practices to prevent disease outbreaks will be important for hemp (and particularly for cannabinoid) production systems. Several fungal diseases have been identified on hemp, and under poor establishment conditions (particularly cool moist soils) "damping off" – in which fungi attack new seedlings – can cause stand loss. While other fungal species appear to have only limited impact on plant productivity, widespread reintroduction of hemp to U.S.A. production systems is likely to increase the chance for a significant disease outbreak. This may have greater implications in flower production, given that mycotoxins may in turn be present and could potentially end up in food products or health aids.

This list of needs discussed here largely focuses on the agronomic realm. Along with these efforts, much opportunity exists to improve hemp through breeding and greater understanding. Of how to control specific constituents such as cannabinoids

and terpenes, seed fatty acid profiles and concentrations, and fiber quality. Along with these efforts, work will be needed to develop and refine scalable extraction and processing, to understand the value of hemp feed and flower products for human and animal nutrition and health, and to determine the economic value of hemp for these purposes and its many other uses.

Hemp production also faces a set of issues common to any other new crop. There are no labeled pesticides for weed, insect or pathogen management for use with industrial hemp in the U.S.A. Growers also face a greater degree of risk with hemp at present, as Federal crop insurance programs common to other crops remain to be implemented.

3.7 Conclusion

Hemp has been an important crop in the U.S.A., but restrictions on the crop prevented its production for almost 70 years. Changes in the law have once again allowed production in the U.S.A., and the hemp industry is gearing up for a rapid expansion across the country. Much of this effort is directed to flower production for CBD, but there are particular questions about the strength and longevity of markets for CBD and other hemp products. Current flower production models are labor-intensive and likely to change; how these systems develop over time and their long-term economic demand remain to be determined. Researchers across the country are working to address a number of questions about this plant, its management and uses. Perhaps no other crop has ever been the subject of such enthusiasm – and perhaps misunderstanding – but the U.S.A. finally appears fully vested in determining how it might best be managed and used.

References

Bidwell PW, Falconer JI (1941) History of agriculture in the northern United States, 1620–1860, Carnegie Institute of Washington. Publication; no. 358. P. Smith Publisher, New York

Clithero G (2018) Registered hemp growers and acreage in production. Vermont center for geographic information and Vermont agency of agriculture, food, and markets

Dewey LH (1902) The hemp industry in the United States. Yearbook of the Unites States Department of Agriculture – 1901. Government Printing Office, Washington, pp 541–554

Dewey LH (1914) Hemp. Yearbook of the United States Department of Agriculture – 1913. Government Printing Office, Washington, DC, pp 283–346

Dewey LH (1928) Hemp varieties of improved type are result of selection. In: What's new in agriculture. Yearbook of the United States Department of Agriculture – 1927. Government Printing Office, Washington, pp 357–360

Duvall C (2014) Cannabis. Reaktion Books/University of Chicago Press, London, p 264

Haney JG (1919) American hemp -a new crop and weed fighter. In: Six years' results on IHC demonstration farms. International Harvester Co, Racine, pp 11–12

Howard HV, Lang AL, Enfield GH (1946) Effects of fertilizers on yields and breaking strengths of American hemp *Cannabis sativa*. J Am Soc Agron 38:551–563

Johnson P (1999) Industrial hemp: a critical review of claimed potentials for *Cannabis sativa*. TAPPI J 82:113–123

Johnson R (2013) Hemp as an agricultural commodity. CRS Report for Congressional Research Service, Washington, DC

National Conference of State Legislatures (2019) State industrial hemp statutes. Webpage. Available at http://www.ncsl.org/research/agriculture-and-rural-development/state-industrial-hemp-statutes.aspx. Updated 1 February 2019

Robinson BB (1943) Hemp. United States Department of Agriculture Farmer's Bulletin no. 1935

Small E, Pocock T, Cavers PB (2003) The biology of Canadian weeds. 119. *Cannabis sativa* L. Can J Plant Sci 83:217–237. https://doi.org/10.4141/P02-021

State of Rhode Island (2019) Approved industrial hemp licenses. Department of Business Regulation. Retrieved from: http://www.dbr.ri.gov/divisions/medicalmarijuana/hemp_approvals.php

USDA (2000) Industrial hemp in the United States: status and market potential. In: AgEcon search, research in agricultural & applied economics. Economic Research Service, p 43. https://ageconsearch.umn.edu/record/278840

Vermont Agency of Agriculture (2019). https://agriculture.vermont.gov/event/2019-industrial-hemp-conference

Wilsie CP, Black CA, Aandahl AR (1944) Hemp production experiments, cultural practices, and soil requirements, Iowa agricultural experiment station bulletin. Iowa State College, Ames, p 63

Wright AH (1918) Wisconsin's hemp industry. In: Agricultural experiment station of the University of Wisconsin, Madison, May 1948, p 47