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Hemp: A New Crop with New Uses for North America*

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"Hemp" refers primarily to *Cannabis sativa* L. (Cannabaceae), although the term has been applied to dozens of species representing at least 22 genera, often prominent fiber crops. For examples, Manila hemp (abaca) is *Musa textilis* Née, sisal hemp is *Agave sisalina* Perrine, and sunn hemp is *Crotolaria juncea* L. Especially confusing is the phrase "Indian hemp," which has been used both for narcotic Asian land races of *C. sativa* (so-called *C. indica* Lamarck of India) and *Apocynum cannabinum* L., which was used by North American Indians as a fiber plant. *Cannabis sativa* is a multi-purpose plant that has been domesticated for bast (phloem) fiber in the stem, a multi-purpose fixed oil in the "seeds" (achenes), and an intoxicating resin secreted by epidermal glands. The common names hemp and marijuana (much less frequently spelled marihuana) have been applied loosely to all three forms, although historically hemp has been used primarily for the fiber cultigen and its fiber preparations, and marijuana for the drug cultigen and its drug preparations. The current hemp industry is making great efforts to point out that "hemp is not marijuana." Italicized, *Cannabis* refers to the biological name of the plant (only one species of this genus is commonly recognized, *C. sativa* L.). Non-italicized, "cannabis" is a generic abstraction, widely used as a noun and adjective, and commonly (often loosely) used both for cannabis plants and/or any or all of the intoxicant preparations made from them.

Probably indigenous to temperate Asia, *C. sativa* is the most widely cited example of a "camp follower." It was pre-adapted to thrive in the manured soils around man's early settlements, which quickly led to its domestication (Schultes 1970). Hemp was harvested by the Chinese 8500 years ago (Schultes and Hofmann 1980). For most of its history, *C. sativa* was most valued as a fiber source, considerably less so as an intoxicant, and only to a limited extent as an oilseed crop. Hemp is one of the oldest sources of textile fiber, with extant remains of hempen cloth trailing back 6 millennia. Hemp grown for fiber was introduced to western Asia and Egypt, and subsequently to Europe somewhere between 1000 and 2000 BCE. Cultivation in Europe became widespread after 500 CE. The crop was first brought to South America in 1545, in Chile, and to North America in Port Royal, Acadia in 1606. The hemp industry flourished in Kentucky, Missouri, and Illinois between 1840 and 1860 because of the strong demand for sailcloth and cordage (Ehrensing 1998). From the end of the Civil War until 1912, virtually all hemp in the US was produced in Kentucky. During World War I, some hemp cultivation occurred in several states, including Kentucky, Wisconsin, California, North Dakota, South Dakota, Minnesota, Indiana, Illinois, Ohio, Michigan, Kansas, and Iowa (Ehrensing 1998). The second world war led to a brief revival of hemp cultivation in the Midwest, as well as in Canada, because the war cut off supplies of fiber (substantial renewed cultivation also occurred in Germany for the same reason). Until the beginning of the 19th century, hemp was the leading cordage fiber. Until the middle of the 19th century, hemp rivaled flax as the chief textile fiber of vegetable origin, and indeed was described as "the king of fiber-bearing plants,—the standard by which all other fibers are measured" (Boyce 1900). Nevertheless, the Marihuana Tax Act applied in 1938 essentially ended hemp production in the United States, although a small hemp fiber industry continued in Wisconsin until 1958. Similarly in 1938 the cultivation of *Cannabis* became illegal in Canada under the Opium and Narcotics Act.

Hemp, grown under license mostly in Canada, is the most publicized "new" crop in North America. Until very recently the prohibition against drug forms of the plant prevented consideration of cultivation of fiber and oilseed cultivars in Canada. However, in the last 10 years three key developments occurred: (1) much-publicized recent advances in the legal cultivation of hemp in western Europe, especially for new value-added products; (2) enterprising farmers and farm groups became convinced of the agricultural potential of hemp in Canada, and obtained permits to conduct experimental cultivation; and (3) lobby groups convinced the government of Canada that narcotic forms of the hemp plant are distinct and distinguishable from fiber and oilseed forms. In March 1998, new regulations (under the Controlled Drugs and Substances Act) were provided to allow the commercial development of a hemp industry in Canada, and since then more than a thousand licenses have been issued. Hectares licensed for cultivation for 1998–2001 were respectively, 2,500,

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14,200, 5,487, and 1,355, the decreasing trend due to a glut of seed produced in 1999 and pessimism over new potential regulations barring exports to the US. Information on the commercial potential of hemp in Canada is in Blade (1998), Marcus (1998), and Pinfold Consulting (1998). In the US, a substantial trade in hemp products has developed, based on imports of hemp fiber, grain, and oil. The American agricultural community has observed this, and has had success at the state level in persuading legislators of the advisability of experimental hemp cultivation as a means of evaluating the wisdom of re-establishing American hemp production. However, because of opposition by the federal government, to date there has only been a small experimental plot in Hawaii. Information on the commercial potential of hemp in the US is presented in the following.

Cannabis sativa is extremely unusual in the diversity of products for which it is or can be cultivated. Popular Mechanics magazine (1938) touted hemp as "the new billion dollar crop," stating that it "can be used to produce more than 25,000 products, ranging from dynamite to Cellophane." Table 1 presents the principal products for which the species is cultivated in Europe, all of which happen to be based on fiber. This presentation stresses the products that hold the most promise for North America, which also include a considerable range of oilseed applications (Table 2; Fig. 1).

BASIC CATEGORIES OF *CANNABIS* AND THEIR FIELD ARCHITECTURE

Cannabis sativa is an annual wind-pollinated plant, normally dioecious and dimorphic, although sometimes monoecious (mostly in several modern European fiber cultivars). Figure 2 presents the basic morphology of the species. Some special hybrids, obtained by pollinating females of dioecious lines with pollen from

Table 1. Hemp fiber usage in the European Union in 1999 (after Karus et al. 2000).

Class of product	Quantity consumed (tonnes)	Relative percentage
Specialty pulp (cigarette paper, bank notes, technical filters, and hygiene products)	24,882	87
Composites for autos	1,770	6
Construction & thermal insulation materials	1,095	4
Geotextiles	234	0.8
Other	650	2.2
Total	26,821	100

Table 2. Analysis of commercial *Cannabis* product potential in North America in order of decreasing value toward the right and toward the bottom.

"Seeds" (achenes)	Long ("bark") fiber	Woody stem core	Female floral (perigonal) bract	Whole plant
Confectionary, baked goods	Plastic-molded products	Animal bedding	Medicinal cannabinoids	Alcohol
Salad oil	Specialty papers	Thermal insulation	Essential oil (for flavor & perfume)	Fuel
Body care "cosmetics"	Construction fiberboard	Construction (fiberboard, plaster board, etc.)	Insect repellant	Silage
Animal food (whole seeds for birds, press-cake for mammalian livestock)	Biodegradable landscape matting & plant culture products			
Gamma-linolenic acid dietary supplements	Coarse textiles (carpets, upholstery)			
Specialty industrial oils	Fine textiles			

monoecious plants, are predominantly female (so-called "all-female," these generally also produce some hermaphrodites and occasional males). All-female lines are productive for some purposes (e.g. they are very uniform, and with very few males to take up space they can produce considerable grain), but the hybrid seed is expensive to produce. Staminate or "male" plants tend to be 10%–15% taller and are less robust than the pistillate or "female" (note the comparatively frail male in Fig. 3). So prolific is pollen production that an isolation distance of about 5 km is usually recommended for generating pure-bred foundation seed. A "perigonal bract" subtends each female flower, and grows to envelop the fruit. While small, secretory, resin-producing glands occur on the epidermis of most of the above-ground parts of the plant, the glands are very dense and productive on the perigonal bracts, which are accordingly of central interest in marijuana varieties. The root is a laterally branched taproot, generally 30–60 cm deep, up to 2.5 m in loose soils, very near the surface and more branched in wet soils. Extensive root systems are key to the ability of hemp crops to exploit deep supplies of nutrients and water. The stems are erect, furrowed, and usually branched, with a woody interior, and may be hollow in the internodes. Although the stem is often woody, the species is frequently referred to as a herb or forb. Plants vary enormously in height depending on genetic constitution and environment (Fig. 4), but are typically 1–5 m (heights of 12 m or more in cultivation have been claimed).

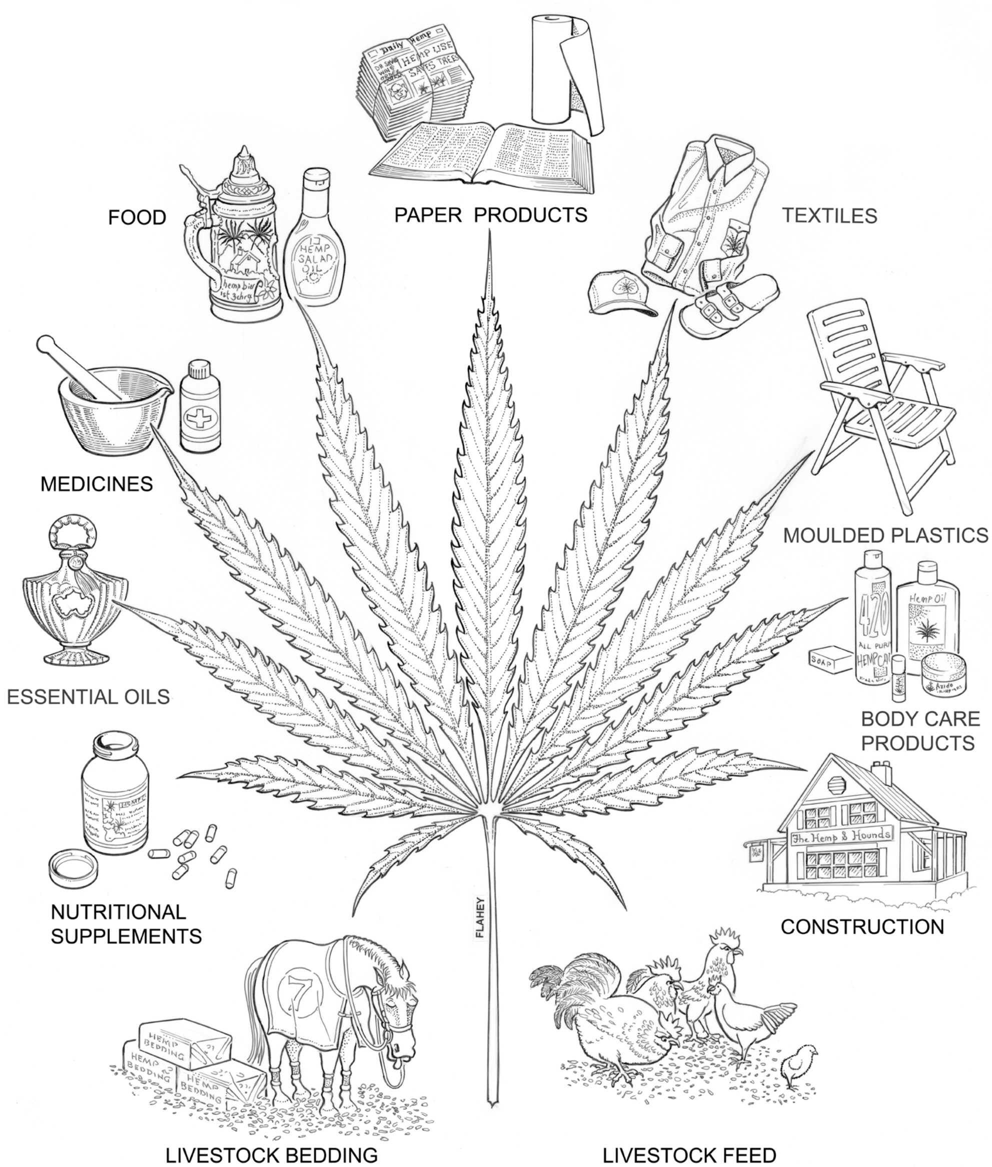

Fig. 1. Major uses of industrial hemp.

