Environmental Costs of Hemp Prohibition in the United States

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ABSTRACT. This article seeks to add to the discussion about hemp prohibition in the United States by comparing the environmental performance of industrial hemp relative to its substitutes in a few key industrial applications. The life cycle environmental performance of industrial hemp products is of particular interest because environmental inefficiencies often impose costs on society as a whole, and additionally, the government has initiated a large number of programs intended both to reduce pollution and to increase production of bio-based industrial feedstocks. The positive attributes of industrial hemp are considered here in the context of countervailing attributes.

KEYWORDS. Hemp, environment, prohibition, regulation, United States

INTRODUCTION

In the United States, the cultivation of *Cannabis sativa* has been perceived to be so essential to national security that at times the government has mandated that farmers grow it, while at other times—including the present—the government has strictly prohibited it. Regulation of *Cannabis sativa* in the United States is complicated by the fact that the law fails to distinguish between two varieties of the plant with very different

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properties: the agricultural variety, known by the common name hemp, and the pharmacological variety, marijuana.

Prior to prohibition in the United States, industrial hemp was the subject of considerable excitement and speculation. Then, in 1937, punitive legislation—purportedly enacted to curtail marijuana cultivation—took hundreds of U.S. hemp farmers and their investors by surprise. In the succeeding years, the domestic hemp industry was driven out of existence and many governments followed suit by prohibiting hemp cultivation as the United States had.

Today, hemp cultivation is still not permitted in the United States, but speculation about the crop has been renewed, as lawmakers and stakeholders nationwide consider the potential for reintroducing industrial hemp into the domestic economy (see also Smith-Heisters, 2008).

The environmental performance of industrial hemp products is of particular interest because, in certain instances, environmental inefficiencies impose costs on society as a whole, not just the producers and consumers of a specific good. In the last century and a half, many commodities that replaced traditional uses of industrial hemp in the United States have created potentially significant environmental externalities.

For example, wood used for the manufacturing of paper in the United States today has very different processing requirements than industrial hemp, once widely used in papermaking. Acre-for-acre and pound-for-pound, the substitution of industrial hemp for cotton in California would likely reduce costs to the environment. The contribution of petroleum combustion to carbon dioxide emissions has become a topic of considerable policy attention recently, and this has helped to renew interest in plant-derived industrial feedstocks for fuel and other purposes. In the United States and elsewhere, hemp has been examined as a candidate for production of biomass and seed oil fuels. Finally, the newest technological applications of this ancient crop, in composite materials such as reinforced plastics, may be the most promising.

CROP INPUTS, IMPACTS, AND YIELDS

As an industrial crop, hemp has been grown either for the long fibers located in the outer layer of the plant's stem ("bast" fiber), for seed, or a combination of both. A secondary product of the high-value bast fiber crop is the internal core, or "hurd," consisting of short fibers and cellulosic biomass with a variety of industrial applications. While seed is a valuable commodity derived from multi-purpose hemp crops (indeed, it is the most valuable hemp product in the current U.S. market), commodities derived from hemp seed are given only incidental consideration in the present discussion, as they do not relate to prevailing environmental policy issues to the degree that hemp fiber commodities do.

Industrial hemp experts consider it a low-input, low-impact crop. Inputs required for cultivation of any crop are an important environmental consideration because of the pollution created in their production and left behind from their use. In the case of chemical fertilizers, herbicides, and other pesticides, life cycle impacts result from their manufacture as well as their shipment, storage, and delivery in the field. The energy required to deliver agricultural inputs to the field adds significantly, if indirectly, to the environmental burden of crop production. For example, in California, where irrigating crop land is the state's single largest water commitment, pumping for crop irrigation accounts for more than 90% of the agricultural sector's electricity use and 5% of the state's total energy use.

Natural gas is inextricably tied to conventional agricultural production through the use of inorganic fertilizers. Fertilizer production is responsible for approximately 1.2% of the world's energy use and total emission of greenhouse gases. In the United States, nitrogen fertilization of soils accounted for 9% of industrial greenhouse gas emissions in 2005 (60% of total nitrous oxide emissions). Fertilizers can also cause environmental damage when they leach from soils, contributing to eutrophication. Soil erosion and eutrophication as a result of agricultural runoff are leading causes of water impairment in the United States.

