Cannabis Sativa: An Optimization Study for ROI

by

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Abstract

Despite hemp's multifarious uses in over 30 countries ranging from the manufacture of paper to specialty textiles, construction, animal feed, and fuel, its acceptance in the US has been shunned because of its association with marijuana, as a drug. While hemp and marijuana are varieties of Cannabis sativa, their similarity ends there. In reality, the growth of industrial hemp adjacent to marijuana results in cross-pollination that radically reduces potency of marijuana. Although restricted in the United States, industrial hemp farming is growing rapidly in many other countries, including Canada, France and China.

Within many of these countries, hemp is grown in different ways and under different conditions to optimize cultivation of particular components of the plant, for either agro-practices or industrial and consumer demands. This study substantiates great economic prospects for cultivars, processors, and industrial partners in the legalization of industrial hemp farming.

Hemp has also consistently demonstrated a versatility to grow and adapt to many soil, climatic and environmental conditions. Additionally, hemp improves the land by ridding it of weeds and insects, helping prepare it for rotation crops. Hemp's various components are capable of contributing to different industries with yields that are on par with competing crops like cotton, corn, and soybean, making it a financially attractive rotation crop with many auxiliary benefits. This study recommends hemp be planted as a rotation crop in approximately 25 plants/m^2 to optimize yield of both grain and straw in roughly 5 months.

Given the potential for hemp to be the most economically viable agro-industry, with incredible ROI and close to effortless farming and cultivation on even the most challenging terrains, it is high time to legalize the production and farming of this non-psychotic plant for the many reasons contained in this report.

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Introduction

For decades, hemp has been cultivated as a rich source of fiber, oil, and biomass. According to a 1938 edition of *Popular Science*, hemp "can be used to produce more than 25,000 products, ranging from dynamite to cellophane." Although restricted in the United States, industrial hemp farming has become common practice in several other countries, spawning a variety of related industries. Within many of these countries, hemp is grown in different ways and under different conditions to optimize cultivation of particular components of the plant. Of these many configurations, for which growth patterns and under what use model can hemp be most profitably grown as a cash crop in America? In the optimal configuration, what is a farmer's return-on-investment (ROI) and to what use will industry ultimately put the respective components of the hemp that is farmed? Despite the extensive propaganda in support of hemp legalization, very little credible work exists to accurately assess its economic feasibility as a cash crop.

Several existing feasibility reports either fall short in estimating the dynamic long-term profit potential of hemp or simply fail to value the crop as a sum of its components. If anything, the recent spotlight on legalizing industrial hemp farming highlights a gap in information that might be useful to policy makers as they gage the potential risks and rewards of allowing hemp farming into our domestic market.

1. Hemp Cultivation

1.1. As distinct from marijuana

Hemp and marijuana both belong to the botanical family of Cannabinaceae, under the taxidermic classification *Cannabis Sativa*. This single classification includes a number of variants, and there exists a long-standing debate on how to classify these variants most accurately. The dispute arises, largely, on the grounds that certain strains of cannabis have psychoactive effects because of the presence of psychoactive ingredient delta9-tetrahyrdocanabinol (THC). Members of the Cannabis genus contain two particularly relevant cannabinoids: delta9-tetrahyrdocanabinol (THC), a psychoactive compound, and cannabidiol (CBD), an antipsychoactive agent known to block the effects of THC. Hemp refers to a breed of *Cannabis Sativa* that contains less than 0.3% THC and high levels of CBD, a variant that cannot produce psychoactive effects. Marijuana, in contrast, when used for psychoactive effects seeks to maximize THC content with levels typically ranging from 3% to 20%.

Although the psychoactive capacity of the two variants is vastly different, they are difficult to distinguish on the basis of their appearances. Hemp and marijuana can also interbreed naturally and spontaneously. This poses a unique advantage in the War on Drugs. Since marijuana with high THC levels needs to be selected for and bred over time, it has to be carefully bred in order to maintain high levels of THC; otherwise it will revert to ineffectual low levels (between 0.3 to 1%). As a consequence, cross-pollination of hemp in a field of marijuana would significantly reduce its potency as a psychoactive drug, whereas cross-pollination of marijuana in a hemp field might elevate THC levels slightly, producing a negligibly psychoactive variant.

1.2. A history in the United States

The history of hemp in the United States is one stepped with policy that was based in deception and misconceptions, almost exclusively catalyzed by the business tycoons William Randolph Hearst and Lammont DuPont in the 1930s. In the years following the American Revolution, there was a period of about one-hundred years where hemp was not only legal but also actually the top cash crop. The Declaration of Independence was written on hemp paper, the first United States flag was constructed from hemp fibers, and the crop was the most widely cultivated crop in the United States. In 1938, hemp was reported by *Popular Science* as one of the most versatile crops, capable of producing over 25,000 products with applications ranging from cellophane to dynamite. Its reign as a top cash crop abruptly ended with the passage of the "Marihuana" Tax Act of 1937. The tax, which essentially levied a fee of $100 per ounce of hemp in a commercial transaction, both made hemp non-competitive and inextricably linked it with marijuana.

Incidentally, the tax was put into effect shortly after the development of the "decorticator," a device that would make fiber cultivation from hemp both significantly cheaper and faster. Hemp was poised to supply the industrial revolution. In fact, not only were the earliest automobiles fueled by hemp, but also the T-Model was even formed from hemp fiber. Hearst, who held a monopoly over paper supplied from timber, stood to lose a lot if the new technology could propel hemp's process efficiency beyond that of timber. With the passage of the 1937 tax, Hearst's newspapers released a libelous campaign against hemp, connecting it with marijuana and ruining its reputation. This slew of articles prayed on the public's fears, connecting hemp with death, insanity, suicide, manslaughter, and rape. In the meanwhile, in what many would call almost too perfect timing, DuPont, the owner of the largest petrochemical company, was able to patent and secure the intellectual property for a number of wood pulp manufacturing processes and synthetic compounds that sought to replace hemp products just as the wave of yellow journalism propagated. By the end of that year, the strong lobbying forces of Hearst and DuPont, whose company lobbied the Chief Council of the Treasury Department—Herman Oliphant—were able to drive the 1937 Prohibitive Marihuana Tax Law through Congress on the basis that hemp was too expensive to regulate and indistinguishable from marijuana. What this legislation failed to acknowledge was that the growth of industrial hemp adjacent to marijuana would cause cross-pollination and invariably reduce the potency, and quality, of marijuana to extremely low levels.

