An Introduction to Industrial Hemp, Hemp Agronomy, and UK Agronomic Hemp Research

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Industrial hemp (*Cannabis sativa* L.) was at one time a major agronomic crop in Kentucky. In *A History of the Hemp Industry in Kentucky* (1951), author James F. Hopkins reported that it was a very common crop on the vast majority of central Kentucky farms. This was true from the late 18th through the 19th century. Nearly all farms at that time grew hemp, mostly for the fiber it produced. However, farms with limited labor pools grew less or no hemp. It was a very labor-intensive crop both in the field and during processing.

An excellent history of the scope and legality of industrial hemp production in Kentucky can be found in the UK extension publication *Economic Considerations for Growing Industrial Hemp: Implications for Kentucky's Farmers and Agricultural Economy.* Since that publication was released in 2013, the 2014 Farm Bill has provided for pilot research projects under the auspices of the Kentucky Department of Agriculture. In addition, the Kentucky General Assembly passed legislation supporting the pilot research program. UK is an approved participant in the pilot research program as administered by the Kentucky Department of Agriculture.

Cannabis sativa is a summer annual plant. It is strongly photosensitive (flowers according to day length; not physiological maturity). It is mostly dioecious in that male and female flowers occur on separate plants (i.e. there are both male plants and female plants). There are a few monoecious varieties (male and female flowers on the same plant), but most cultivated hemp varieties are dioecious. Different plant parts are harvested from hemp for specific purposes. Depending on the harvestable component of interest, (i.e. fiber, grain or cannabinoids) male plants might be vitally necessary or completely unwanted.

Industrial hemp is produced for one or sometimes dual purposes. Fiber from plant stems can be utilized in numerous ways ranging from low tech yarn and fabric to high tech electrical super-capacitors manufactured from carbon nanosheets. Other potential uses of hemp fibers could include alternatives for wood in construction materials (chip board or particle board), strength-increasing components added to concrete (hempcrete), or fiber used in composite materials in place of synthetic fibers (molded plastics). A complete list of the potential uses for hemp fibers is too long to provide here. Uses for hemp fibers today are different and much broader than when hemp was last grown in Kentucky. Today, there is not as much need for hemp rope or perhaps large hemp linens for sailing ships, etc. as there was in the 19th century. But, fibers from hemp possess several very positive attributes that make them useful as modern natural fibers.

The grain (seed) of hemp can also be used in numerous ways. As a dietary supplement for humans, it is very rich in omega-3 and omega-6 fatty acids compared to many other potential sources. It is also relatively high in oil content. Hemp grain processors in Canada produce a wide array of consumer products including toasted hemp seed, hemp seed oil, hemp flour, and even hemp coffee. It is also used as bird feed and livestock feed, either whole or in part, much the same as soybean hulls are used today. Again, an entire list of potential uses of hemp grain is very long. It is not uncommon for producers to harvest hemp grain with combines and subsequently harvest the remaining stems for fiber. This is the most common example of a dual-purpose industrial hemp crop. Of course, if hemp does become a viable commodity crop in Kentucky and the U.S., seed production for establishing next year's hemp crops could be an excellent option for producers. Our soils and climate are very conducive to high hemp seed and grain yields.

Cannabinoids are another harvestable component of Cannabis plants. They are plant-generated molecules that are known to have certain significant effects on humans. Cannabinoids are mainly produced by plants in the genus *Cannabis.* The most familiar cannabinoid is delta-9 tetrahydrocannabinol, or THC. This molecule is psychoactive and is responsible for the 'high' obtained from using marijuana. Under the 2014 Farm Bill, the concentration of THC (by weight) defines a Cannabis plant as either marijuana (>0.3% THC) or industrial hemp (=/<0.3% THC). This is the only distinction between marijuana and industrial hemp. They are the same plant species. A simple analogy might be to compare sweet corn and field corn. They are both *Zea mays*, but sweet corn (marijuana) has much more sugar (THC) than field corn (industrial hemp) which is higher in starch (other cannabinoids).