Significant in hemp's credentials as a low-impact industrial feedstock are the medium-to-low inputs required for growing the crop. Herbicides are not typically used in hemp cultivation. When industrial hemp is grown for fiber, the crop is seeded at very high densities, and the plants' rapid growth crowds out most weed species that might be present in the field. (Hemp seed crops, which are grown with more space between plants, do not perform as well in this regard.) Industrial hemp is also grown profitably with little or no use of pesticides. It is fair to assume that, like any other crop, if industrial hemp were grown intensively (with fertilizer and irrigation) in monoculture, over time it would inevitably develop pests and disease that required treatment, a scenario that is avoided by boosting crop genetic diversity and crop rotation.

Reported fertilizer inputs for hemp range widely. At the high end, fertilizer requirements are similar or less than those of corn or a high-yielding wheat crop. Nitrogen is principal in sustaining the rapid biomass growth of these crops. In Canada, industrial hemp is reportedly being grown with inputs of anywhere from 55 to 80 lbs/acre nitrogen and 30 to 40 lbs/acre phosphate, but much higher nitrogen fertilizer rates are often reported in other hemp-producing regions of the world.

Fiber hemp is seeded in the spring and matures in roughly 90 days, a relatively quick harvest, resulting in potential opportunity for various complimentary crop rotations. This is particularly true in California's climate, where hemp could be planted as early as February. Hawaiian hemp advocates boast of a local climate capable of producing "at least" three hemp crops per year. The relationship between industrial hemp crops and other crops grown in rotation is an important economic and agronomic consideration.

The broad adaptability of hemp to different climates makes it a viable crop on virtually all U.S. cropland. Wild *Cannabis sativa*, a relict of historic hemp crops, grows so prolifically in some parts of the country that 98% of the plants seized every year through the federal government's drug eradication program are this feral "ditchweed" rather than cultivated marijuana. Historically, however, hemp has been grown in states where summer rains or abundant irrigation were available: Kentucky, Wisconsin, California, North Dakota, South Dakota, Minnesota, Indiana, Illinois, Ohio, Michigan, Kansas, and Iowa. Hemp requires less irrigation than many of the competing crops, and it is drought-tolerant once established, but reliably high yields are associated with supplemental irrigation.

One rigorous life cycle analysis has been conducted on field production of fiber hemp (van der Werf, 2004). This study compared emissions and resource use per acre for all the processes up to and including harvest of industrial hemp as compared to seven other major crops in France: sunflower, canola/rapeseed, pea, wheat, maize/corn, potato, and sugar beet. For all impact categories examined—which included eutrophication, climate change, acidification, terrestrial ecotoxicity, and energy use—fiber hemp and sunflower were found to have consistently lower impacts and potato and sugar beet were found to have consistently higher environmental impacts. In this and other studies, reduction of eutrophication resulting from leaching of nitrogen fertilizers was identified as a priority to improve the environmental profile of industrial hemp cultivation.

In Europe and Canada, certified seed programs have developed patented low-tetrahydrocannabinol (THC, the regulated psychoactive constituent) varieties, and researchers continue to breed varieties maximized for specific qualities: cellulose for biofuels, fiber yield for textiles, proteins for food, and so forth. Seed stocks developed in the early history of the United States appear to have been lost during the extended period of hemp prohibition.

Any honest claims about production of industrial hemp in the United States must be prefaced by the fact that meaningful current yield data is unavailable for this country. The cost imposed by federal regulation on any potential field trial has made it virtually impossible to collect useful data. Wild estimates of the productivity of hemp as a crop have gone so far as to claim that “Hemp is the number one biomass producer on planet earth: 10 tons per acre in approximately 4 months.”

A more realistic estimate of industrial hemp productivity in the United States, at least initially, seems to be in the range of two to five tons of dry stems per acre—less than any number of common crops, including corn or specialty crops like kenaf. (*Arundo donax*, or giant reed, a type of grass invading western states, can grow 2 feet a week for a period of months, reaching a biomass of more than 30 tons per acre.)