There is great variation in *Cannabis sativa*, because of disruptive domestication for fiber, oilseed, and narcotic resin, and there are features that tend to distinguish these three *cultigens* (cultivated phases) from each other. Moreover, density of cultivation is used to accentuate certain architectural features. Figure 5 illustrates the divergent appearances of the basic agronomic categories of *Cannabis* in typical field configurations.

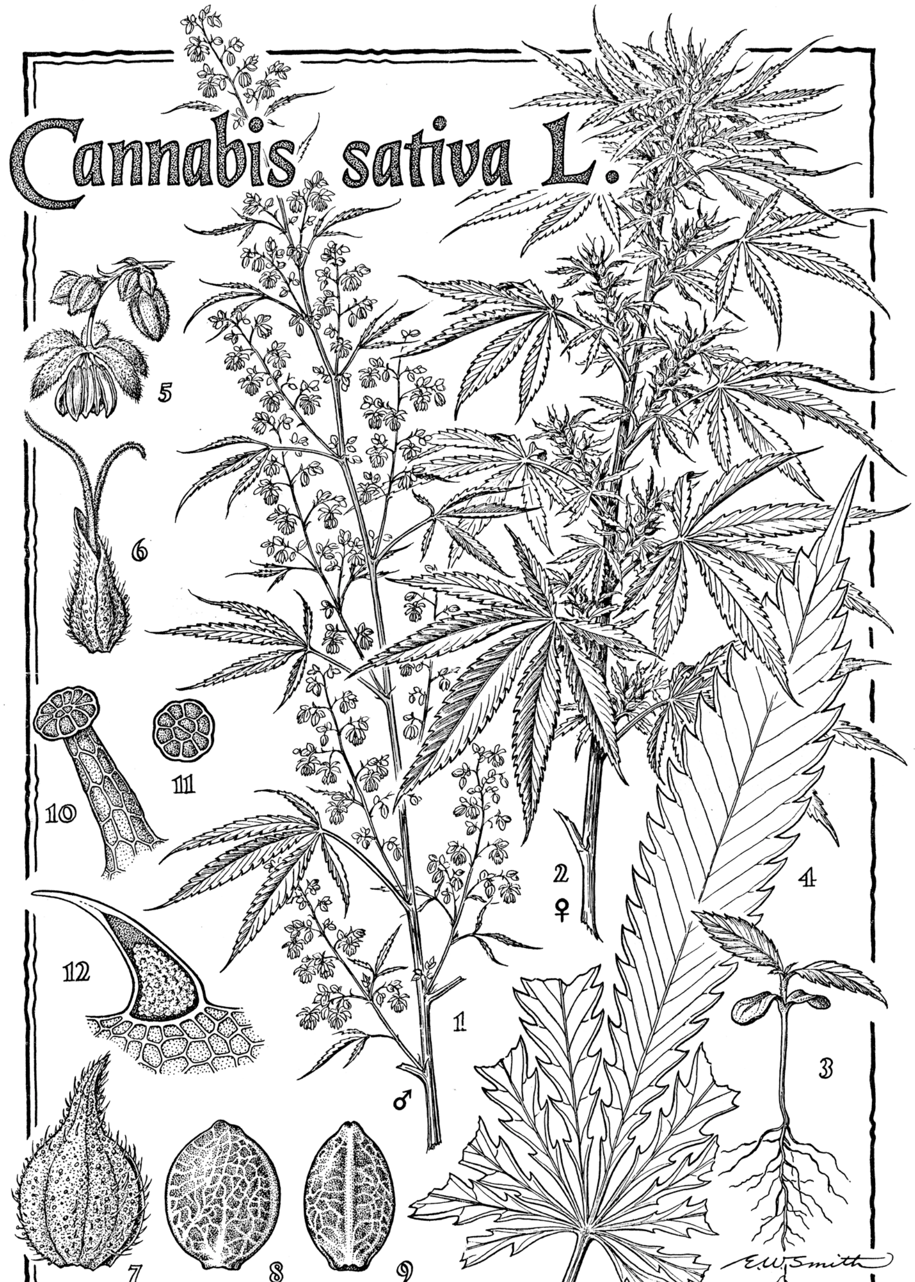

Fig. 2. *Cannabis sativa*. This superb composite plate by artist Elmer Smith, often reproduced at a very small scale and without explanation in marijuana books, is the best scientific illustration of the hemp plant ever prepared. 1. Flowering branch of male plant. 2. Flowering branch of female plant. 3. Seedling. 4. Leaflet. 5. Cluster of male flowers. 6. Female flower, enclosed by perigonal bract. 7. Mature fruit enclosed in perigonal bract. 8. Seed (achene), showing wide face. 9. Seed, showing narrow face. 10. Stalked secretory gland. 11. Top of sessile secretory gland. 12. Long section of cystolith hair (note calcium carbonate concretion at base). Reproduced with the permission of Harvard University, Cambridge, MA.

Highly selected forms of the fiber cultigen possess features maximizing fiber production. Since the nodes tend to disrupt the length of the fiber bundles, thereby limiting quality, tall, relatively unbranched plants with long internodes have been selected. Another strategy has been to select stems that are hollow at the internodes, with limited wood, since this maximizes production of fiber in relation to supporting woody tissues. Similarly, limited seed productivity concentrates the plant's energy into production of fiber, and fiber cultivars often have low genetic propensity for seed output. Selecting monoecious strains overcomes the problem of differential maturation times and quality of male (staminate) and female (pistillate) plants (males mature 1–3 weeks earlier). Male plants in general are taller, albeit slimmer, less robust, and less productive. Except for the troublesome characteristic of dying after anthesis, male traits are favored for fiber production, in contrast to the situation for drug strains noted below. In former, labor-intensive times, the male plants were harvested earlier than the females, to produce superior fiber. The limited branching of fiber cultivars is often compensated for by possession of large leaves with wide leaflets, which obviously increase the photosynthetic ability of the plants. Since fiber plants have not generally been selected for narcotic purposes, the level of intoxicating constituents is usually limited.

Fig. 3. Photograph of *Cannabis sativa*. Left, staminate ("male") plant in flower; right, pistillate ("female") plant in flower.

Fig. 4. United States National Institute of Health, University of Mississippi marijuana plantation site, showing variation in plant size. A tall fiber-type of hemp plant is shown at left, and a short narcotic variety (identified as "Panama Gold") at right.

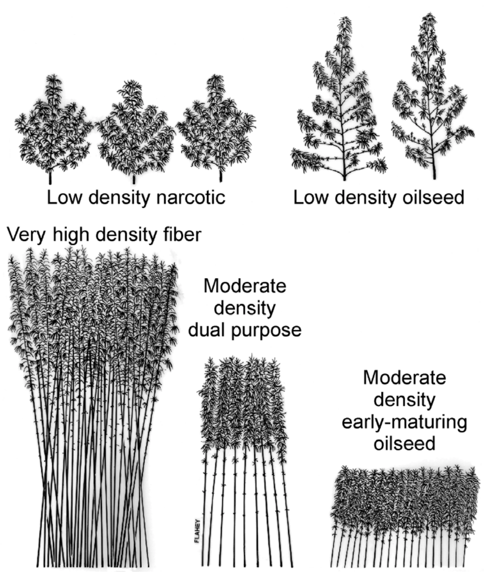

Fig. 5. Typical architecture of categories of cultivated *Cannabis sativa*. Top left: narcotic plants are generally low, highly branched, and grown well-spaced. Top right: plants grown for oilseed were traditionally well-spaced, and the plants developed medium height and strong branching. Bottom left: fiber cultivars are grown at high density, and are unbranched and very tall. Bottom center: "dual purpose" plants are grown at moderate density, tend to be slightly branched and of medium to tall height. Bottom right: some recent oilseed cultivars are grown at moderate density and are short and relatively unbranched. Degree of branching and height are determined both by the density of the plants and their genetic background.

An absence of such fiber-strain traits as tallness, limited branching, long internodes, and very hollow stems, is characteristic of narcotic strains. Drug forms have historically been grown in areas south of the north-temperate zone, often close to the equator, and are photoperiodically adapted to a long season. When grown in north-temperate climates maturation is much-delayed until late fall, or the plants succumb to cold weather before they are able to produce seeds. Unlike fiber strains that have been selected to grow well at extremely high densities, drug strains tend to be less persistent when grown in high concentration (de Meijer 1994). Drug strains can be very similar in appearance to fiber strains. However, a characteristic type of narcotic plant was selected in southern Asia, particularly in India and neighboring countries. This is dioecious, short (about a meter in height), highly branched, with large leaves (i.e. wide leaflets), and it is slow to mature. The appearance is rather like a short, conical Christmas tree.

Until recent times, the cultivation of hemp primarily as an oilseed was largely unknown, except in Russia. Today, it is difficult to reconstruct the type of plant that was grown there as an oilseed, because such cultivation has essentially been abandoned. Oilseed hemp cultivars in the modern sense were not available until very recently, but some land races certainly were grown specifically for seeds in Russia. Dewey (1914) gave the following information: "*The short oil-seed hemp with slender stems, about 30 inches high, bearing compact clusters of seeds and maturing in 60 to 90 days, is of little value for fiber production, but the experimental plants, grown from seed imported from Russia, indicate that it may be valuable as an oil-seed crop to be harvested and threshed in the same manner as oil-seed flax.*" Most hemp oilseed in Europe is currently obtained from so-called "dual usage" plants (employed for harvest of both stem fiber and seeds, from the same plants). Of the European dual-usage cultivars, 'Uniko B' and 'Fasamo' are particularly suited to being grown as oilseeds. Very recently, cultivars have been bred specifically for oilseed production. These include 'Finola,' formerly known as 'Fin-314' (Fig. 6) and 'Anka' (Fig. 7), which are relatively short, little-branched, mature early in north-temperate regions, and are ideal for high-density planting and harvest with conventional equipment. Dewey (1914) noted that a Turkish narcotic type of land race called "Smyrna" was commonly used in the early 20th century in the US to produce birdseed, because (like most narcotic types of *Cannabis*) it is densely branched, producing many flowers, hence seeds. While oilseed land races in northern Russia would have been short, early-maturing plants in view of the short growing season, in more southern areas oilseed landraces likely had moderate height, and were spaced more widely to allow abundant branching and seed production to develop. Until Canada replaced China in 1998 as a source of imported seeds for the US, most seeds used for various purposes in the US were sterilized and imported from China. Indeed, China remains the largest producer of hempseed. We have grown Chinese hemp land races, and these were short, branched, adapted to a very long growing season (i.e. they come into flower very slowly in response to photoperiodic

Fig. 6. 'Finola,' the first cultivar of *Cannabis sativa* bred exclusively for grain. (Courtesy of the breeder, J.C. Callaway, Univ. Kuopio, Finland.)