The smear campaign succeeded in criminalizing the industrial farming of hemp, forcing the United States to import hemp until 1942, during World War II, when our supply was cut off. Ironically, during this time the government offset the ban and actually incentivized hemp cultivation and processing, only revoking the right to farm hemp after the end of the war. It has since never escaped the stigma and association of marijuana, as it continues to be regulated by the Drug Enforcement Agency (DEA) as a psychoactive drug. The only way to legally grow hemp is with a special permit from the

DEA that often requires a 12-foot security fence that is electrified or razor-wire-topped and protected by 24-hour surveillance.

1.3. Plant characteristics

Hemp is classified as an annual herb, because it manages to germinate, flower, and die over the course of a season. It is considered a fast-growing, medium-to-tall crop, developing a rigid woody stem that ranges from 1 to 5 m in height in a single season. When planted in a dense arrangement of about 100 plants/m^2, it develops long, slender stems (6 to 20 mm in diameter) that are branchless and without foliage; whereas, when planted spread out to 25 plants/m^2, it forms thicker stems (30 to 60 mm in diameter) that are branched with foliage, including the widely-recognized 7-11 pointed serrate leaves that are characteristic of hemp.

Hemp lays a branched primary root that reaches a depth of 2 to 2.5 m and branches off secondary nodes that typically grow between 60 and 80 cm below the ground. Hemp is a very versatile crop thatwill grow, and adapt, to many soil and climatic conditions, with a minimum requirement of abundant irrigation or moisture. For optimal growth, it is most suited to the temperate environments of warm regions and tosoils with high nitrogen content to sustain its high biomass, rapid growth.

The growth characteristics of the male (staminate) and female (pistillate) genders of hemp are vastly different. Hemp is a dioecious plant that can assume both monoecious and dioecious characteristics, in that male and female flowers can appear on separate plants or they can both appear together on a similar plant. Male plants have few leaves and are tall and slender, while females release seeds, have more leaves surrounding their flowers, and are shorter and thicker in diameter. As an annual herb, the male plants die shortly after releasing their pollen and the females stay alive until shortly after their seeds have germinated. By regulating pollination, the gender of plants grown and their respective products or growth characteristics can be selected for with relative ease.

1.4. Growth cycle

Whether hemp is cultivated for seed, fiber, or biomass—or even naturally in the wild—it exhibits the same routine growth cycle. Over a four to six month season, hemp will reach its final height, bear seeds or release pollen, flower, and wither then die. The growth cycle can be separated into six distinct phases:

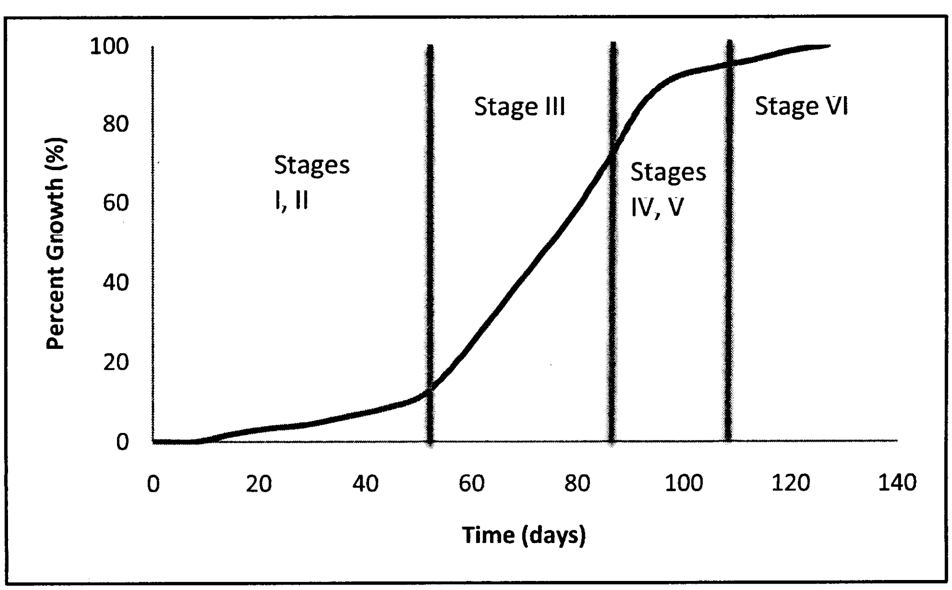
I. Germination: fertilization of seed to sprouting
II. Slow growth: the appearance of the first pair of true leaves to the growth of the fifth pair of leaves
III. Rapid growth: the appearance of the fifth pair of leaves to the development of the first buds
IV. Bud development: bud formation to the opening of the first flower
V. Flowering: the blossoming of each bud
VI. Seed or pollen production and release

The life of a hemp plant begins with the deposition of a seed in moist soil. Water is absorbed, enabling the proliferation of an embryo that then allows the seed to split along its suture and thrust its primary root into the soil to anchor the germinating plant. Meanwhile the stem extends upward, exposing the first pair of embryonic leaves, known as the cotyledons, to unfold. With the exposure of the first pair of leaves, the 3 to 10 day process of germination is concluded and the slow-growth phase is initiated.

The separation of slow and rapid growth is arbitrarily defined by the appearance of the fifth pair of leaves. As leaves are formed and their blades grow, they increase the plant's ability to absorb light and carry out the photosynthetic processes that fuel development. During the slow and rapid growth phases, therefore, vegetative growth occurs at an increasing rate. As a consequence, sunlight is critical throughout both phases. To optimize the growth of hemp, it is important to understand the photoperiod of the plant. Hemp can grow only as fast as its leaves can supply photosynthetic energy from the sun. The number of hours in a day that hemp is exposed to light, and the intensity of that sunlight, directly influence(s) both seed formation and vegetative growth. For maximal vegetative growth, 12to 14hours of daytime exposure are required, depending on the intensity of sunlight. To accelerate flowering and seed production, in contrast, shorter days are required with more nighttime.