Biomass is perhaps the least important measure of hemp yield, however. The composition of the hemp stalk—averaging around 25–35% bast fiber—determines how much of the plant is useful in many specific applications. Yield is also a factor of processing, which includes technological innovation at every stage: cutting the plant in the field, retting, baling, pulping, and so on. Fiber length, cellulose, and lignin content are additional quality parameters important to most industrial uses.

Aggressive crop research and development might help growers in the United States to realize a crop yield in the range of six to eight tons of dry stems per acre, approaching the reported yields of specialized hemp varieties grown historically in the United States or in ideal conditions in other parts of the world. (To this end, hemp experts in the United States believe that the genetic stock of wild “ditchweed” would be valuable for breeding regionally specialized hemp varieties domestically in the future.)

INDUSTRIAL USES

Industrial hemp applications include both traditional and distinctly modern uses, with varied costs and benefits as compared to substitutes. Among the industrial uses discussed below, biocomposites may represent the most environmentally efficient and cost-effective application, albeit limited in the United States by the expense of importing fiber from overseas producers.

Paper

Three qualities of hemp make it an attractive raw material for papermaking: hemp fibers are long (lending strength to paper), and hemp contains high levels of cellulose (corresponding with high pulp yield from the raw stalk) and low lignin content (an undesirable constituent that requires intensive processing to remove). But while hemp as a raw material has clear environmental advantages, trees, where available, are a more efficient source of pulp than any nonwood fiber crop.

The advantages of hemp crops for papermaking come at a cost: annual crops like hemp require more irrigation and fertilizers than forests or tree plantations; annual planting and harvest results in higher energy consumption and soil disturbance; an annual crop has generally lower incidental wildlife and other biological value; and transportation and storage of nonwood fiber crops is more expensive. A tree plantation grown over a number of years may require some irrigation and fertilizer initially, but active management is minimal for the subsequent years until harvest. In contrast, hemp crops are irrigated and fertilized every year, with farm equipment making dozens if not hundreds of passes over the field in the time that equivalent plantation trees take to grow. The average annual yield of industrial hemp and U.S. tree plantations on a per acre basis appears to be in the same general range, depending on pulping processes used.

The Great Lakes region has long had one of the greatest concentrations of paper and pulp mills in the United States. Although timber production for paper pulp is increasingly shifting to other countries, domestic mills still account for roughly one-third of world pulp production. Concern that the fiber supply in Minnesota is increasingly limiting the state's paper production prompted a recent evaluation of the potential for industrial hemp cultivation for papermaking in that region (Bowyer, 2001). That investigation concluded that production of hemp fiber would likely result in significantly greater environmental impacts than producing pulp from poplar plantations. Mills on Wisconsin's Fox River deal mainly in de-inking and recycling paper waste imported from outside the state. A USDA Forest Products Laboratory market analysis optimistically concluded that Wisconsin farmers could profitably produce hemp fiber to supplement recycled wood paper pulp for local mills, but the analysis did not evaluate the environmental trade-offs of doing so (Houtman, 1997).

Economic analyses suggest that hemp has potential in a variety of specialty, recycled, and low-value paper markets (e.g., unbleached cardboard packaging and transport materials).

Environmentally, however, little net benefit would be expected from the substitution of hemp papermaking for domestic tree plantations and modern wood pulp mills in the United States.

Cloth

Hemp offers some environmental benefits over cotton for use in cloth, but the degree of increased efficacy, in particular the per-acre fiber yield of hemp as compared to cotton, has often been exaggerated in popular writing on the subject. Cotton inputs and yields show very large variation throughout the world as well as within the cotton-producing areas of the United States. (For example, in one recent year, total pesticide treatment rates ranged from 4 to 19 pounds of active ingredient per treated acre, depending on region.) The best available estimates indicate that in the United States, hemp fiber yield could total at most three times per acre that of domestic cotton (assuming successful application of "cottonization" and other technologies which maximize yarn yield from the unprocessed stalks).

One recent study compared available data for life cycle water and energy inputs consumed in various hemp and cotton cultivation scenarios as well as polyester production (Cherret et al., 2005). The researchers found that polyester manufacturing required six times more total energy inputs (36% of it for chemical feedstock) than required for U.S. cotton production or hemp production (per ton). The chief difference between energy requirements in industrial hemp and cotton production was that most of the cotton energy requirement was a result of pesticide and irrigation inputs, while most of the life cycle energy consumption for hemp yarn occurred in the relatively intensive processing stage.