There are dozens of other naturally-occurring cannabinoids besides THC. One particular molecule, cannabidiol or CBD, is currently of deep and broad interest among pharmaceutical and medical researchers. Cannabidiol is known to have strong pharmaceutical effects. For example, certain epileptic patients treated with CBD experience highly significant reductions in the frequency and severity of seizures. There are other known, positive effects of CBD. Examples include uses as an analgesic, appetite enhancer, and anti-depressant. Many of the cannabinoids identified to date have not been studied for their potential as pharmaceutical agents. It is also thought that some number of cannabinoids remain to be identified.

Cannabinoids are present throughout the plant, but are mostly concentrated in the bracts (actually in the trichomes on bracts) of female flowers. Cannabinoids are found at much lower concentrations in root, shoot and leaf tissues, and are not found in significant concentrations in hemp seed, seed oil or pollen. In the case of optimizing cannabinoid production on a field scale, it is not known if the entire plant would be harvested and processed for cannabinoids, or just the female flowers. Field-scale cannabinoid production could be a case where male plants are totally unwanted. The concentrations of cannabinoids in male plants is very low relative to female flowers. Also, it appears that unfertilized female flowers tend to produce more cannabinoids than when they are allowed to produce seed following fertilization by male plants.

General Production Information

It is important to note that there have been no U.S.-based agronomic research studies with industrial hemp since the early 20th century. Information from previous research is important and useful, but may not always be optimal for modern production systems. It is already very clear that different varieties of industrial hemp will respond differently to basic agronomic inputs. This is especially true regarding varieties grown for different purposes. Varieties grown for fiber-only will be established, managed and harvested differently than varieties grown for grain or dual-purpose. Fiber and/or grain varieties will likely be established and managed very differently than those grown for cannabinoids. The University of Kentucky and others will conduct basic agronomic trials beginning in 2015 with varieties grown for all three harvestable components (fiber, grain, and cannabinoids). Until the information from this and other work in the U.S. is available, we must rely on previous U.S.-based research and more recent research from other countries as provided below.

Site selection and inputs

Although industrial hemp has been touted as a low-input crop highly adaptable to marginal lands, the scientific literature from other countries clearly indicates that maximum yields are realized with inputs equivalent to current grain production systems (e.g. wheat, corn) and on productive land (>170 bu/A corn). If maximum industrial hemp yields are the goal, select good corn land and plan on inputs equal to current grain crops. If maximum yields are not the goal, industrial hemp can be expected to perform on lands with lower productivity and with reduced inputs much the same as our current commodity crops would.

Varietal responses

Variety selection will be key to success for many reasons. These include days to maturity (regional adaptation) and seed quality. There is much to know about selecting the proper variety; too much information to include here. For example, varieties bred primarily for grain production could have significantly different maturity dates relative to each other and therefore would have very different establishment dates for maximum yields. Producers should research varieties based on the harvestable component of interest (fiber, grain/fiber, or cannabinoids) and choose varieties that are proven performers in other countries with acceptable germination rates. Also, consider the latitude from which the variety originates. If it is significantly different than Kentucky, the size of the plant at flowering in Kentucky may be much smaller or much larger than the plant would be when grown where it was originally adapted. It appears that germination can be affected by several factors including seed quality (maturity at harvest, age, storage conditions) as well as variety. Today, there are no U.S. standards for seed certification. Work is underway to define and then implement standards for the production and sale of certified industrial hemp seed in the U.S. Until that time, we must rely on the standards of other countries, or in some cases, have no standard information from unbiased sources about the varieties that are available.