Rapid growth ends with the formation of the first bud, making way for the reproductive biological pathways that culminate in the cessation of the plant's life. Up through most of the rapid growth phase, distinguishing between male and female plants is not possible by simple observation. With the development of the bud and the formation of the flower, gender distinction becomes possible. Male primordia are readily recognizable by their curved claw-like shape and the differentiation of round flower buds that have five radial segments. Female primordia have an enlarged tubular bract (2 to 8 mm) that contains an ovary for fertilization and two long stigma protrusions. They, in contrast, are very short and tightly clustered, usually consisting of a single green leaf calyx that surrounds the bract.

This approximate life cycle can be seen below, normalized by peak growth height for an average season.



As the plot of the growth cycle demonstrates, hemp grows very rapidly. When planted in a dense arrangement for biomass or fiber it can reach heights of 5 m, attaining peak growth rates of up to 11 cm/day (Merfield 1999; Bócsa & Karus 1998). In contrast, when planted in a less dense arrangement for seed cultivation, heights reduced by as much as 60% (2 m) are expected. In addition to regulating the planting pattern, farmers can also vary fertilizer content to reduce growth height down to as low as 20 cm, enabling short bast cultivation (Ildikó & Izsáki 2009). While many factors can influence hemp growth, the plant is still one of the most robust crops and will grow, even compete with weeds, in almost any environment.

Figure 1: Vertical growth as a percentage of final length, with stages of growth cycle elucidated(Bócsa & Karus 1998; Roulac 1997).

1.5. Equipment

The process of sowing the seed and harvesting the straw can be done with traditional machinery. Seeds are sown with a grain drill to a depth of about 1 in for growth that is optimized for grain harvesting and about 6.5 in for straw harvesting. If only a single product is desired (ie. grain or straw), the process can be performed using completely standard harvesting machinery. Single-purpose grain harvesting is usually accomplished by either a combine equipped with a dual beam cutter or a front conveyor system. Single-purpose straw harvesting can be accomplished by standard swathers or sickle-bar mowers (Kraenzel et al., 1998). This straw harvesting process changes when cultivars are growing hemp as a dual-purpose crop for both the straw and the grain. Cultivars must deviate from the conventional process by harvesting the seed at its maturity using a combine that is modified to cut at a raised height (Scheifele 2000; USDA 2000). The remaining straw is then separated by a decortication process. It is important to recognize that a major challenge in delayed (dual-purpose) harvesting of the straw is that over the time that the seed matures, the fiber also lignifies, making it rougher and more suited for industrial fiber applications like pulping for paper. (USDA 2000; Kraenzel et al., 1998)

1.6. Cultivation as a rotation crop

Hemp is a robust rotation crop that can grow over a wide and almost extreme range of climatic and soil conditions. While it may not grow optimally in substandard conditions, it still achieves very significant yields over a wide variety of environmental conditions (Lloyd 2009). As such, the recommendations for its growth are based on a balance between minimizing added cultivation cost, maximizing the returns to mass growth and cutting short cultivation time. In some cases, through experience of growing the crop for years, cultivars have refined an understanding for the rotation configuration and cultivation techniques that achieve the maximum marginal return on investment.

With that said, despite not being a nitrogen fixer, hemp is one of the best rotation crops. Its growth characteristics, particularly its early—roughly 30-day—process of laying a long 12 in taproot, helps prevent topsoil erosion and helps form a long root that prepares the soil for the crops that follow it in rotation. Although it is not a nitrogen-fixer, it does not rob the soil of nutrients because the roots and leaves, which tend to concentrate the soil's nutrients, are returned to or stay within the ground at harvest (Young 2006). Beyond preserving the soil and helping prepare it for the following rotation crop, hemp also improves the land by ridding it of weeds and insects. Its taste is unpalatable to insects and its growth out-competes weeds, allowing it to be grown without pesticides or herbicides. The auxiliary benefit herein is that the surrounding rotation crops may grow organically after a few cycles. It has been grown in Ontario with soy and been shown to reduce cyst nematodes (soy parasites) by 50-80% after its first rotation year. In England, it has been grown with wheat, increasing wheat yields by 20% (Kerr 2008).

Hemp will grow very well with any crop that corn would work in rotation with, though it can grow with virtually any other crop. Ideally, it will grow optimally (even without fertilizer) if grown in series with any nitrogen-fixing crop, like clover, peas, or grass sod. Even without fertilizer or a nitrogen-fixing crop, it will still obtain decent yields (West 2003). If, however, it is grown after wheat, oats, corn, or any other nitrogen-tolling crop, it is recommended that the ground be fertilized with barnyard manure or at least a comparable chemical fertilizer. While hemp grows best under fertile soil, it also grows decently under arid and barren conditions (Dewey 1913). It is important to remember that, unlike any of the nitrogen-tolling crops mentioned, hemp leaves behind most of the nutrients it pulls from the soil in growth. Hemp's characteristics as a pest- and weed-resistant crop that prepares the soil for following rotation crops without robbing the soil of nutrients make it an excellent rotation crop.

2. Hemp Components

2.1. The seed

The hemp seed is not a true seed; rather, it is technically defined as a nut. Each seed is enclosed and surrounded by a thin pericarp that gives it a bright grey-brown luster. Anatomically, the seed consists of two cotyledons, or seed leaves, and a set of rootlets. The cotyledons and rootlets are particularly rich in oil, yielding approximately 30-32% oil by weight. Beyond their value in oil content, hemp seeds are also 20-25% protein, 20-30% carbohydrate, and the remaining roughly 10-15% insoluble fiber and minerals. They contain all eight essential amino acids and both of the essential fatty acids. This composition yields a number of options for producing oil, food, and seed cakes (Deeley 2004).