The U.S. is the second largest producer of cotton, accounting for roughly one-fifth of world production. Cotton is a crop especially suited to warm or hot climates, but it also requires relatively high quantities of available nutrients and water. California and the desert southwest meet these requirements, due in large part to the massive state- and federally built irrigation projects in these areas. All cotton grown in California is irrigated. Comparing average cotton production costs for California's three cotton-growing regions (Sacramento Valley, San Joaquin Valley, and Imperial Valley), and three cotton varietals (Acala, Upland, and Pima), to conservative estimates of irrigation, fertilizer, and pesticide use for fiber hemp production suggests that acre-for-acre and pound-for-pound, the substitution of industrial hemp for cotton in the state would reduce costs to the environment.

The greatest benefit would likely be in reduced herbicide and pesticide use, followed by reduced nitrogen fertilizer use and reduced irrigation—for example, production of industrial hemp would require less than half of each input needed for cotton cultivation in the Imperial Valley. (In the Imperial Valley, cotton is produced with 60 acre inches of irrigation water, 250 lbs. nitrogen, 104 lbs. phosphorus, 9 applications of pesticide and other chemical treatments, and yields 1500 lbs. of lint per acre.) Though potentially planted at the same time of year as cotton, hemp also matures in half the time that cotton takes to mature. (Whether the hemp crop would be as economically viable as cotton, especially given the still-immature state of commercial hemp yarn processing technologies, is a different question.)

Fuel

Corn ethanol is the biofuel most favored by current U.S. government subsidies for renewable fuels. While the environmental cost-benefit analysis of fuel produced from an agricultural rather than petrochemical source is complicated and controversial, what can be said is that hemp is an improvement over grain ethanol derived from corn on several counts: slightly higher soil conservation, no pesticide requirements, higher potential yield, and greater suitability for cellulosic (as opposed to grain) ethanol production. Although it remains a subject of intense debate, proponents of cellulosic ethanol production posit that it could reduce greenhouse gas emissions more than 80% below gasoline, as compared to (at best) a 20 or 40% reduction in emissions derived from grain ethanol. Research into the cost-effective production of cellulosic ethanol is in progress, with commercial breakthroughs some years away.

At present, biodiesel is more readily produced from hemp than ethanol, but canola is a cheaper and more eco-efficient biodiesel feedstock. At most, given current technology and the higher value of hemp for other uses, biofuels might be a secondary market for industrial hemp.

Composites

Although use of natural fibers in composite materials is a relatively new market for hemp, it is already a well-proven one. Hemp composites perform well in many applications requiring moisture adsorption and desorption, thermal and acoustic insulation, and stiff strength. Industrial hemp composites are found in automotive and general construction materials, geotextiles, filters, and other applications, many of which replace materials with greater environmental costs. Natural fiber benefits over mineral fibers include better occupational safety conditions, lower manufacturing costs (including equipment wear and energy consumption), greater recyclability (especially within the manufacturing process), favorable weight and strength characteristics, and more economical product end-of-life options.

In particular, the use of industrial hemp in natural fiber-reinforced plastics (thermosets and thermoplastics) has grown from virtually nonexistent a decade ago, to widespread use in the automotive industry. In the past, glass and asbestos fibers were the most common mineral fibers and flax and jute were the most common vegetable fibers used in automotive composites. Today, natural fiber blends are common in this application, but manufacturers would use more hemp if supplies were dependable and cost-competitive.

Since hemp and other natural fibers are usually used in a matrix of polypropylene (or another synthetic polymer) in these composites, net savings in manufacturing energy result both from the glass replaced and the matrix material displaced because of the greater proportion of natural fiber used in the mix. Energy use in glass fiber manufacturing appears to be in the range of five times the energy required for hemp fiber production—polypropylene, acrylonitrile-butadiene-styrene (ABS), and epoxy resin require at least 10 to 20 times as much energy for the same weight, respectively (see, for example, Joshi et al., 2004).