Establishment from seed

It appears that industrial hemp seed could be quite sensitive to soil moisture at planting. This trait has not been quantified but could readily contribute to stand failures. Seed should be planted in soils with adequate moisture to encourage rapid germination. If soil moisture is inadequate for industrial hemp germination, it is likely still adequate to support the germination of many weed seeds. Without the availability of legal herbicide applications in industrial hemp production systems, we rely heavily on rapid industrial hemp canopy development and closure to reduce or eliminate competition from weeds. Adequate soil temperature (>/=50^{o}F) and moisture at planting will help accomplish this. Planting depth should never exceed one inch (1”), and 0.5 inch would be preferred. It appears that industrial hemp seed can be successfully drilled with both conventional tillage and no-till protocols. Seeding dates will depend on the harvestable component and equally on variety. Fiber crops will be harvested at the onset of reproductive growth and should be planted as early as possible to maximize vegetative growth. Days to maturity of grain crops can vary a great deal among varieties. As such, some grain varieties should be planted much later than others. Field-scale cannabinoid production systems are not yet well-defined. Lacking appropriate research-based information, cannabinoid production from seed should be thought of similarly to grain production. In very general terms, industrial hemp seed should be planted in late April or early May in Kentucky. Seedling industrial hemp is tolerant of light frosts, but it is probably best to avoid the last killing frost while still taking advantage of good soil moisture and adequate soil temperatures.

Pesticides

There are currently no pesticides (herbicides, insecticides, fungicides, nematicides, etc.) labeled for use in industrial hemp crops in the U.S. This is true for both indoor and outdoor (field-scale) production systems. This means that any pesticide applications to industrial hemp crops are off-label and therefore illegal. The only exceptions would be applications made by researchers holding a Category 10 (research and demonstration) pesticide certification and license. Work is underway to evaluate pesticides for use in industrial hemp production systems and also to investigate several options for emergency exemptions within the rules and policies of the U.S. EPA. Today, it is imperative to make good management decisions to reduce the negative effects of pests, particularly weeds. Seeding dates, seeding rates, and fertility are examples of management decisions that will potentially reduce competition from weeds and increase yields without herbicides. To date, we have not witnessed significant pressure from insect or disease pests in field-scale production systems. There have been serious reports of both disease and insect pests in indoor growing systems in Kentucky.

Harvest protocols

Harvesting industrial hemp grain by combine is the norm in other countries and was accomplished successfully in Kentucky in 2014. Again, variety selection is key as the growth habits of those varieties bred primarily for grain production are more conducive to harvest by combine. Grain from varieties bred primarily for fiber production could be very difficult or perhaps impossible to harvest efficiently by combine, especially if planted early. Harvesting fiber crops is much more complex. Fiber crops will require retting prior to baling or chopping. Retting is essentially a quasi-controlled rotting process. During retting, microbial activity breaks down the pectin layer between the bast and hurd fibers thus allowing for separation. Microbial activity will be very sensitive to temperature and moisture. Generally speaking, warm and moist conditions will encourage microbial activity. The equipment for optimal cutting and then management of the crop during retting does not yet exist in the U.S. Additionally, field-retting industrial hemp will require new skills remotely similar to those involved in making high quality hay. Successful field retting will be totally dependent on weather conditions just as is making good hay. Over-retting will dramatically reduce the quality of the fiber. Today, harvesting for fiber will be difficult at best. Current thinking involves mowing by sickle-bar, retting in the field, followed by baling (round or square). Another option is harvest by forage chopper, but this presents new issues such as efficient transportation and storage prior to processing. Harvesting methods for fiber crops will also depend heavily on the intended use of the fiber (e.g., longer fiber for yarns and fabric compared to shorter fiber for industrial uses or animal bedding). Optimal harvest methods for cannabinoids are not well defined in field-scale systems. Research is planned at UK in 2015 to address all of these questions including harvest timing and methods for fiber production.

General agronomic recommendations for the main harvestable components of industrial hemp.

	Fiber	Grain/dual purpose	Cannabinoids*
Seeding Rate (PLS*)	60#/A	20-40#/A	20-40#/A
Row spacing	4-8 inches**	8-16 inches	8-16 inches
Applied Nitrogen	50 units/A	100 units /A	50-100 units/A
Harvest	</=20% male flowering	~70% grain maturity	~75% trichome maturity

*PLS=pure live seed and would be equal to the amount of seed necessary to achieve 100% germination; taking into account the amount of crop seed, other seeds, inert material, and the germination rate.