When the seed is processed for its oil content, it can be harvested by one of two methods: mechanical cold pressing or chemical industrial extraction that also involves a mechanical pre-processing. The methods for extracting oils and fatty acids from hemp seeds are not unique to hemp and are the same for rape, palm fruit, soybean, sunflower, cottonseed, maize, and virtually any other plant seed. Both industrial extraction and cold pressing require a pre-cleaning and a moisture addition treatment to ensure quality and yield, respectively. In cold pressing the cleaned, de-hulled seed is ground through a rotating or hydraulic apparatus that presses and collects oil from the substrate, leaving behind a seed cake (Ferchau 2000). The oil that is extracted is of high quality and with a yield that is between 32-36% of the seed's initial weight (Deeley 2004). The byproduct seed cake still holds a significant amount of protein, oil, and fatty acids that can be used as animal feed. Mechanical cold pressing would end at this stage, separating the seed cake from the oil, whereas the chemical industrial extraction process might have heated the seeds before crushing and then washed them with a solvent like liquid propane or hexane to extract even more oil and get out as much as 96% of the seed's initial weight. Industrial extraction is relatively expensive and most suited for very high volume, high-energy processes that extract the maximum oil content from the seed, leaving a negligible amount of waste matter that is usable.

Within the mechanical process that is a part of both extraction techniques, both humidity and temperature are important in regulating oil quality, yield, and throughput. Processing techniques that heat the seed (>20° C) are likely to increase yield, while decreasing throughput and quality. In contrast, high moisture or environmental humidity (>8%) can decrease oil yield, while increasing throughput and quality. Therefore, to obtain the highest quality oil; high moisture, low temperature, and a purely mechanical cold pressing apparatus should be used. By comparison, to obtain the maximum oil yield; optimally minimal moisture, a high temperature, and a mechanical pre-processing step must precede chemical extraction.

2.2. *The bast*

The bast is a fibrous structure that comprises the exterior 20-30% of the stalk (Newman 2008). Beyond serving as a key element of the plant's transport system, responsible for the transmission of both water and photosynthetic products across its length, the bast also plays an integral structural role. The bast fiber's most critical function is to provide tensile strength and torque resistance (Altman 1996). In strengthening and reinforcing the plant's stem, these fibers form a fibrous structure that is among the strongest to naturally occur in plants (Merfield 1999; Newman 2008). In fact, prior to the restriction of industrial hemp farming, practices that focused on bast cultivation, were extremely popular in the manufacture of commercial-and military-grade lightweight, high-strength cords, ropes, and twines (Ash 1948).

The bast is typically of two different varieties: a set of high quality primary fibers and a set of lower quality secondary fibers. The distinction between the two types lies in their tissue composition. Primary fibers are longer, and have high levels of cellulose and low levels of lignin. About 70% of the hemp bast is composed of primary fibers and 30% of secondary fibers. The strength of a fiber is directly governed by its length and its cellulose content; its ease of use is negatively correlated with its lignin content. The higher the lignin content, the harder it is to separate or process the fiber in pulping. On average, bast tissue is extremely high in cellulose (~65%) and hemicellulose (~15%) content, and low in lignin (~4%) content; making it a stronger and easier to process from the fiber stage than the more common textile and paper sources, cotton and wood (Natural Hemphasis 2004).

For both textile and paper manufacture, the bast tissue needs to be separated from the rest of the stem. To do this, the stalk needs to be decorticated in a process that breaks the bonds holding the bundles together around the stem. Retting is one such decortication process, and it relies on the natural microbial process of partial rotting that begins to separate the fiber from the stem. Retting is enhanced during wetter months at warm temperatures, hence making it ideal to harvest fiber during the months following summer (Ash 1948; Newman 2008). One can in fact speed up this process by capitalizing on the fact that warm, wet weather enhances retting. In a retting technique known as wet retting or dew retting, the stems are cut and submersed in a wet field, shortening the retting cycle to as short as 1-2 weeks. Once retted, the dried stalk is passed between fluted rollers that break the central woody core. The broken woody core, which becomes known as the hurds, is separated from the fiber by a scutching process in which a mechanical apparatus beats the hurds from the flattened fiber (Nelson 2000). The now separated fiber can then be combed for twining as rope or spinning as a yarn. Alternatively, instead of combing the fiber, one can subject it to a pulping process and produce paper in much the same way one might use wood. Though the process of hemp fiber separation is more intensive than wood bark removal, the process for pulping hemp bast fibers is less intensive than wood fiber because of its lower lignin content (Vote Hemp 2009). In fact, the rapid growth cycle of hemp allows it to "produce more paper pulp from less land than three wood plantations intended for this purpose." (Deeley 2004)

2.3. The core

The core is the inner center of the stalk that is surrounded by the bast fibers. When the bast fibers are separated from the core, what remains is a mesh of the broken up woody fragments known as the hurds. The hurds contain large amounts of lignin, a cellular adherent that maintains rigidity and levels of cellulose that are as high as 77%. By mass, the hurds comprise 70-80% of the stalk (Hayo 2001; Michka 1994). Their chip structure and relatively large volume gives them a low specific mass and a high surface-area-to-volume ratio. This unique set of characteristics, lends itself well to a number of applications that require dampening or absorbency. As a raw material the hurds, which were once discarded as waste, now get used in a number of industries from construction to energy generation (Dewey 1916).

The rapid rate of growth of the stalk allows biomass to be accumulated at a very rapid rate. Because of its high cellulose content, this biomass is an ideal candidate for conversion into ethanol as a cellulosic biofuel (Briggs 2010). In fact, the two biofuel crops typically grown for biomass—Miscanthus and Switchgrass—have a range of yields 3 to 10 tons/acre that is on par with hemp when it is grown for solely biomass accumulation. Through gasification or cellulolysis, the core can be converted and distilled into pure ethanol (Service 2007; Crowe 2008). Although the process of conversion is currently expensive, its cost is forecasted to decline within the upcoming years as the technology develops, and fossil fuels become less available and more expensive (U.S. Senate Advisory Committee 2010).

Beyond its capacity for use as a high yield biofuel, the core can also be used lucratively in the construction industry. Its high silica content allows it to form a mineral when mixed with lime that is stronger than cement, yet five to seven times stronger and a better thermal insulator and fire retardant (David 1995; Newman 2008). The use of the core for building materials extends beyond concrete to acoustic insulation and even animal bedding. In fact, the use of the hurds in construction is becoming increasingly common in Europe, where hemp is attracting attention from venture capital and large corporations (Newman 2008). The core, which was once discarded as a useless component, is now being grown for its great biomass and unique material properties.