Using hemp in car parts saves energy not only in production, but also by creating a more lightweight product. Natural fiber components can be 20 to 30% lighter than conventional composites, improving fuel efficiency for the life of the vehicle.

Finally, hemp composites provide an environmental advantage at the end of a product's life cycle. In its unalloyed form, hemp decomposes and the carbon dioxide it has sequestered is released. Likewise, if it is incinerated after use in a composite with petroleum-based plastics, the sequestered carbon is rereleased. However, incineration of hemp composites offers more combustion value than incineration of glass-reinforced counterparts.

Other construction materials made from hemp include fiberboard, plasters, and concrete alternatives. These products share many of the favorable qualities of the bio-composites discussed previously.

There is good reason to expect that composites will continue to be one of the most environmentally preferable and cost-effective applications of industrial hemp, limited in the United States by the expense of importing fiber from mostly overseas producers.

Other Uses

Other uses of hemp include food and cosmetics—the primary markets for hemp seed crops grown just over the United States border, in Canada. These products are both legal and popular in the United States. However, the environmental significance of this market is minimal.

In a crop rotation, hemp can add value to other agricultural commodities, including staple food crops. For example, planted in a rotation with either organic or conventionally grown crops, hemp may naturally reduce weeds and other pests. Hemp is reportedly used in China as a barrier to repel insect pests from vegetable crops; in Canada in rotation with soybeans to reduce cyst nematodes, a parasitic pest; in The Netherlands in rotation with potatoes to reduce harmful nematodes, and in other rotation experiments has excelled at reducing infestations of *Cyperus esculentus*, a weed, as well as reportedly boosting yields of winter wheat when alternated in the field with that crop. Anecdotes such as these illustrate the positive value of crop rotation—in particular, alternating between vegetable and fiber crops—as opposed to the regional dominance of any single crop.

Lastly, a number of studies have identified industrial hemp as a top candidate in bioremediation applications, especially phytoextraction of heavy metals from industrially contaminated soils. Hemp has been used to process greywater in Australia; extensively tested in Europe for the removal of heavy metals, including cadmium, lead, copper, zinc, and nickel often associated with mining; used for the clean-up of polycyclic aromatic hydrocarbons at a site in Hawaii; and cultivated on radionuclide-contaminated soils at the Chernobyl nuclear reactor site. Although industrial hemp is not considered a "hyperaccumulator" of heavy metals, many researchers believe it has strong potential for use in phytoremediation because it is so adaptable, and is comparable or better in phytoremediation applications than many plants of equal economic value.

LEGAL ISSUES

The United Nations Single Convention on Narcotic Drugs, adopted in 1961, requires that *Cannabis* is regulated just as opium is, but exempts industrial hemp, stating: "This Convention shall not apply to the cultivation of the cannabis plant exclusively for industrial purposes (fiber and seed) or horticultural purposes." When the Controlled Substances Act of 1970 was enacted in the United States to fulfill the treaty obligations of the nation as a signatory of the U.N. Single Convention, however, no exception was made for industrial hemp varieties of Cannabis in cultivation. Marijuana and its primary drug constituent, tetrahydrocannabinol (THC), were placed in the most tightly controlled group of drugs: substances defined by the Act as having a high potential for abuse and no currently accepted medical use. The newly created Drug Enforcement Administration (DEA) assumed responsibility for the regulation of industrial hemp and marijuana alike.

Individually, beginning in the 1990s, a growing number of states have passed legislation to allow for limited research and/or cultivation of industrial hemp. Both the National Conference of State Legislators (2000) and the National Association of State Departments of Agriculture (2003) have passed resolutions asking Congress to direct the DEA to revise its policies and allow states to establish regulatory programs for industrial hemp farming and research. In neighboring Canada, commercial hemp cultivation has been legal for a decade.

However, the DEA has generally sought to expand rather than liberalize regulation of industrial hemp, even going so far as to attempt to regulate processed hemp products containing miniscule (non-psychoactive) amounts of THC. Very likely, even if zero-THC strains of industrial hemp were developed for use in the United States, the DEA would push to maintain the prohibition of industrial hemp on the grounds that "problems of detection and enforcement easily justify a ban broader than the psychoactive variety of the plant," as the court ruled in one modern case which tried to show that federal laws against marijuana did not prohibit the production of hemp.