**Broadcast seeding (e.g., Brillion seeder) following by cultipacking can be an acceptable method of establishing industrial hemp for fiber.

Optimum agronomic protocols for cannabinoid production in field-scale systems have not been defined. Much of the available information is extrapolated from Cannabis production systems in U.S. states where it is legal and/or from other countries. Nearly all of these systems are indoor and not field-scale, or are very limited in scale. Very important questions remain regarding field-scale systems to produce cannabinoids. These include variety selection, establishment methods (e.g., seeding rates, direct seeding versus transplanting), and management decisions including nitrogen fertility and harvesting methods. Research is planned at UK in 2015 to address these questions.

UK Agronomic Research

Within the UK Department of Plant and Soil Sciences and the Kentucky Tobacco Research and Development Center, our overarching research goal is to provide Kentucky producers with sound, science-based information on industrial hemp production and utilization. Specifically, our goals are to investigate agronomic parameters to optimize industrial hemp establishment, production and harvest protocols for fiber, grain, or cannabinoids. We note that research with industrial hemp is extremely exciting. The potential to enhance the operations of, and hence the lives of Kentucky farmers is very real. At the same time, we do not propose that industrial hemp is any kind of a miracle plant that will transform Kentucky agriculture. Rather, we view industrial hemp as a potential new crop that Kentucky producers might consider for inclusion in their existing production systems. If we consider the agricultural impacts of legal industrial hemp production in Canada, Europe, Asia, and Australia, it has definitely been a positive crop for these regions and cultures. But, industrial hemp has not transformed any of the economies, agricultural or otherwise, in any of these countries/cultures. The market for industrial hemp products in Kentucky and in the U.S. remains to be defined. Consumers will ultimately determine the breadth and depth of the industrial hemp industry. The goal of our program is to support Kentucky producers who choose to include industrial hemp in their farm operations by providing solid, science-based information aimed at optimizing industrial hemp production systems. Our research plans for 2015 include the following areas of immediate interest. We note that funding for the research outlined below must be derived from corporate or individual entities currently active in the industrial hemp industry. Today, there are no sources of state and or federal funding for industrial hemp research. The depth and breadth of the 2015 studies listed below will be totally dependent on financial support from the industrial hemp industry.

Standard Variety Trials and Germplasm Screenings

We will conduct standard variety trials with industrial hemp for the production of fiber, grain, or cannabinoids. In some cases with some varieties, both grain and fiber could be evaluated from the same plots, and perhaps both cannabinoids and fiber with other varieties. We will conduct two separate but concurrent trials; one at the UK Agricultural Experiment Station in Lexington, and a second trial on the WKU farm in Bowling Green. Data from these trials will allow producers in Kentucky to make science-based decisions on variety selections. All data from these trials will be made available to the public through the UK Extension Program. Germplasm screenings are basically the same type of trial as standard variety trials. The difference is that the sponsor of entries in germplasm screenings uses the data generated to make decisions on the potential for crossing plants in a breeding program, or maybe whether or not a particular germplasm should be entered into the standard variety trials and compared against all other entries. Data from germplasm screenings are generally available only to the sponsor of the screening.

Evaluate Land Races for Fiber, Grain, and Cannabinoid Production.

There is strong anecdotal evidence for the existence of industrial hemp land races (feral hemp, heirloom hemp, ditch weed, etc.) in Kentucky. Assuming they do exist, it is quite likely that many of these plants could share genetic material with the industrial hemp crops produced in Kentucky decades or even hundreds of years ago. It is also very likely that these plants are extremely well-adapted to the climate and latitude of Kentucky due to their persistence over many, many years as self-reproducing plants grown on unmanaged lands. We should investigate the performance and yields of these land races relative to commonly cultivated varieties from around the globe. Well-adapted land races would also be very useful in plant breeding programs aimed at optimizing industrial hemp production systems in Kentucky.