Fig. 7. 'Anka,' the first registered North American bred cultivar of *Cannabis sativa*. This variety is best suited for grain production. (Courtesy of the breeder, P. Dragla, and of the Industrial Hemp Seed Development Company, Chatham, Ontario.)

induction of short days in the fall), and altogether they were rather reminiscent of Dewey's description of Smyrna. Although similar in appearance to narcotic strains of *C. sativa*, the Chinese land races we grew were in fact low in intoxicating constituents, and it may well be that what Dewey thought was a narcotic strain was not. Although some forms of *C. sativa* have quite large seeds, until recently oilseed forms appear to have been mainly selected for a heavy yield of seeds, usually recognizable by abundant branching. Such forms are typically grown at lower densities than hemp grown only for fiber, as this promotes branching, although it should be understood that the genetic propensity for branching has been selected. Percentage or quality of oil in the seeds does not appear to have been important in the past, although selection for these traits is now being conducted. Most significantly, modern selection is occurring with regard to mechanized harvesting, particularly the ability to grow in high density as single-headed stalks with very short branches bearing considerable seed.

CONTROLLING THE DRUG ABUSE POTENTIAL OF HEMP

As detailed below, the development of hemp as a new legal crop in North America must be considered in relation to illicit cultivation, so it is important to appreciate the scope of the drug situation. Up until the first half of the 20th century, drug preparations of *Cannabis* were used predominantly as a recreational inebriant in poor countries and the lower socio-economic classes of developed nations. After World War II, marijuana became associated with the rise of a hedonistic, psychedelic ethos, first in the United States and eventually over much of the world, with the consequent development of a huge international illicit market that exceeds the value of the hemp market during its heyday. Table 3 shows the "economic significance" (dollars generated in the black market plus dollar cost of control measures) of the illicit drug industry associated with *C. sativa*, and contrasts this with the estimated dollar value of major categories of legitimate uses. In the Netherlands, the annual value of narcotic hemp cultivation (ca. $10 billion) exceeds the value of tulips (Collins 1999). Marijuana has become the most widely disseminated illicit species in the world (Schultes and Hofmann 1980). With the exception of alcohol, it is the most widely used recreational euphoric drug. About 25% of North Americans are believed to have used *Cannabis* illegally. According to the US National Institute on Drug Abuse (www.nida.nih.gov/Infofax/marijuana.html), more than 72 million Americans (33%) 12 years of age and older have tried marijuana. Cultivation, commerce, and consumption of drug preparations of *Cannabis* have been proscribed in most countries during the present century. The cost of enforcing the laws against *Cannabis* in North America is in the billions of dollars annually. In addition, there are substantial social costs, such as adverse effects on users, particularly those who are convicted. Tragically this includes some legitimate farmers who, faced with financial ruin because of the unprofitability of crops being grown, converted to growing marijuana.

A rather thorough analysis of the scope of the illicit marijuana industry in Canada for 1998 is reported at www.rcmp-grc.gc.ca/html/drugsituation.htm#Marihuana and summarized in MacLeod (1999). At least 800 tonnes (t) of marijuana were grown in Canada in 1998, representing a harvest of 4.7 million flowering plants. More than 50% of the marijuana available in Canada is grown domestically. An average mature plant was estimated to produce 170 g of "marketable substance." The value of the Canadian crop is uncertain, but has been estimated to be in the billions of dollars annually (Heading 1998; MacLeod 1999).

Table 3. Comparative annual world economic significance of categories of *Cannabis* activity.

Category	World ($)	North America ($)	Type of investment
Recreational drugs	> 1 trillion	100s of billions	Law enforcement, eradication, education
Industrial hemp	100s of millions[z]	10s of millions	Production, development, marketing, research
Therapeutic drugs	100s of millions	10s of millions	Production, development, marketing, research
Phytoremediation	10s of thousands	nil	Research
Ornamental hemp	thousands	nil	Development

[z]"The global market for hemp-derived products is valued at between $100 million and $200 million annually" (Pinfold Consulting 1998; De Guzman 2001).

The US Drug Enforcement Administration's online criminal justice statistics for 2000 (cscmosaic.albany.edu/sourcebook/1995/pdf/t440.pdf) shows the following seizures and eradication of plants of *C. sativa*: 40,929 outdoor plots (2,597,796 plants), 139,580,728 ditchweed (ruderal plants), 2,361 indoor operations (217,105 plants), for a grand total of 2,814, 903 plants destroyed. Impressively, the species was grown in all 50 states (including outdoor seizures in every state except Wyoming)! It is of course impossible to know exactly how much marijuana is cultivated in the United States, and perhaps only 10% to 20% of the amount grown is seized. The profitability of the illegal crop is indicated by a comparison of the cost of a bushel of corn (roughly $2.50) and a bushel of manicured marijuana (about $70,000; it has been suggested that prices range from $500 a pound, for low-quality marijuana, to more than $5,000 a pound for "boutique" strains like "Northern Lights" and "Afghan Kush"). According to a National Organization for the Reform of Marijuana Laws (NORML) (mir.drugtext.org/marijuananews/marijuana_ranks_fourth_largest_c.htm) marijuana is at least the fourth most valuable crop in America, outranked only by corn, soybeans, and hay. It was estimated that 8.7 million marijuana plants were harvested in 1997, worth $15.1 billion to growers and $25.2 billion on the retail market (the wholesale value was used to compare marijuana to other cash crops). Marijuana was judged to be the largest revenue producing crop in Alabama, California, Colorado, Hawaii, Kentucky, Maine, Rhode Island, Tennessee, Virginia, and West Virginia, and one of the top five cash crops in 29 other states.

Cannabis contains a seemingly unique class of chemicals, the cannabinoids, of which more than 60 have been described, but only a few are psychoactive. Cannabinoids are produced in specialized epidermal glands, which differ notably in distribution on different organs of the plant (high concentrations occur on the upper surface of the young leaves and young twigs, on the tepals, stamens, and especially on the perigonal bract). Given this distribution, the glands would seem to be protective of young and reproductive above-ground tissues (the roots lack glands). Two classes of epidermal glands occur—stalked and sessile (Fig. 8), but in either case the glandular cells are covered by a sheath under which resin is accumulated, until the sheath ruptures, releasing resin on the surface. The resin is a sticky mixture of cannabinoids and a variety of terpenes. The characteristic odor of the plant is due to the abundant terpenes, which are not psychoactive. The more important cannabinoids are shown in Fig. 9. In the plant the cannabinoids exist predominantly in the form of car-

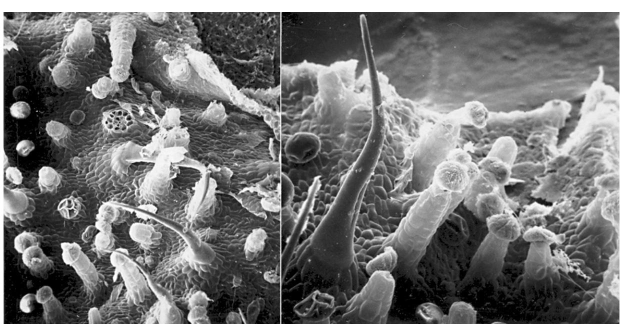

Fig. 8. Scanning electron micrographs of the abaxial surface of a perigonal bract (which envelops the fruit). These bracts are the most intoxicating part of the plant, and may contain 20% THC, dry weight. The resin is synthesized both in stalked and sessile glands. Multicellular secretory glands (of phallic appearance), some broken stalks of these (note cellular appearance), and unicellular cystolith hairs (claw-like structures) are pictured.

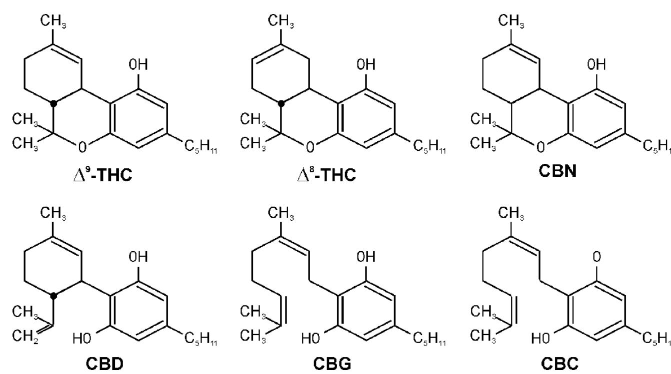

Fig. 9. Some important cannabinoids of cannabis resin. Δ^9-THC (delta-9 tetrahydrocannabinol) is the chief intoxicant chemical and predominates in intoxicant strains, while the isomer Δ^8-THC is usually present in no more than trace amounts. CBD (cannabidiol) is the chief non-intoxicant chemical, and predominates in non-intoxicant strains; it has sedative effects. The non-intoxicant CBN (cannabinol) is a frequent degradation or oxidation product. The non-intoxicant cannabichromene (CBC) is typically found in trace amounts in intoxicant strains. The non-intoxicant cannabigerol (CBG) is considered to be a precursor of the other cannbinoids (see Fig. 10).

boxylic acids, which decarboxylate with time or when heated. Delta-9-tetrahydrocannabinol (Δ^9-THC, or simply THC) is the predominant psychoactive component. Other THC isomers also occur, particularly Δ^8-THC, which is also psychoactive. Technically, the euphoric psychological effects of THC are best described by the word *psychotomimetic*. Cannabidiol (CBD) is the chief non-psychotomimetic cannabinoid. A THC concentration in marijuana of approximately 0.9% has been suggested as a practical minimum level to achieve the (illegal) intoxicant effect, but CBD (the predominant cannabinoid of fiber and oilseed varieties) antagonizes (i.e. reduces) the effects of THC (Grotenhermen and Karus 1998). Concentrations of 0.3% to 0.9% are considered to have "only a small drug potential" (Grotenhermen and Karus 1998). Some cannabinoid races have been described, notably containing cannabichromene (particularly in high-THC forms) and cannabigerol monomethyl ether (in some Asian strains). The biosynthetic pathways of the cannabinoids are not yet satisfactorily elucidated, although the scheme shown in Fig. 10 is commonly accepted. At least in some strains, THC is derived from cannabigerol, while in others it may be derived from CBD. CBN and Δ^8-THC are considered to be degradation products or analytical artifacts (Pate 1998a).