TECHNOLOGICAL FEASIBILITY

Most experts agree that, legal questions aside, the largest obstacle for profitable industrial hemp production in the United States is technological. Many of the same properties that make hemp perform so well in industrial applications—for instance, its durability and light weight—also make it expensive to process. In some countries, processing hemp for industrial use is accomplished with abundant manual labor and methods that would be environmentally unacceptable in the United States. Like many other fiber crops, long distances between the field and processing locations are often uneconomical. The entry of smaller regional processors into the market can be very difficult in the United States, where highly centralized and mechanized processing is the norm. That's a reason why, for instance, domestic virgin paper pulp is derived almost exclusively from trees. Improved environmental and economic performance is a double dividend for the large wood mills that enjoy this economy of scale.

Technological advances have frequently been sought in order to more fully or cheaply exploit the valuable natural properties of industrial hemp. For 50 years, the prohibition of industrial hemp production in the West (and to a lesser extent, the low cost of production in the East) has been a disincentive for investment, research, and development of industrial hemp processing technologies. With the lifting of prohibition outside of the United States, that barrier is now lower and some progress is being made.

Similarities between hemp and flax in the textile industry, or between hemp and other cellulosic biofuel feedstocks, might allow technological advances for the processing of one to be adapted to the other. The status of hemp in the United States is a disadvantage in highly specialized and time-sensitive research, however. If permitted again, a domestic hemp industry will face tough competition from both more-entrenched U.S. industries (e.g., corn ethanol) and hemp-producing nations with more experience.

Greater use of the hemp plant, including bast fiber, hurds, and seed, with development of more markets for co- and byproducts, will improve the viability of hemp industries. At the same time, more economical use of agricultural residues such as corn stalks, cereal straw, flax shives, and sugarcane bagasse might fill many of the same needs as dedicated fiber crops like hemp with greater resource efficiency.

Plant breeding and genetic engineering; streamlined harvesting, retting, and fiber separation; development of specialized processing facilities and retooling of existing facilities, including cotton mills; commercialized "cottonization" technologies for the production of hemp yarn; commercialized microbial/enzymatic processes for ethanol production; improved nontoxic pulping processes and/or improved chemical recovery in milling; further development of industrial-grade cellulosic and other bio-based plastics; and standardization at every level (to compete with highly standardized synthetic feedstocks) are all key advances that would be important to the success of the industrial hemp industry in the future.

CONCLUSION

The development of regionally and commodity specialized industrial hemp breeds and processing capability, including complementary processing infrastructure and other innovation in the U.S. market has been stifled through severe regulation of this plant. Examination of the unique qualities of hemp suggests that hemp prohibition affects a broad array of enterprises, ranging from those that may have mainly local economic significance, to global industries and products.

Nations that followed the United States in prohibiting hemp cultivation have, for the most part, rescinded these laws—some more than a decade ago. A report by the U.S. Congressional Research Service recently noted that "the United States is the only developed nation in which industrial hemp is not an established crop" (Rawson, 2005).

Examined in applications alongside functionally comparable conventional industrial feedstocks, including hydrocarbon feedstocks, often industrial hemp: consumes substantially less energy during manufacture; is suited to a less toxic means of processing; provides competitive product performance (especially in terms of durability, light weight, and strength), greater recyclability and/or biodegradability; and has a product life cycle characterized by a variety of marketable co-products and value-added applications. In contrast to petrochemical production, industrial hemp production offsets carbon dioxide emissions, helping to close the carbon cycle.

The positive aspects of industrial hemp as a crop must be considered in the context of countervailing attributes. Production stages where industrial hemp may have higher average environmental costs than comparable conventional materials include, broadly: use of water and fertilizer during crop cultivation; greater frequency of soil disturbance during cultivation as compared to forests and some perennial field crops; and often, relatively high water use during fiber processing.

Overall, social pressure and domestic government mandates for lower dioxin production, lower greenhouse gas emissions, greater bio-based product procurement, and a number of other environmental initiatives, are all directly contrary to the continued U.S. prohibition of this evidently useful and unique crop.

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