3. Cultivation abroad

3.1. China

The history of hemp almost certainly began in China, where it has been grown consistently for over 4000 years (Carr 2010). China has been, and continues to be, the largest commercial producer of hemp in the world. It is also the world's largest exporter of hemp paper and textiles. With roughly 80% of China's massive population working in agriculture, processes that are typically performed by expensive high throughput machinery can now be done quickly and without capital expenditure by hand. China's large labor force, therefore, poises it distinctly for bast fiber production where the decortication is done by hand after dew- or enzymatic-retting.

Although grown for the bast fiber, none of hemp's other components are wasted. The leftover seeds are collected and serve as a major source of animal feed. On individual farms, the seed is typically used for re-growth and subsistence, where it is often eaten directly or roasted as a snack (Clarke 1995). In fact, in a recent effort toward poverty alleviation, at least one province is actually giving out free seeds and technical training in an attempt to subsidize hemp farming (GoKunming 2009). China is also a major exporter of seed-based products, simply because of the scale of their cultivation operations. It is further aggressively dedicated to expanding its production capabilities and has set a goal of reaching 3.2 million acres (FAO 2009). As a major importer of cotton textile fibers, which are softer in texture than the hemp fibers because of their lower lignin content, China has invested in the development of de-gumming machines that reduce lignin content from 8-10% to 0.2% (FAO 2009). This recent development will create fabrics that are significantly softer and more integrateble as a replacement, or at least a supplement, within their cotton market. The groundbreaking development of this new technology forecasts substantial growth in cultivation and processing within the next few years.

3.2. Canada

With its legalization of industrial hemp farming in 1998, Canada experienced a roller-coaster ride of an experience and has only recently stabilized. In its early years hemp received a lot of attention, but advocates and cultivars did not have a very realistic idea of exactly what to expect despite piloting earlier experimental programs. The aggressive jump in production the year following legalization resulted in significant crop growth that was not met with a correspondingly large processing capacity, due to the demise of the Consolidated Growers and Processors Inc. (CGP). The lack of processing capabilities on par with the production volume bankrupted many farmers who couldn't sell their stalks. After hemp production decreased over the early millennium years, it rapidly built up to almost world record high levels by 2006 and, in overshooting processing capacity again, injured the industry (Chaudhary 2010). The volatile history has helped inspire a healthy amount of skepticism that will hopefully keep the industry along the stable and sustainable growth trajectory it has achieved over the past few seasons.

It is interesting to also note a shift in Canada's attention toward the grain market. Consistent growth is attained by a number of companies that have the strong regional distribution of a wide range of seed-based niche products (Chaudhary 2010). The transition away from fiber cultivation, which is a more advanced and transportation-intensive process, might be a factor influencing what appears to be the newfound stability. Alternatively, the more distributed regional processing arrangement could be the determining change. Time may tell, but the experience of legalizing hemp in Canada will be a valuable guide if hemp is to regain its legitimacy in the US.

3.3. France

France is the only European country in which hemp production was never shut down (Askew 2002). Although it dwindled down to as low as 1730 acres in the 1960s, production never stopped (Girouard 1994). Today, it leads the European hemp producers with an annual yearly production of about 23,000 acres that is divided among a large number of smaller cultivars (Kenyon 2008). A few different growth configurations are in use, and for the most part cultivation has targeted the stalk through single-purpose stalk and dual-purpose (stalk and seed) growth. A significant amount of this hemp is used in high quality currency and filter-paper markets. The remaining hurds are often used to feed a growing insulation and construction market to form building materials like lightweight, durable concrete, structural beams, and thermal and acoustic insulation products (Girouard 1994).

The French hemp production market, which like other European countries receives subsidies for hemp growth, has also received a lot of recent attention from high-profile fashion designers that are beginning to use hemp in their designer lines. Giorgio Armani, Ralph Lauren, The Body Shop, and Calvin Klein are just a few companies that have either released products or announced plans to use release products that use hemp (Benhaim 2004; Anonymous 2010). The designer market might be an emerging niche market opportunity in the next few years.

3.4. United Kingdom

The hemp industry has taken on a very unique growth path in the UK. In a country very limited by agricultural land space, local entrepreneurs have developed creative strategies for profiting from and adding value to the production process chain of hemp (DEFRA 2009). During the 18th and 19th centuries, when space was more available, long hemp fibers were grown and wound into ropes that achieved unparalleled strength and durability, maintaining their properties without fatigue or strain under extreme conditions. These ropes would suspend sails that were also made of hemp canvas, weighing up to 100 tons (Charlier 2008). Years later in modern times, even with space as a limiter, entrepreneurs have fostered relationships that allow them to source the raw materials to products, either processing them locally or outsourcing the implementation. For example, Hemcore, a company based in Essex, sources and sells a shredded stalk component as horse bedding. A significant amount of the hemp bast fiber that is cultivated or imported is actually channeled to Germany for use in paneling within the automotive industry. In some parts of the UK, hemp is processed into eco-composites that are fully biodegradable structural elements that can be used for construction of whole buildings. Many of the most standard components are even exported; they include: flooring panels, roofing, and fire-retardant insulators (Askew 2002).

4. Optimization

4.1. Demand

Due to its classification and regulation as a narcotic, hemp's demand within the United States is not straightforward to assess. The first strategy might be to look to its industrial cultivation in the 30 or more countries in which it is legal. In fact, many of these countries have large enough stable markets that they might be a starting point for estimating profit potential within the United States. Unfortunately, since neither import prices nor international sale prices are published or reported on a regular basis, estimations will need to be made on quotes from prominent international producers and any stable data that is available. Although cultivation within the United States would expand the market, increasing supply and decreasing demand, the price elasticity—as estimated in other feasibility analyses—is negligibly small (around 0.55%) and can be ignored (Vantreese 1997).