Both in Canada and the US, the most critical problem to be addressed for commercial exploitation of *C. sativa* is the possible unauthorized drug use of the plant. Indeed, the reason hemp cultivation was made illegal in North America was concern that the hemp crop was a drug menace. The drug potential is, for practical purposes, measured by the presence of THC. THC is the world's most popular illicit chemical, and indeed the fourth most popular recreational drug, after caffeine, alcohol, and nicotine. "Industrial hemp" is a phrase that has become common to designate hemp used for commercial non-intoxicant purposes. Small and Cronquist (1976) split *C. sativa* into two subspecies: *C. sativa* subsp. *sativa*, with less than 0.3% (dry weight) of THC in the upper (reproductive) part of the plant, and *C. sativa* subsp. *indica* (Lam.) E. Small & Cronq. with more than 0.3% THC. This classification has since been adopted in the European Community, Canada, and parts of Australia as a dividing line between cultivars that can be legally cultivated under license and forms that are considered to have too high a drug potential. For a period, 0.3% was also the allowable THC content limit for cultivation of hemp in the Soviet Union. In the US, Drug Enforcement Agency guidelines issued Dec. 7, 1999 expressly allowed products with a THC content of less than 0.3% to enter the US without a license; but subsequently permissible levels have been a source of continuing contention. Marijuana in the illicit market typically has a THC content of 5% to 10% (levels as high as 25% have been reported), and as a point of interest, a current Canadian government experimental medicinal marijuana production contract calls for the production of 6% marijuana. As noted above, a level of about 1% THC is considered the threshold for marijuana to have intoxicating potential, so the 0.3% level is conservative, and some countries (e.g. parts of Australia, Switzerland) have permitted the cultivation of cultivars with higher levels. It should be appreciated that there is considerable variation in THC content in different parts of the plant. THC content increases in the following order: achenes (excluding bracts), roots, large stems, smaller stems, older and larger leaves, younger and smaller leaves, flowers, perigonal bracts covering both the female flowers and fruits. It is well known in the illicit trade how to screen off the more potent fractions of the plant in order to increase THC levels in resultant drug products. Nevertheless, a level of 0.3% THC in the flowering parts of the plant is reflective of material that is too low in intoxicant potential to actually be used practically for illicit production of marijuana or other types of cannabis drugs. Below, the problem of permissible levels of THC in food products made from hempseed is discussed.

There is a general inverse relationship in the resin of *Cannabis* between the amounts of THC present and the amount of the other principal cannabinoid, CBD. Whereas most drug strains contain primarily THC and little or no CBD, fiber and oilseed strains primarily contain CBD and very little THC. CBD can be converted to THC by acid catalyzed cyclization, and so could serve as a starting material for manufacturing THC. In theory, therefore, low-THC cultivars do not completely solve the problem of drug abuse potential. In practice, however, the illicit drug trade has access to easier methods of synthesizing THC or its analogues than by first extracting CBD from non-drug hemp strains.

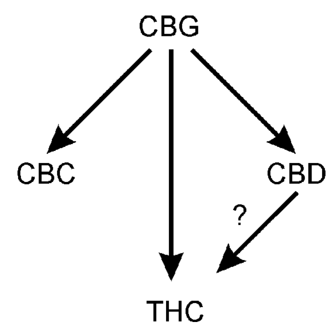

Fig. 10. Proposed biosynthetic pathways of the principal cannabinoids (after Pate 1998b).

Breeding for low THC cultivars in Europe has been reviewed by Bócsa (1998), Bócsa and Karus (1998), and Virovets (1996). Some researchers have claimed to have produced essentially THC-free strains, although at present no commercial cultivar seems to be 100% free of THC. THC content has proven to be more easily reduced in monoecious than in dioecious varieties. It should be possible to select THC-free strains, and there has been speculation that genetic engineering could be helpful in this regard. As a strategic economic and political tactic, France has been attempting for several years to have the European Union (EU) adopt legislation forbidding the cultivation of industrial hemp cultivars with more than 0.1% THC, which would mean that primarily French varieties would have to be cultivated in Europe. However, the Canadian government has found that some French material has proven to be excessively high in THC.

There is certainly a need to utilize available germplasm sources in order to breed suitable cultivars for North America. A list of the 24 approved cultivars for the 2001 season in Canada is at www.hc-sc.gc.ca/hpb-dgps/therapeut/htmleng/hemp.html. Most of these are regulated by the European Organization of Economic Cooperation and Development (OECD). These cultivars are “approved” for use in Canada not on agricultural criteria, but merely on the basis that they meet the THC criterion. Indeed, most of these are unsuitable or only marginally suitable for Canada (Small and Marcus 2000), and only a very few Canadian cultivars to date have been created. In Canada, every acquisition of hemp grown at a particular place and time must be tested for THC content by an independent laboratory and, under the industrial hemp regulations, fields of hemp with more than 0.3% THC may require destruction (a slight degree of flexibility is generally exercised). Importation of experimental hemp lines (i.e. other than the approved cultivars) requires importation licenses (as well as phytosanitary clearance of the shipment by the Canadian Food Inspection Agency), and the importation licenses require an indication that the THC contents are low.

In Canada, the methodology used for analyses and sample collection for THC analysis of hemp plantings is standardized (at the Health Canada/Therapeutics Program/Hemp web site at www.hc-sc.gc.ca/hpb-dgps/therapeut/htmleng/hemp.html, see “Industrial Hemp Technical Manual” for procedures on sampling plant materials and chemical procedures for determining THC levels). The regulations require that one of the dozen independent laboratories licensed for the purpose conduct the analyses and report the results to Health Canada. Sample collection is also normally carried out by an independent authorized firm. The Canadian system of monitoring THC content has rigidly limited hemp cultivation to cultivars that consistently develop THC levels below 0.3%.

Because *C. sativa* has been a neglected crop for so long in North America, there are only negligible genetic resources available on this continent. Most germplasm stocks of hemp are in Europe, and the largest and most important collection is the Vavilov Institute gene bank in Leningrad. Figure 11 shows THC concentrations in the Vavilov collection, as well as in our own collection, largely of European germplasm. A disturbingly high percentage of the collections have THC levels higher than 0.3%, making it difficult to incorporate these into breeding programs.

Soil characteristics, latitude and climatic stresses have been found to have significant effects on THC concentrations, and there are seasonal and even diurnal variations (Small 1979; Pate 1998b). However, the range of THC concentrations developed by low-THC cultivars (those

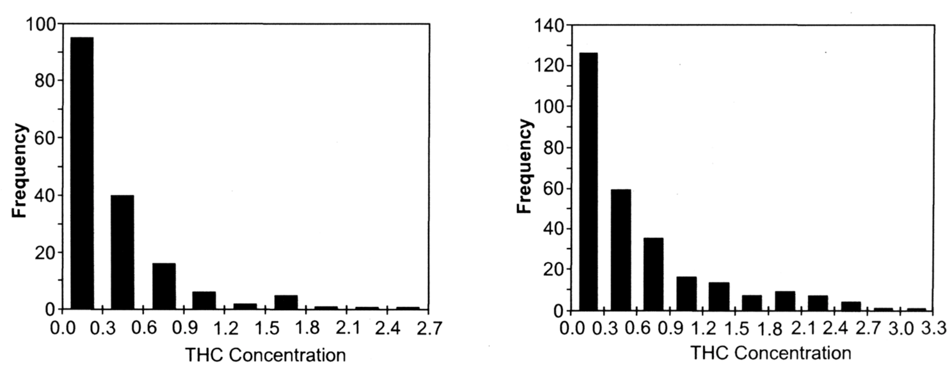

Fig. 11. Frequency histograms of THC concentration in germplasm collections. Left, collection of E. Small and D. Marcus; of the 167 accessions, 43% had THC levels >0.3%. Right, the collection of the Vavilov Institute, St. Petersburg; of the 278 accessions for which chemical analyses were reported in Anonymous (1975), about 55% had THC levels >0.3%.

typically with ≤0.3% THC) under different circumstances on the whole is limited, for the most part generally not varying more than 0.2 percentage points when grown in a range of circumstances, and usually less (note information in Scheifle et al. 1999; Scheifle 2000, Scheifle and Dragla 2000). Practically, this has meant in Canadian experience that a few cultivars have been eliminated from further commercial cultivation because they sometimes exceed the 0.3% level ('Fedora 19' and 'Futura,' authorized in 2000, have now been removed because some test results in several years exceeded 0.3%; 'Finola' and 'Uniko B' are under probation because of elevated levels), but on the whole most of the permitted cultivars have maintained highly consistent development of quite low levels of THC.

Hemp seeds contain virtually no THC, but THC contamination results from contact of the seeds with the resin secreted by the epidermal glands on the leaves and floral parts, and also by the failure to sift away all of the bracts (which have the highest concentration of THC of any parts of the plant) that cover the seeds. This results in small levels of THC appearing in hempseed oil and foods made with the seeds. Although most of the western hemp-growing world uses 0.3% THC as a maximum concentration for authorized cultivation of hemp plants, regulations in various countries allow only a much lower level of THC in human food products manufactured from the seeds. Currently, up to 10 ppm THC is permitted in seeds and oil products used for food purposes in Canada. In Germany, more stringent limits were set for food in 2000: 5 ppm in food oil, 0.005 ppm in beverages, and 0.15 ppm in all other foods. The US Drug Enforcement Administration published new regulations on hemp in the Federal Register on October 9th 2001 that in effect 4 months later would ban the food use of hemp in the US because any amount of THC would be unacceptable in foods (follow links at www.hempreport.com/). These proposals are currently being challenged by the hemp industry. Limits have been set because of concerns about possible toxicity and interference with drug tests (Grotenhermen et al. 1998). An extensive analysis of literature dealing with the toxicity of hemp is in Orr and Starodub (1999; see Geiwitz 2001 for an analysis). Because hemp food products are considered to have great economic potential, there is considerable pressure on the hemp industry in North America to reduce THC levels.

The Drug Enforcement Agency and the Office of National Drug Control Policy of the US raised concerns over tests conducted from 1995 to 1997 that showed that consumption of hempseed products available during that period led to interference with drug-testing programs for marijuana use. Federal US programs utilize a THC metabolite level of 50 parts per billion in urine. Leson (2000) found that this level was not exceeded by consuming hemp products, provided that THC levels are maintained below 5 ppm in hemp oil, and below 2 ppm in hulled seeds. Nevertheless the presence of even minute trace amounts of THC in foods remains a tool that can be used by those wishing to prevent the hemp oilseed industry from developing.

FIBER USES

Based on world production of fibers in 1999, about 54.5% was synthetic (of which 60.3% was polyester), 42.9% was plant fiber (of which 78.5% was cotton), and 2.6% was wool (Karus 2000). In addition to cotton, flax is the only other significant plant fiber crop grown in temperate regions of the world (kenaf has received some enthusiastic backing in the southern US in recent years, but is most cheaply produced in India, Bangladesh, and China). Flax held 2.7% of the world plant fiber market in 1999, while hemp had only 0.3% (Karus 2000). Hemp fiber can potentially replace other biological fibers in many applications, but also, as noted below, can sometimes compete with minerals such as glass fiber and steel. As forests diminish, cultivation of annual plants as fiber sources is likely to increase. While crop residues like cereal straw will probably supply much of the need, specialty fiber plants such as hemp also have potential. The four conditions that will need to be met are (after Bolton 1995): (1) the material should be produced at a large enough scale; (2) the price should be low enough; (3) the fiber characteristics should be adequate for the end use; and (4) proven technology should be available for the processing of the new raw material. Of these criteria only point 3 is adequately met at this time for hemp in North America, but this is to be expected in a crop that has only begun to be cultivated after an absence of many years.