Industrial Hemp Establishment and Management Trials for Cannabinoid Production

While there is a fair amount of information in the scientific literature regarding the agronomy of industrial hemp production for fiber and grain, very little refereed information exists on the agronomy of cannabinoid production. Regarding agronomy and cannabinoids, it has been reported that cannabis plant height was negatively correlated with THC concentrations, suggesting that shorter plants under stress produced THC at higher concentrations than taller, unstressed plants. It has also been reported that CBD concentrations were negatively correlated with soil phosphorus, but positively correlated with plant nitrogen. In a later study, it was reported that concentrations of both THC and CBD increased with adequate soil nitrogen and phosphorus. Others have reported a negative correlation between THC production and increasing nitrogen fertility. It is interesting to note that all of these studies were conducted using plants grown in pots in greenhouses. These results seem to provide a strong impetus for additional studies to elucidate the optimal fertility regimes for maximizing yields of CBD in field-level production systems.

Population dynamics will certainly affect the morphology of individual plants, hence the differences in recommended seeding rates for industrial hemp grown for fiber (60 lbs. of seed per acre) and grain (20 lbs. of seed per acre). Lower seeding rates usually result in shorter plants more likely to produce more grain (and thus female flowers for cannabinoids) than would taller plants resulting from higher seeding rates. However, decreased plant densities would also decrease stress from competition. It is unknown if increased production of female flowers as would be expected with decreased plant densities would result in increased yields of CBD.

In addition to seeding rates, precise plant spacing such as is achieved by transplanting rather than direct seeding, may have an additional positive effect on female flower production and consequently yields of cannabinoids. Precise plant spacing may also have a positive effect on the ease of harvesting female flowers relative to establishment by seeding in rows. Today, there are no automated or mechanical technologies for harvesting female flower buds. Lacking equipment, harvests will have to be conducted by hand. There are other strong potential advantages of transplanting which include: i) use of pre-emergent herbicides with pre-plant cultivation to reduce competition from many weedy species; ii) use of industrial hemp plants that are at advanced growth stages relative to industrial hemp plants from seeding on the same date. Advanced growth stages of transplanted industrial hemp relative to weedy species should also prove advantageous as the season progresses.

A non-agronomic potential benefit of transplanting cannabis is the broad familiarity with transplant systems among Kentucky farmers. Nearly all Kentucky farms large and small are fully conversant in transplant protocols; already owning and utilizing the necessary technology and equipment for tobacco production. We propose that industrial hemp production by transplanting would be broadly accepted by farmers if there are significant CBD yield benefits relative to direct seeding. Our research is designed to quantify any differences in the yields of cannabinoids between transplanting and direct seeding protocols, along with quantifying of the effects of applied nitrogen (N) fertilizer.

Determination of the Tolerance of Industrial Hemp to Agricultural Herbicides

While chemical inputs to industrial hemp production systems may be reduced relative to other common commodities (e.g., corn, soybeans, wheat), this would only be true when industrial hemp is planted under highly optimal conditions. In particular, industrial hemp seed is very sensitive to soil moisture levels at planting. If soil moisture is low at planting, many common weeds may germinate prior to industrial hemp and even become well-established before industrial hemp germination. This would certainly reduce industrial hemp establishment and yields. There has been some work in Canada regarding the tolerance of industrial hemp to some common agricultural herbicides, but, these studies did not test all of the products available in the U.S. Additionally, these studies are now several years old. New active ingredients have become available since the earlier work was conducted in Canada. Considering that industrial hemp is not a legal crop in the U.S., there are no herbicides labeled for use in industrial hemp production systems. Assuming that industrial hemp will become a legal crop, data on industrial hemp tolerance to herbicides will be necessary for new labeling that includes industrial hemp as a tolerant crop. We propose to evaluate agricultural herbicides for potential inclusion as weed control tools in field-scale industrial hemp production systems, and to provide early and applicable data for labeling of appropriate herbicides. This trial will be conducted as a cooperative effort between UK and WKU. It will be established on the WKU research farm in Bowling Green and the UK Spindletop Farm. Two industrial hemp varieties will be tested; one bred primarily for fiber production and one for grain production. Data collected will be visual evaluations of industrial hemp tolerance to herbicide applications and the effects of herbicides on yields of fiber and grain.