4.2. Component valuation

The hemp material process cycle can be divided into three broad segments with developers at each level. Farmers cultivate the plant and obtain straw (the stalk-containing fibers and hurds) and grain (the seed). A portion of the seeds that are harvested—roughly 1%—go back into re-growth and the remaining raw materials are then processed along their individual pathways toward their destination end products (Ferchau 2000). Each of the development stages is typically performed by a different type of company that is equipped with the proper capital equipment for the process. Raw material cultivation is achieved by a farm. With the exception of the straw, which is usually processed in a nearby facility to reduce transportation costs, the fiber and grain can be transported for processing elsewhere. Any grain that is cultivated can then be mechanically cold pressed at an equipped facility, generating oil and seed cake. An overview of the overall hemp process cycle can be seen in Figure 2.

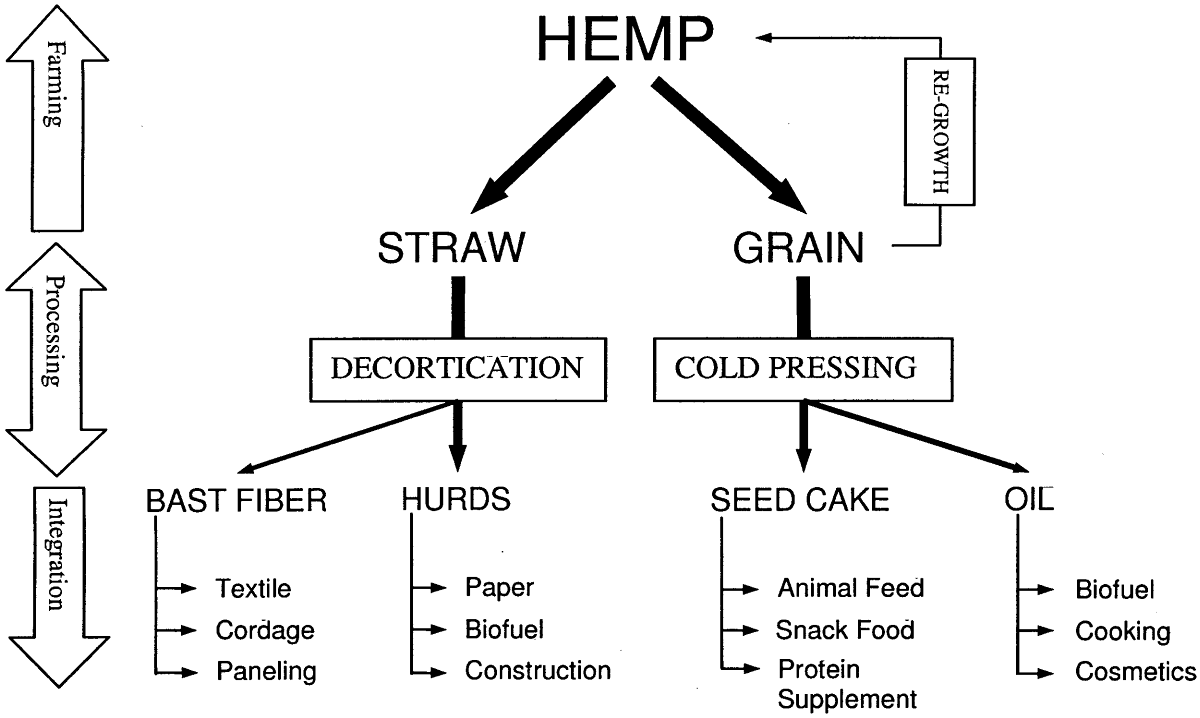


Figure 2: Hemp development cycle to illustrate the three development sectors, their value addition processes, and the final products of each stage.

The outputs for each of these processes, developed within "Hemp Components," are summarized in Table 1.

Table 1: Hemp component process output/input efficiencies.

Process	Output, Percent Mass of Input
Oil from grain	32.00%
Seedcake from grain	68.00%
Fiber from straw	28.00%
Hurds from straw	68.00%
Farming re-growth of grain	1.00%

It would be both extremely naive and terribly inaccurate to develop a bulk- or volume-based cost model for estimating the operational costs of the cultivation and processing stages. The cultivation and processing costs will be a complex function of the efficiency and throughput of the machinery at each facility, the geography, and potentially even the season (Nelson 2000; Merfield 1999). Although a number of models attempt to estimate the operational costs of each processing stage, there is significant deviation among models over the bulk-scaled variable costs (Merfield 1999; Ehrensing 1998; Vantreese 1997; Boulder Hemp Initiative Project 1994). Therefore, the precise determination of operational cost has been externalized to the cultivar, who will have the most accurate understanding of what his/her operational costs will be. It is important to remind him/her that if s/he cycles hemp with crops that are not nitrogen-tolling, they can eliminate fertilizer costs altogether.

While cultivars will likely have some familiarity with the very standard stalk/grain cultivation and grain pressing processes, along with their associated costs, processors will probably need a basis for estimating the cost of decortication. Estimates for the variable costs of decortication—more specifically the power, maintenance, and wage—are available for a particular throughput, but we must warn that they are dated. An operations analysis suggests a moderately sized facility designed to separate 36,300 tons of stalk per year will cost $100.50 per ton of stalk, or $0.11 per lb (Thompson et al. 1998). This rate is about a sixth the cost of cotton fiber separation (around $0.62 per lb); and this is in part due to the fact that the capital expenditure is not depreciated into the bulk cost estimates, which represent exclusively variable costs (Thomas 2005).

Sales revenue estimates are, however, obtainable from last published US import prices or international market point-of-sale quotes. For the grain and oil prices, we were able to get current bulk pricing estimates from Manitoba Harvest in Canada. To estimate straw and fiber prices, the most recent USDA publication forum was consulted (USDA 1997). According to a subsequent publication on global markets and pricing for industrial hemp, these prices have stabilized within the United States and are assumed to reflect modern values (Vantreese 1997). The estimated market value of hurds was derived from the same hemp price revenue analysis (Vantreese 1997). These valuation estimates are summarized in Table 2.

Table 2: Hemp component values.