One of the reasons hemp fiber has been valued is because of its length. The primary bast fibers in the bark are 5–40 mm long, and are amalgamated in fiber bundles which can be 1–5 m long (secondary bast fibers are about 2 mm long). The woody core fibers are short—about 0.55 mm—and like hardwood fibers are cemented together with considerable lignin. The core fibers are generally considered too short for high grade paper applications (a length of 3 mm is considered ideal), and too much lignin is present. While the long bast fibers have been used to make paper almost for 2 millennia, the woody core fibers have rarely been so used. Nevertheless it has been suggested that the core fibers could be used for paper making, providing appropriate technology was developed (de Groot et al. 1998). In any event, the core fibers, have found a variety of uses, as detailed below. The long, lignin-poor bast fibers also have considerable potential to be used in many non-paper, non-textile applications, as noted below.

Selection for fiber has resulted in strains that have much more bark fiber tissues and much less woody core than encountered in narcotic strains, oilseed strains, and wild plants (Fig. 12). In non-fiber strains of *Cannabis*, bark can be less than one quarter of the stem tissues (i.e. more than three quarters can be woody core). By contrast, in fiber strains half of the stem tissues can be bark, and more than half of this can be the desirable long primary fibers (de Meijer 1995). Non-fiber strains rarely have as much as 15% fiber in the bark.

Other desirable features of hemp fibers are strength and durability (particularly resistance to decay), which made hemp useful in the past for rope, nets, sail-cloth, and oakum for caulking. During the age of sailing ships, *Cannabis* was considered to provide the very best of canvas, and indeed this word is derived from *Cannabis*. Several factors combined to decrease the popularity of hemp in the late 19th and early 20th centuries. Increasing limitation of cheap labor for traditional production in Europe and the New World led to the creation of some mechanical inventions, but too late to counter growing interest in competitive crops. Development of other natural fibers as well as synthetic fibers increased competition for hemp's uses as a textile fiber and for cordage. Hemp rag had been much used for paper, but the 19th century introduction of the chemical woodpulping process considerably lowered demand for hemp. The demise of the sail diminished the market for canvas. Increasing use of the plant for drugs gave hemp a bad image. All this led to the discontinuation of hemp cultivation in the early and middle parts of the 20th century in much of the world where cheap labor was limited. In the 19th century softer fabrics took over the clothing market, and today, hemp constitutes only about 1% of the natural fiber market. At least some production of hemp for fiber still occurs in Russia, China, the Ukraine, Poland, Hungary, the countries of the former Yugoslavia, Romania, Korea, Chile, and Peru. There has been renewed interest in England, Australia, and South Africa in cultivating fiber hemp. Italy has an outstanding reputation for high-quality hemp, but productivity has waned for the last several decades. In France, a market for high-quality paper, ironically largely cigarette paper, has developed (such paper is completely free of the intoxicating resin). Modern plant breeding in Europe has produced several dozen hemp strains, although by comparison with other fiber crops there are relatively few described varieties of hemp. Since World War II, breeding has been concerned most particularly with the development of monoecious varieties. Gehl (1995) reviewed fiber hemp development in Canada in the early 20th century, and concluded that the prospects for a traditional fiber industry were poor. However, as outlined below, there are now many non-traditional usages for hemp fiber which require consideration. Hemp long fiber is one of the strongest and most durable of natural fibers, with high tensile strength, wet strength, and other characteristics that make it technically suited for various industrial products (Karus and Leson 1996).

From 1982 to 2002 the EU provided the equivalent of about 50 million dollars to develop new flax and hemp harvesting and fiber processing technologies (Karus et al. 2000). Because of the similarities of flax and hemp, the technologies developed for one usually are adaptable to the other. In addition, various European nations and private firms contributed to the development of hemp technologies. Accordingly, Europe is far more advanced in hemp development with respect to all fiber-based applications than other parts of the world. The EU currently dedicates about

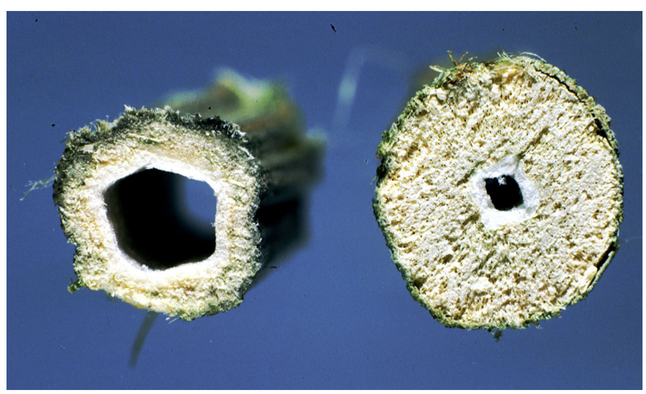

Fig. 12. Cross sections of stems at internodes of a fiber plant (left) and of a narcotic plant (right). Fiber cultivars have stems that are more hollow at the internodes, i.e. less wood, since this allows more energy to be directed into the production of bark fiber.

30,000 ha to hemp production. France is the leading country in hemp cultivation in the EU, and 95% of the non-seed production is used for "specialty pulp" as described below. Harvesting and processing machinery for fiber hemp is highly advanced in Europe, and some has been imported into Canada. However, there is insufficient fiber processing capacity to handle hemp produced in Canada.

Textiles

Hemp is a bast fiber crop, i.e. the most desirable ("long") fibers are found in the phloem-associated tissues external to the phloem, just under the "bark." The traditional and still major first step in fiber extraction is to ret ("rot") away the softer parts of the plant, by exposing the cut stems to microbial decay in the field ("dew retting," shown in Figs. 46 and 47) or submerged in water ("water retting, " shown in Fig. 13). The result is to slough off the outer parts of the stem and to loosen the inner woody core (the "hurds") from the phloem fibers (Fig. 14). Water retting has been largely abandoned in countries where labor is expensive or environmental regulations exist. Water retting, typically by soaking the stalks in ditches, can lead to a high level of pollution. Most hemp fiber used in textiles today is water retted in China and Hungary. Retting in tanks rather than in open bodies of water is a way of controlling the effluents while taking advantage of the high-quality fiber that is produced. Unlike flax, hemp long fiber requires water retting for preparation of high-quality spinnable fibers for production of fine textiles. Improved microorganisms or enzymes could augment or replace traditional water retting. Steam explosion is another potential technology that has been experimentally applied to hemp (Garcia-Jaldon et al. 1998). Decorticated material (i.e. separated at least into crude fiber) is the raw material, and this is subjected to steam under pressure and increased temperature which "explodes" (separates) the fibers so that one has a more refined (thinner) hemp fiber that currently is only available from water retting. Even when one has suitably separated long fiber, specialized harvesting, processing, spinning and weaving equipment are required for preparing fine hemp textiles. The refinement of equipment and new technologies are viewed as offering the possibility of making fine textile production practical in western Europe and North America, but at present China controls this market, and probably will remain dominant for the foreseeable future.

There are practical, if cruder alternatives to separate the long fiber for high-quality textile production, but in fact such techniques are used mostly for non-textile applications. This involves production of "whole fibers" (i.e. harvesting both the long fibers from the cortex and the shorter fibers from throughout the stem), and technologies that utilize shortened hemp fibers. This approach is currently dominant in western Europe and Canada, and commences with field dew retting (typically 2–3 weeks). A principal limitation is climatic—the local environment should be suitably but not excessively moist at the close of the harvest season. Once

Fig. 13. Water retting of hemp in Yugoslavia. (Courtesy of Dr. J. Berenji, Institute of Field and Vegetable Crops, Novi Sad.)

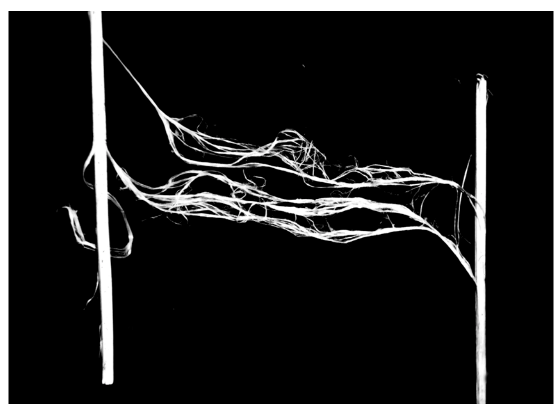

Fig. 14. Fiber in retted hemp stem. This stem was bent sharply after retting, breaking the woody central portion (hurds), leaving the bark fibers unbroken. The two portions of stem are separated in this photograph, and are joined by the tough bark fibers.

stalks are retted, dried, and baled, they are processed to extract the fiber. In traditional hemp processing, the long fiber was separated from the internal woody hurds in two steps, *breaking* (stalks were crushed under rollers that broke the woody core into short pieces, some of which were separated) and *scutching* (the remaining hurds, short fibers ("tow") and long fibers ("line fiber, " "long-line fiber") were separated). A single, relatively expensive machine called a decorticator can do these two steps as one. In general in the EU and Canada, fibers are not separated into tow and line fibers, but are left as "whole fiber." In western Europe, the fiber is often "cottonized," i.e. chopped into short segments the size of cotton and flax fiber, so that the fibers can be processed on flax processing machinery, which is very much better developed than such machinery is for hemp. In North America the use of hemp for production of even crude textiles is marginal. Accordingly, the chief current fiber usages of North American, indeed of European hemp, are non-textile.

Although always sold at a premium price, hemp clothing has a natural appeal to a sector of the population. Hemp clothes are resistant to abrasion, but are typically abrasive. However, appropriate processing and blending with other natural fibers has significantly improved the "feel" of the product, and in China hemp textiles indistinguishable from fine linens in texture are available. Weaving of hemp fibers into textiles and apparel is primarily done in China, Hungary, Romania, Russia, and the Ukraine. Processing costs are higher for industrial hemp because the fibers vary from the standard specifications for fiber length and diameter established for the equipment used in most textile and apparel factories, necessitating the use of specialty machines. The North American hemp apparel industry today is based on fiber, yarn, and fabrics imported from Eastern Europe and China. The extraction technology and spinning facilities, to say nothing of much lower labor costs, make it very difficult for the potential development of a hemp textile industry in North America. The fact that spinning facilities for natural fibers are so concentrated in China is making it increasingly difficult to competitively produce hemp fabrics elsewhere. This of course lessens the value-added future of growing hemp for a potential textile industry in North America. It is possible, however, that new technologies could change this situation, and especially in the EU development is underway to establish a fledgling domestic hemp textile industry. In addition to textiles used in clothing, coarser woven cloth (canvas) is used for upholstery, bags, sacks, and tarpaulins. There is very little effort in North America to produce such woven products, and non-woven material (Fig. 15) can be more easily produced. Hempline in Ontario, the first firm to grow hemp for commercial purposes in North America since the second word war (starting with experimental cultivation in 1994), is the exception, and is concerned with production of fiber for upholstery and carpeting.