	$/lb	Source
Straw	$0.06	USDA, 1997
Grain	$0.33	Gourdie, 2009
Oil	$2.99	Gourdie, 2010
Seed Cake	$0.30	Thompson et al., 1998
Fiber	$0.67	Gourdie, 2009
Hurds	$0.03	Vantreese, 1997

4.3. Growth for straw

Growth for straw optimizes the seed growth configuration for a maximally dense arrangement that will yield more stalks that, although less thick in diameter, will ascend to greater heights. This configuration is typically used in countries where the fiber is most demanded. In this configuration, the growth of approximately 100 plants/m^2 generates 3.4 tons/acre of straw in as little as four months, while generating an insignificant amount of grain from immature seeds. (Bócsa & Karus 1998; Thompson et al. 1998).

In countries where this configuration is often used, like China and France, cultivars can grow up to three seasons of hemp in a year—retting the fiber either by hand or by dew—while the next growth cycle is already in progress (Jianchun 2008; Kenyon 2008; Askew 2002). This configuration is most profitable when grown in a context that either has extremely low labor costs or access to high-throughput, rapid-cycle decortication capital equipment.

4.4. Growth for grain

Growth for grain, in contrast, is done in a significantly less dense arrangement and over a longer cycle. Since the crop must reach Stage VI of its growth cycle in order to seed, it takes about six months to seed and reach its maturity. The configuration results in longer, more mature stalks that are more spread out, larger in diameter, and have a greater amount of biomass than those grown for straw. Countries that use this configuration, like Sweden, are often looking to produce energy from hemp growth (Jyväskylä Innovation Oy & MTT Agrifood Research Finland, 2009). The combination of high oil yields from the seed and the ability to produce cellulosic fuels from the high biomass stalk best enable fuel production. Alternatively in Canada, hemp is often grown for the grain, and its oil and seed are more typically channeled into specialty markets (Gourdie 2010).

In maximizing grain production, this configuration significantly reduces fiber production. A planting configuration that grows approximately 20 plants/m^2 generates a reduction of 0.5 tons/acre of straw for an increased 0.5345 tons/acre of grain for two seasons in a year (Thompson et al. 1998)

4.5. Optimal growth configuration

Experimentation in France and a price optimization has shown that maximum revenue per acre can be generated by a combination of the formerly described approaches. Hemp can be grown at an intermediate planting density that allows for an intermediate amount of both grain and straw, resulting in a configuration that is maximally profitable for all material processers (cultivars, processors, and industry partners). The configuration of growing approximately 100 plants/m^2 and cultivating after 5 months yields 3.5 tons/acre of straw and 1.25 tons/acre of grain (Thompson et al. 1998).

Table 3: Comparison of revenue potential for each growth configuration

	Cultivar Revenue	Downstream Value
Straw Only	$408.00	$1,391.28
Grain Only	$409.24	$1,445.20
Optimal	$498.69	$1,733.07

5. Recommendations for US Cultivation

5.1. Development of the use model

Although hemp is one of the most versatile crops, with the potential to produce thousands of different products, many of these products are not financially viable. In these cases, benefits associated with the cost are not great enough for the application of hemp to these markets to be financially feasible. In past years a number of market feasibility analyses have attempted to estimate the potential of hemp components in local markets. Many of these studies were either idealistic in overestimating market potential or unrealistic in cost estimates, thereby underestimating the market potential. The inaccuracy in their estimates stems from a failure to properly estimate the processing costs and/or the yields of hemp.

Since this study develops an optimal growth configuration with substantiated conservative yields, inaccuracy in grain and straw yields is not expected. However, as mentioned in "Component Valuation," the processing costs are still variable and anticipated to change in the upcoming years. In particular, the costs associated with hemp straw processing will decline sharply with the commercialization of new chemical and mechanical decortication techniques that have already been developed. As a result, the bast fiber, that was once expensive to separate relative to cotton and other textile crops, will become significantly cheaper. Since we have neither the information nor the expertise to estimate these costs, we externalize their identification to the findings of other literature. Where processing costs are mentioned, they are taken from the most conservative estimates available for an estimated throughput of the equivalent of a 2.5 acre farm with the optimal growth configuration.

5.2. The grain

To breakdown the likely markets for each of the components, we evaluate the potential products that are obtained from the optimal growth configuration and then roughly assess the financial potential of each of them within their corresponding market. For the case of the grain, it will involve mechanically cold pressing the seed to yield both a protein-rich seed cake that can serve as a well-balanced animal feed and high-quality oil that can be refined as a biofuel (Jyväskylä Innovation Oy & MTT Agrifood Research Finland 2009; Callaway 2004). A conservative approximation of the variable costs of an industrial factory that could perform this process is estimated at $8.14 per lb of grain (Ferchau 2000). Once cold pressed, the resulting oil can either be sold to a niche market or made into biodiesel for an additional cost of about $2.83 per L of hemp oil

(Castleman 2001). After this treatment, the resulting biodiesel can now be sold for $10.58 per L on the consumer market (Babcock & Carriquiry 2008). The remaining seed cake can be sold as animal feed at the average market price of $0.30 per lb (Thompson et al., 1998). Together, the oil and seed cake can produce an estimated total profit of $1.42per lb grain, after the value of the original grain used is subtracted. Note that since wholesale market prices are not listed for either the seed cake or the biodiesel, and we have assumed consumer market prices, sidetracking a distribution chain that might offer wholesale rather than retail prices and slightly overestimating profit potential.

5.3. The bast fiber

Similarly, the stalk can be separated to feed multiple markets. Once removed from the core, the bast fiber is most profitably used as a substitute for wood-based paper. The decortication step, as a starting point to any form of fiber processing, costs approximately $100.50 per ton of straw; though this cost is anticipated to decline with the commercialization of new decortication technology (Thompson et al. 1998). Once separated, the fiber is pulped and then treated. The total cost of the most standard chemo mechanical pulping process approaches $1330 per ton of stalk, whereas it would cost $1620 to process a wood-based fiber (Newman 2008; Dewey 1916). The savings in variable costs do, however, come at the expense of initial fixed costs. Due to the higher lignin content in the hemp fiber, a portion of the equipment on existing wood paper mills needs to be retooled in order to accommodate hemp fiber. In spite of this, major companies like Germany's largest paper company have already started retooling mills to accommodate hemp fiber (Hemphasis 2004).