Pulp and Paper

Van Roekel (1994) has pointed out that Egyptian papyrus sheets are not "paper," because the fiber strands are woven, not "wet-laid;" the oldest surviving paper is over 2,000 years of age, from China, and was made from hemp fiber (Fleming and Clarke 1998). Until the early 19th century, hemp, and flax were the chief papermaking materials. In historical times, hemp rag was processed into paper. Using hemp directly for paper was considered too expensive, and in any event the demand for paper was far more limited than today. Wood-based paper came into use when mechanical and chemical pulping was developed in the mid 1800s in Germany and England. Today, at least 95% of paper is made from wood pulp.

The pulp and paper industry based on wood has considered the use of hemp for pulp, but only on an experimental basis. Hemp's long fibers could make paper more recyclable. Since virgin pulp is required for added strength in the recycling of paper, hemp pulp would allow for at least twice as many cycles as wood pulp. However, various analyses have concluded that the use of hemp for conventional paper pulp is not profitable (Fertig 1996).

Fig. 15. Multi-purpose matting, fabricated from hemp. (Courtesy of Kenex Ltd., Pain Court, Ontario.)

"Specialty pulp" is the most important component of the hemp industry of the EU, and is expected to remain its core market for the foreseeable future. The most important specialty pulp products made from hemp are cigarette paper (Fig. 16), bank notes, technical filters, and hygiene products. Other uses include art papers and tea bags. Several of these applications take advantage of hemp's high tear and wet strength. This is considered to be a highly stable, high-priced niche market in Europe, where hemp has an 87% market share of the "specialty pulp" sector (Karus et al. 2000). In Europe, decortication/refining machines are available that can produce 10 t/hour of hemp fiber suitable for such pulp use. North American capacity for hemp pulp production and value-added processing is much more limited than that of Europe, and this industry is negligible in North America.

Hemp paper is useful for specialty applications such as currency and cigarette papers where strength is needed. The bast fiber is of greatest interest to the pulp and paper industry because of its superior strength properties compared to wood. However, the short, bulky fibers found in the inner part of the plant (hurds) can also be used to make cheaper grades of paper, apparently without greatly affecting quality of the printing surface. Hemp is not competitive for newsprint, books, writing papers, and general paper (grocery bags, coffee cups, napkins), although there is a specialty or novelty market for those specifically wishing to support the hemp industry by purchasing hemp writing or printing paper despite the premium price (Fig. 17).

A chief argument that has been advanced in favor of developing hemp as a paper and pulp source has been that as a non-wood or tree-free fiber source, it can reduce harvesting of primary forests and the threat to associated biodiversity. It has been claimed that hemp produces three to four times as much useable fiber per hectare per annum as forests. However, Wong (1998) notes evidence that in the southern US hemp would produce only twice as much pulp as does a pine plantation (but see discussion below on suitability of hemp as a potential lumber substitute in areas lacking trees).

Hemp paper is high-priced for several reasons. Economies of scale are such that the supply of hemp is minute compared to the supply of wood fiber. Hemp processing requires non-wood-based processing facilities. Hemp paper is typically made only from bast fibers, which require separation from the hurds, thereby increasing costs. This represents less than 50% of the possible fiber yield of the plant, and future technologies that pulp the whole stalks could decrease costs substantially. Hemp is harvested once a year, so that it needs to be stored to feed mills throughout the year. Hemp stalks are very bulky, requiring much handling and storage. Transportation costs are also very much higher for hemp stalks than for wood chips. Waste straw is widely available from cereals and other crops, and although generally not nearly as desirable as hemp, can produce bulk pulp far more cheaply than can be made from hemp. In addition to agricultural wastes, there are vast quantities of scrub trees, especially poplar, in northern areas, that can supply large amounts of low-quality wood fiber extremely cheaply. Moreover, in northern areas fast-growing poplars and willows can be grown, and such agro-forestry can be very productive and environmentally benign. And, directly or indirectly, the lumber/paper industry receives subsidies and/or supports, which is most unlikely for hemp.

Fig. 16. Hemp cigarette paper, the most profitable paper product currently manufactured from hemp.

Fig. 17. Hemp paper products (writing paper, notebook, envelopes).

Plastic Composites for the Automobile and Other Manufacturing Sectors

With respect to fiber, a "composite" is often defined as a material consisting of 30%–70% fiber and 70%–30% matrix (Bolton 1995). However, in North America particleboards and fiberboards, which generally contain less than 10% adhesive or matrix, are sometimes referred to as composites. This section addresses plastic-type composites. In plastics, fibers are introduced to improve physical properties such as stiffness, impact resistance, bending and tensile strength. Man-made fibers of glass, kevlar and carbon are most commonly used today, but plant fibers offer considerable cost savings along with comparable strength properties.

Plastic composites for automobiles are the second most important component of the hemp industry of the EU. Natural fibers in automobile composites are used primarily in press-molded parts (Fig. 18). There are two widespread technologies. In thermoplastic production, natural fibers are blended with polypropylene fibers and formed into a mat, which is pressed under heat into the desired form. In thermoset production the natural fibers are soaked with binders such as epoxy resin or polyurethane, placed in the desired form, and allowed to harden through polymerization. Hemp has also been used in other types of thermoplastic applications, including injection molding. The characteristics of hemp fibers have proven to be superior for production of molded composites. In European manufacturing of cars, natural fibers are used to reinforce door panels, passenger rear decks, trunk linings, and pillars. In 1999 over 20,000 t of natural fiber were used for these purposes in Europe, including about, 2,000 t of hemp. It has been estimated that 5–10 kg of natural fibers can be used in the molded portions of an average automobile (excluding upholstery). The demand for automobile applications of hemp is expected to increase considerably, depending on the development of new technologies (Karus et al. 2000).

Henry Ford recognized the utility of hemp in early times. In advance of today's automobile manufacturers, he constructed a car with certain components made of resin stiffened with hemp fiber (Fig. 19). Rather ironically in view of today's parallel situation, Henry Ford's hemp innovations in the 1920s occurred at a time of crisis for American farms, later to intensify with the depression. The need to produce new industrial markets for farm products led to a broad movement for scientific research in agriculture that came to be labeled "Farm Chemurgy," that today is embodied in chemical applications of crop constituents.

There is also considerable potential for other industries using hemp in the manner that the automobile industry has demonstrated is feasible. Of course, all other types of transportation vehicles from bicycles to airplanes might make use of such technology. Natural fibers have considerable advantages for use in conveyance (Karus et al. 2000): low density and weight reduction, favorable mechanical, acoustical, and processing properties (including low wear on tools), no splintering in accidents, occupational health benefits (compared

Fig. 18. C-class Mercedes-Benz automobiles have more than 30 parts made of natural fibers, including hemp. (Courtesy of T. Schloesser, Daimler-Chrysler.)

Fig. 19. Henry Ford swinging an axe at his 1941 car to demonstrate the toughness of the plastic trunk door made of soybean and hemp. (From the collections of Henry Ford Museum & Greenfield Village.)

to glass fibers), no off-gassing of toxic compounds, and price advantages. Additional types of composite using hemp in combination with other natural fibers, post-industrial plastics or other types of resins, are being used to produce non-woven matting for padding, sound insulation, and other applications.

Building Construction Products

Thermal Insulation. Thermal insulation products (Fig. 20, 21) are the third most important sector of the hemp industry of the EU. These are in very high demand because of the alarmingly high costs of heating fuels, ecological concerns about conservation of non-renewable resources, and political-strategic concerns about dependence on current sources of oil. This is a market that is growing very fast, and hemp insulation products are increasing in popularity. In Europe, it has been predicted that tens of thousands of tonnes will be sold by 2005, shared between hemp and flax (Karus et al. 2000).

Fiberboard. In North America the use of nonwood fibers in sheet fiberboard ("pressboard" or "composite board") products is relatively undeveloped. Flax, jute, kenaf, hemp, and wheat straw can be used to make composite board. Wheat straw is the dominant nonwood fiber in such applications. Although it might seem that hemp bast fibers are desirable in composite wood products because of their length and strength, in fact the short fibers of the hurds have been found to produce a superior product (K. Domier, pers. commun.). Experimental production of hemp fiberboard has produced extremely strong material (Fig. 22). The economic viability of such remains to be tested. Molded fiberboard products are commercially viable in Europe (Fig. 23), but their potential in North America remains to be determined.

Cement (Concrete) and Plaster. Utilizing the ancient technique of reinforcing clay with straw to produce reinforced bricks for constructing domiciles, plant fibers have found a number of comparable uses in modern times. Hemp fibers added to concrete increase tensile strength while reducing shrinkage and cracking. Whole houses have been made based on hemp fiber (Fig. 24, 25). In North America, such usage has only reached the level of a cottage industry. Fiber-reinforced cement boards and fiber-reinforced plaster are other occasionally produced experimental products. Hemp fibers are produced at much more cost than wood chips and straw from many other crops, so high-end applications requiring high strength seem most appropriate.

The above uses are based on hemp as a mechanical strengthener of materials. Hemp can also be chemically combined with materials. For example, hemp with gypsum and binding agents may produce light panels that might compete with drywall. Hemp and lime mixtures make a high quality plaster. Hemp hurds are rich in silica (which occurs naturally in sand and flint), and the hurds mixed with lime undergo mineralization, to produce a stone-like material. The technology is most advanced in France (Fig. 26). The mineralized material can be blown or poured into the cavities of walls and in attics as insulation. The foundations, walls, floors, and ceilings of houses have been made using hemp hurds mixed with natural lime and water. Sometimes plaster of Paris (pure gypsum), cement, or sand is added. The resulting material can be poured like

Fig. 20. Spun, loosely compacted hemp insulation. (Manufactured by La Chanvrière de l'Aube, France.)

Fig. 21. Loose Isochanvre® thermal insulation being placed between joists. (Courtesy of M. Périer, Chènovotte Habitat, France.)

Fig. 22. Experimental fiberboard made with hemp. (Courtesy Dr. K. Domier, Univ. Alberta, Edmonton.)

Fig. 23. Molded fiberboard products. (Courtesy of HempFlax, Oude Pekela, The Netherlands).

Fig. 24. New building in France being constructed entirely of hemp. Wall castings are a conglomerate of Isochanvre® lime-hemp, for production of a 200 mm thick monolithic wall without an interior wall lining. (Courtesy of M. Périer, Chènovotte Habitat, France.)

Fig. 25. The "hemp house" under construction on the Oglala Lakota Nation (Pine Ridge Reservation), South Dakota. Foundation blocks for the house are made with hemp fiber as a binder in cement. Stucco is also of hemp. Shingles are 60% hemp in a synthetic polymer. Hemp insulation is used throughout. (Courtesy of Oglala Sioux Tribe, Slim Butte Land Use Association, and S. Sauser.)

Fig. 26. Renovation of plaster walls of a traditional timber frame 16th century house (Mansion Raoul de la Faye, Paris) with Isochanvre® lime-hemp conglomerate. (Courtesy of M. Périer, Chènovotte Habitat, France.)

concrete, but has a texture vaguely reminiscent of cork—much lighter than cement, and with better heat and sound-insulating properties. An experimental "ceramic tile" made of hemp has recently been produced (Fig. 27).

Animal Bedding

The woody core (hurds, sometimes called shives) of hemp makes remarkably good animal bedding (Fig. 28, 29). The hurds are sometimes molded into small pellets for bedding applications (Fig. 30). Such appears to be unsurpassed for horse bedding, and also make an excellent litter for cats and other pets (Fig. 31). The hurds can absorb up to five times their weight in moisture (typically 50% higher than wood shavings), do not produce dust (following initial dust removal), and are easily composted. Hemp bedding is especially suited to horses allergic to straw. In Europe, the animal bedding market is not considered important (Karus et al. 2000), but in North America there are insufficient hemp hurds available to meet market demand.

The high absorbency of hemp hurds has led to their occasional use as an absorbent for oil and waste spill cleanup. Hemp as an industrial absorbent has generated some interest in Alberta, for use in land reclamation in the oil and gas industry. Because hemp hurds are a costly product, it is likely that animal bedding will remain the most important application.

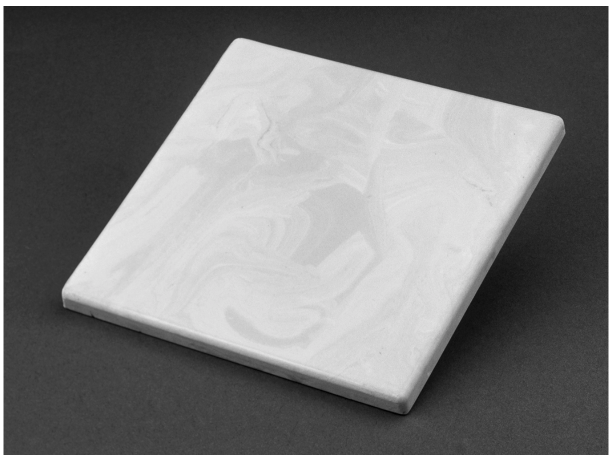

Fig. 27. Hemp "ceramic tile." (Courtesy of Kenex Ltd., Pain Court, Ontario.)

Fig. 28. Commercial warehouse of baled hemp animal bedding. (Courtesy of Kenex Ltd., Pain Court, Ontario.)

Fig. 29. Animal bedding made from hemp hurds.

Fig. 30. Pelleted hemp hurds. (Courtesy of La Chanvrière de l'Aube, Bar sur Aube, France.)

Geotextiles

"Geotextiles" or "agricultural textiles" include (1) ground-retaining, biodegradable matting designed to prevent soil erosion, especially to stabilize new plantings while they develop root systems along steep highway banks to prevent soil slippage (Fig. 32); and (2) ground-covers designed to reduce weeds in planting beds (in the manner of plastic mulch). At present the main materials used are polymeric (polythene, spun-blown polypropylene) and some glass fiber and natural fibers. Both woven and non-woven fibers can be applied to geotextiles; woven and knitted materials are stronger and the open structure may be advantageous (e.g. in allowing plants to grow through), but non-wovens are cheaper and better at suppressing weeds. Flax and hemp fibers exposed to water and soil have been claimed to disintegrate rapidly over the course of a few months, which would make them unacceptable for products that need to have long-term stability when exposed to water and oil. Coco (coir) fiber has been said to be much more suitable, due to higher lignin content (40%–50%, compared to 2%–5% in bast fibers); these are much cheaper than flax and hemp fibers (Karus et al. 2000). However, this analysis does not do justice to the developing hemp geotextile market. Production of hemp erosion control mats is continuing in both Europe and Canada. Given the reputation for rot resistance of hemp canvas and rope, it seems probable that ground matting is a legitimate use. Moreover, the ability to last outdoors for many years is frequently undesirable in geotextiles. For example, the widespread current use of plastic netting to reinforce grass sod is quite objectionable, the plastic persisting for many years and interfering with lawn care. Related to geotextile applications is the possibility of using hemp fiber as a planting substrate (biodegradable pots and blocks for plants), and as biodegradable twine to replace plastic ties used to attach plants to supporting poles. Still another consideration is the "green ideal" of producing locally for local needs; by this credo, hemp is preferable in temperate regions to the use of tropical fibers, which need to be imported.

Fig. 31. Songbirds on hemp litter. (Courtesy of La Chanvrière de l'Aube, Bar sur Aube, France.)

Fig. 32. Hemp-based erosion control blanket. Top left: Close-up of 100% hemp fiber blanket. Top right: Grass growing through blanket. Bottom: Demonstration of installation of blanket, near La Rivière, Manitoba. (Courtesy of Mark Myrowich, ErosionControlBlanket.com)

OILSEED USES

The cultivation of hemp in the EU is heavily weighted toward fiber production over oilseed production. In 1999, the EU produced about 27,000 t of hemp fiber, but only about 6,200 t of hemp seeds, mostly in France, and 90% of this was used as animal feed (Karus et al. 2000). The seeds (Fig. 33) have traditionally been employed as bird and poultry feed, but feeding the entire seeds to livestock has been considered to be a poor investment because of the high cost involved (although subsidization in Europe allows such usage, especially in France where hemp seeds are not legally permitted in human food). As pointed out later, higher yield and better harvesting practices may make whole hempseed an economical livestock feed. Moreover, seed cake left after expressing the oil is an excellent feed. Efforts are underway in Europe to add value in the form of processed products for hemp, especially cosmetics and food but, as noted below, the North American market is already quite advanced in oilseed applications.

In the EU and Canada, hemp has often been grown as a dual-purpose crop, i.e. for both fiber and oilseed. In France, dual purpose hemp is typically harvested twice—initially the upper seed-bearing part of the stems is cut and threshed with a combine, and subsequently the remaining stems are harvested. Growing hemp to the stage that mature seeds are present compromises the quality of the fiber, because of lignification. As well, the hurds become more difficult to separate. The lower quality fiber, however, is quite utilizable for pulp and non-woven usages.

In North America, oilseed hemp has several advantages over fiber hemp. Hemp seed and oil can fetch higher prices than hemp fiber. Hemp seed can be processed using existing equipment, while processing of hemp fiber usually requires new facilities and equipment.

Canada is specialized on oilseed production and processing, so that hemp oil and grain are much more suitable than fiber. Because of the extensive development of oilseeds in Canada, there is extensive capacity to produce high-quality cold-pressed hemp oil. Canada in the last 5 years has made great advances in the growing, harvesting, and processing of hempseed, and indeed has moved ahead of the EU in the development of raw materials and products for the natural foods, nutraceuticals, and cosmetics industries. In the EU, a yield of 1 t/ha is considered good. In Canada, extraordinary yields of 1.5 t/ha have been realized, at least locally, although in the initial years of hempseed development in Canada yields were often less than 500 kg/ha. In 1999, the year of largest Canadian hemp acreage, yields averaged 900 kg/ha. (Ideally, hemp seed yield should be based on air dry weight—with about 12% moisture. Hemp yields are sometime uncertain, and could be exaggerated by as much as 50% when moist weights are reported.)

Canadian experience with growing hemp commercially for the last 4 years has convinced many growers that it is better to use a single-purpose cultivar, seed or fiber, than a dual-purpose cultivar. The recent focus of Canadian hemp breeders has been to develop cultivars with high seed yields, low stature (to avoid channeling the plants' energy into stalk, as is the case in fiber cultivars), early maturation (for the short growing seasons of Canada), and desirable fatty acid spectrum (especially gamma-linolenic acid).

Food

Dehulled (i.e. hulled) hemp seed is a very recent phenomenon, first produced in quantity in Europe. Hemp seeds have been used as food since ancient times, but generally the whole seed, including the hull, was eaten. Hemp seed was a grain used in ancient China, although there has been only minor direct use of hemp seed as food by humans. In the past, hemp seed has generally been a food of the lower classes, or a famine food. Peanut-butter type preparations have been produced from hemp seed in Europe for centuries, but were rather gritty since technology for removing the hulls was rudimentary. Modern seed dehulling using mechanical separation produces a smooth, white, gritless hemp seed meal that needs no additional treatment before it is con-

Fig. 33. "Seeds" (achenes) of hemp, with a match for scale.

sumed. It is important to understand, therefore, that the quality of modern hemp seed for human consumption far exceeds anything produced historically. This seed meal should be distinguished from the protein-rich, oil-poor seed cake remaining after oil has been expressed, that is used for livestock feed. The seed cake is also referred to as "seed meal," and has proven to be excellent for animals (Mustafa et al. 1999).

Hemp seeds have an attractive nutty taste, and are now incorporated into many food preparations (Fig. 34), often mimicking familiar foods. Those sold in North America include nutritional (granola-type) or snack bars, "nut butters" and other spreads, bread, pretzels, cookies, yogurts, pancakes, porridge, fruit crumble, frozen dessert ("ice cream"), pasta, burgers, pizza, salt substitute, salad dressings, mayonnaise, "cheese," and beverages ("milk," "lemonade," "beer," "wine," "coffee nog"). Hemp seed is often found canned or vacuum-packed (Fig. 35). Alcoholic beverages made with hemp utilize hempseed as a flavorant. Hemp food products currently have a niche market, based particularly on natural food and specialty food outlets.

Edible Oil

The use of *Cannabis* for seed oil (Fig. 36) began at least 3 millennia ago. Hempseed oil is a drying oil, formerly used in paints and varnishes and in the manufacture of soap. Present cultivation of oilseed hemp is not competitive with linseed for production of oil for manufacturing, or to sunflower and canola for edible vegetable oil. However, as noted below, there are remarkable dietary advantages to hempseed oil, which accordingly has good potential for penetrating the salad oil market, and for use in a very wide variety of food products. There is also good potential for hemp oil in cosmetics and skin-care products.

Foreign sources, China in particular, can produce hemp seed cheaply, but imported seed must be sterilized, and the delays this usually requires are detrimental. Seed that has been sterilized tends to go rancid quickly, and so it is imperative that fresh seed be available, a great advantage for domestic production. An additional extremely significant advantage that domestic producers have over foreign sources is organic production, which is important for the image desired by the hemp food market. Organic certification is much more reliable in North America than in the foreign countries that offer cheap seeds. Whereas China used to supply most of the hempseed used for food in North America, Canadian-grown seeds have taken over this market.

About half of the world market for hemp oil is currently used for food and food supplements (de Guzman 2001). For edible purposes, hempseed oil is extracted by cold pressing. Quality is improved by using only the first pressing, and minimizing the number of green seeds present. The oil varies in color from off-yellow to dark green. The taste is pleasantly nutty, sometimes with a touch of bitterness. Hemp oil is high in unsaturated fatty acids (of the order of 75%), which can easily oxidize, so it is unsuitable for frying or baking. The high degree of unsaturation is responsible for the extreme sensitivity to oxidative rancidity. The oil has a

Fig. 34. Some North American food products made with hemp seed and/or hemp seed oil.