5.4. The core

After the removal of the fiber, the remaining hurds can then either be processed into a biofuel or channeled into the construction industry. Use in the construction industry is the most reliable market for the hurds; and it is already well developed in several European countries, including the UK, France, Switzerland, and several others (Askew 2002). Existing companies that deliver superior hemp-based thermal insulation, concrete, and other building materials charge a premium of approximately 10% for their products (Michka 1994; Kenyon 2008).

The biofuel industry, in contrast, is a lot less developed. Although the process of generating cellulosic ethanol from the hurds is on its way to becoming cost-competitive with gasoline, current technology places ethanol processing costs around $1.57 per gallon. With 2008-2013 US energy subsidies this cost reduces to $1.01 per gallon, and enzymatic technology developments forecast it to further reduce to $0.80 per gallon by 2012. With yields of 100 gallons per ton of biomass using the latest cellulolysis technologies, and an estimated hemp core market value $100 per ton (see Component Valuation), current total costs can be conservatively estimated at $2.01 per gallon of biofuel. This is about 56% above current wholesale gasoline prices of $2.014 after they have been adjusted for energy-equivalence (US Senate Advisory Committee 2010; Service 2007). Hence, although the process of conversion is currently expensive, as the technology develops and as fossil fuels become less available and more expensive, this alternative will become increasingly attractive.

5.5. Comparison of cash crop revenue potentials

If a cultivar is faced with the economic decision of whether to grow hemp on an industrial scale in rotation with other crops, the relative revenue potential of the crop with respect to its competition is of critical importance. The farmer's decision to cultivate hemp can be influenced by subsidies or incentives; but for the crop to stand on its own, it needs to be the most sustainable and profitable option at all levels of the agricultural chain. It can be worth a lot in its final processed form, but it will never reach that stage in high volume unless it is deemed economically attractive by farmers. As mentioned in the "Development of the use model," since the fixed and variable costs of production vary with geography, climate, technology access, and a number of error-propagating factors, the costs associated with cultivation are externalized to the cultivar, who will have a better basis for estimating them. As such, the cultivar's sales revenues from the optimal growth configuration are compared against anticipated revenues for cotton, wheat, soybeans, and corn grain as investigated by the USDA in their most recent comparative report published in 2000.

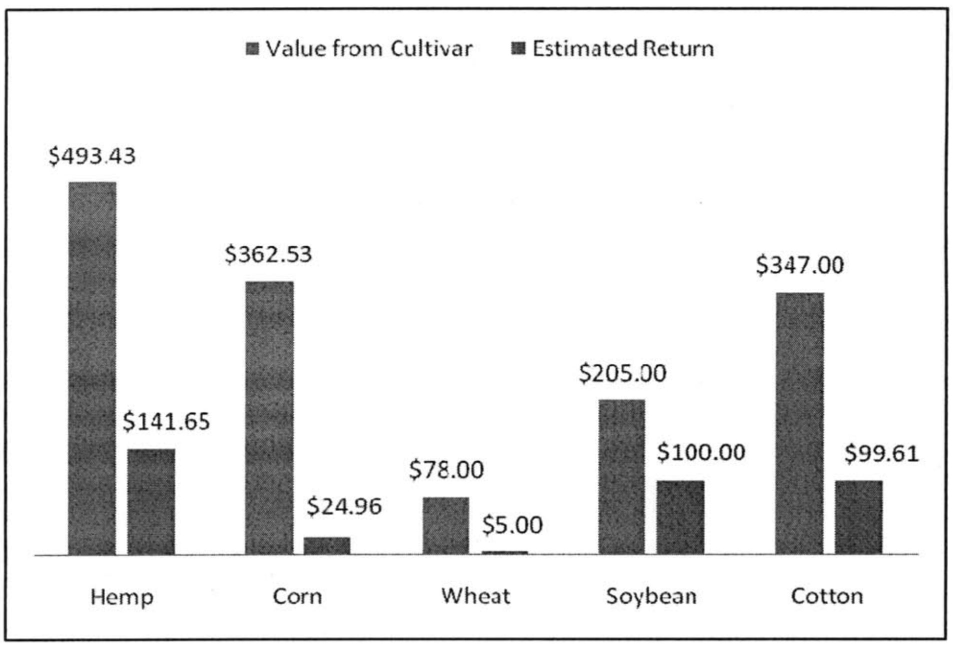


Figure 3: Hemp as a cash crop, comparison of estimated returns and crop values

6. Conclusions

Today, there are over 30 countries that successfully produce, process and benefit from the use of hemp. During the years following the American Revolution, there was a period of about one-hundred years where hemp was not only legal but also actually the top cash crop. America's production would be similar today if not for the libelous campaigns from William Randolph Hearst and Lammont DuPont that outlawed hemp in the US in 1936. Given our ability to differentiate hemp from its psychoactive kin marijuana, it is time we lift the ban on hemp and adopt the best of the Canadian distribution processing model, whilst avoiding its pitfalls. Given the advancements in technology and processing methods over the last 3 years, hemp could easily become the most economical and practical cash crop for America in the 21st century.

Regardless of whether hemp is cultivated for seed, fiber, or biomass—or even naturally in the wild—it exhibits the same routine rapid annual growth rate. While many factors can influence hemp growth, the plant is still one of the most robust crops that will grow, even compete with weeds, in almost any environment. Each of hemp's respective components is capable of generating products that have possible market niches and could be more efficient than current resources.

Hemp seed composition yields a number of options for producing oil, food, and seed cakes. Hemp bast was also used for the manufacture of commercial- and military-grade lightweight, high-strength cords, ropes, and twines. The composition of bast tissue makes it stronger and easier to process from the fiber stage than the more common textile and paper sources, cotton and wood. In fact, the rapid growth cycle of hemp allows it to produce more paper pulp from less land than three wood plantations intended for this purpose.

The fast rate of growth of the stalk allows biomass to be accumulated at a very rapid rate, comparable to the top two biofuel crops (Miscanthus and Switchgrass). The use of the core for building materials extends beyond concrete to acoustic insulation and even animal bedding—without the additional overhead of having to spend on fertilizers!

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