Fig. 35. Canned hulled hemp seed. (Courtesy of Kenex Ltd., Pain Court, Ontario.)

relatively short shelf life. It should be extracted under nitrogen (to prevent oxidation), protected from light by being kept in dark bottles, and from heat by refrigeration. Addition of anti-oxidants prolongs the longevity of the oil. Steam sterilization of the seeds, often required by law, allows air to penetrate and so stimulates rancidity. Accordingly, sterilized or roasted hemp seeds, and products made from hemp seed that have been subjected to cooking, should be fresh. The value of hemp oil from the point of view of the primary components is discussed below. In addition, it has been suggested that other components, including trace amounts of terpenes and cannabinoids, could have health benefits (Leizer et al. 2000). According to an ancient legend (Abel 1980), Buddha, the founder of Buddhism, survived a 6-year interval of asceticism by eating nothing but one hemp seed daily. This apocryphal story holds a germ of truth—hemp seed is astonishingly nutritional.

Fatty Acids. The quality of an oil or fat is most importantly determined by its fatty acid composition. Hemp is of high nutritional quality because it contains high amounts of unsaturated fatty acids, mostly oleic acid (C18:1, 10%–16%), linoleic acid (C18:2, 50%–60%), alpha-linolenic acid (C18:3, 20%–25%), and gamma-linolenic acid (C18:3, 2%–5%) (Fig. 37). Linoleic acid and alpha-linolenic acid are the only two fatty acids that must be ingested and are considered essential to human health (Callaway 1998). In contrast to shorter-chain and more saturated fatty acids, these essential fatty acids do not serve as energy sources, but as raw materials for cell structure and as precursors for biosynthesis for many of the body's regulatory biochemicals. The essential fatty acids are available in other oils, particularly fish and flaxseed, but these tend to have unpleasant flavors compared to the mellow, slightly nutty flavor of hempseed oil. While the value of unsaturated fats is generally appreciated, it is much less well known that the North American diet is serious nutritionally unbalanced by an excess of linoleic over alpha-linonenic acid. In hempseed, linoleic and alpha-linolenic occur in a ratio of about 3:1, considered optimal in healthy human adipose tissue, and apparently unique among common plant oils (Deferne and Pate 1996). Gamma-linolenic acid or GLA is another significant component of hemp oil (1%–6%, depending on cultivar). GLA is a widely consumed supplement known to affect vital metabolic roles in humans, ranging from control of inflammation and vascular tone to initiation of contractions during childbirth. GLA has been found to alleviate psoriasis, atopic eczema, and mastalgia, and may also benefit cardiovascular, psychiatric, and immunological disorders. Ageing and pathology (diabetes, hypertension, etc.) may impair GLA metabolism, making supplementation desirable. As much as 15% of the

Fig. 36. Hemp oil. (Courtesy of La Chanvrière de l'Aube, Bar sur Aube, France.)

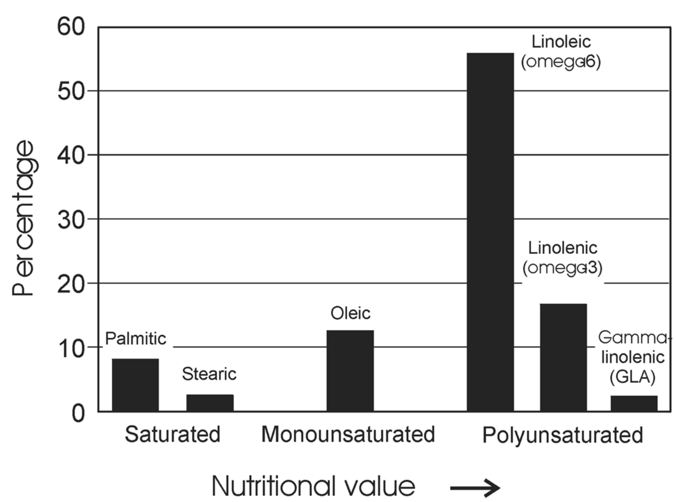

Fig. 37. Content of principal fatty acids in hempseed oil, based on means of 62 accessions grown in southern Ontario (reported in Small and Marcus 2000).

human population may benefit from addition of GLA to their diet. At present, GLA is available in health food shops and pharmacies primarily as soft gelatin capsules of borage or evening primrose oil, but hemp is almost certainly a much more economic source. Although the content of GLA in the seeds is lower, hemp is far easier to cultivate and higher-yielding. It is important to note that hemp is the only current natural food source of GLA, i.e. not requiring the consumption of extracted dietary supplements. There are other fatty acids in small concentrations in hemp seed that have some dietary significance, including stearidonic acid (Callaway et al. 1996) and eicosenoic acid (Mölleken and Theimer 1997). Because of the extremely desirable fatty acid constitution of hemp oil, it is now being marketed as a dietary supplement in capsule form (Fig. 38).

Tocopherols. Tocopherols are major antioxidants in human serum. Alpha- beta-, gamma- and delta-tocopherol represent the vitamin E group. These fat-soluble vitamins are essential for human nutrition, especially the alpha-form, which is commonly called vitamin E. About 80% of the tocopherols of hempseed oil is the alpha form. The vitamin E content of hempseed is comparatively high. Antioxidants in hempseed oil are believed to stabilize the highly polyunsaturated oil, tending to keep it from going rancid. Sterols in the seeds probably serve the same function, and like the tocopherols are also desirable from a human health viewpoint.

Protein. Hemp seeds contain 25%–30% protein, with a reasonably complete amino acid spectrum. About two thirds of hempseed protein is edestin. All eight amino acids essential in the human diet are present, as well as others. Although the protein content is smaller than that of soybean, it is much higher than in grains like wheat, rye, maize, oat, and barley. As noted above, the oilcake remaining after oil is expressed from the seeds is a very nutritious feed supplement for livestock, but it can also be used for production of a high-protein flour.

Personal Care Products

In the 1990s, European firms introduced lines of hemp oil-based personal care products, including soaps, shampoos, bubble baths, and perfumes. Hemp oil is now marketed throughout the world in a range of body care products, including creams, lotions, moisturizers, and lip balms. In Germany, a laundry detergent manufactured entirely from hemp oil has been marketed. Hemp-based cosmetics and personal care products account for about half of the world market for hemp oil (de Guzman 2001).

One of the most significant developments for the North American hemp industry was investment in hemp products by Anita and Gordon Roddick, founders of The Body Shop, a well known international chain of hair and body care retailers. This was a rather courageous and principled move that required overcoming American legal obstacles related to THC content. The Body Shop now markets an impressive array of hemp nutraceutical cosmetics (Fig. 39), and this has given the industry considerable credibility. The Body Shop has reported gross sales of about a billion dollars annually, and that about 4% of sales in 2000 were hemp products.

Industrial Fluids

The vegetable oils have been classified by "iodine value" as drying (120–200), semi-drying (100–120), and non-drying (80–100), which is determined by the degree of saturation of the fatty acids present (Raie et al. 1995). Good coating materials prepared from vegetable oil depend on the nature and number of double bonds present in the fatty acids. Linseed oil, a drying oil, has a very high percentage of linolenic acid. Hempseed oil has been classified as a semi-drying oil, like soybean oil, and is therefore more suited to edible than industrial oil purposes. Nevertheless hemp oil has found applications in the past in paints, varnishes, sealants, lubricants for machinery, and printing inks. However, such industrial end uses are not presently feasible as the oil is considered too expensive (de Guzman 2001). Larger production volumes and lower prices may be possible, in which case hemp oil may find industrial uses similar

Fig. 38. Hemp oil in capsule form sold as a dietary supplement.

to those of linseed (flax), soybean, and sunflower oils, which are presently used in paints, inks, solvents, binders, and in polymer plastics. Hemp shows a remarkable range of variation in oil constituents, and selection for oilseed cultivars with high content of valued industrial constituents is in progress.

MEDICINAL MARIJUANA

Marijuana has in fact been grown for medicinal research in North America by both the Canadian (Fig. 40) and American governments, and this will likely continue. The possibility of marijuana becoming a legal commercial crop in North America is, to say the least, unlikely in the foreseeable future. Nevertheless the private sector is currently producing medicinal marijuana in Europe and Canada, so the following orientation to marijuana as a potential authorized crop is not merely academic.

The objectivity of scientific evaluation of the medicinal value of marijuana to date has been questioned. In the words of Hirst et al. (1998): "*The ...status of cannabis has made modern clinical research almost impossible. This is primarily because of the legal, ethical and bureaucratic difficulties in conducting trials with patients. Additionally, the general attitude towards cannabis, in which it is seen only as a drug of abuse and addiction, has not helped.*" In a recent editorial, the respected journal Nature (2001) stated: "*Governments, including the US federal government, have until recently refused to sanction the medical use of marijuana, and have also done what they can to prevent its clinical testing. They have defended their inaction by claiming that either step would signal to the public a softening of the so-called 'war on drugs.'... The pharmacology of cannabinoids is a valid field of scientific investigation. Pharmacologists have the tools and the methodologies to realize its considerable potential, provided the political climate permits them to do so.*" Given these current demands for research on medicinal marijuana, it will be necessary to produce crops of drug types of *C. sativa*.

Earliest reference to euphoric use of *C. sativa* appears to date to China of 5 millennia ago, but it was in India over the last millennium that drug consumption became more firmly entrenched than anywhere else in the world. Not surprisingly, the most highly domesticated drug strains were selected in India. While *C. sativa* has been used as a euphoriant in India, the Near East, parts of Africa, and other Old World areas for thousands of years, such use simply did not develop in temperate countries where hemp was raised. The use of *C. sativa* as a recreational inebriant in sophisticated, largely urban settings is substantially a 20th century phenomenon.

Cannabis drug preparations have been employed medicinally in folk medicine since antiquity, and were extensively used in western medicine between the middle of the 19th century and World War II, particularly as a substitute for opiates (Mikuriya 1969). A bottle of commercial medicinal extract is shown in Fig. 41. Medical use declined with the introduction of synthetic analgesics and sedatives, and there is very limited authorized medical use today, but considerable unauthorized use, including so-called "compassion clubs" dispensing marijuana to gravely ill people, which has led to a momentous societal and scientific debate regarding the

Fig. 39. Body care products offered by the Body Shop. ("Chanvre" is French for hemp.)

Fig. 40. A truckload of Canadian medicinal marijuana from a plantation in Ottawa in 1971. More than a ton of marijuana was prepared for experimental research (described in Small et al. 1975).

wisdom of employing cannabis drugs medically, given the illicit status. There is anecdotal evidence that cannabis drugs are useful for: alleviating nausea, vomiting, and anorexia following radiation therapy and chemotherapy; as an appetite stimulant for AIDS patients; for relieving the tremors of multiple sclerosis and epilepsy; and for pain relief, glaucoma, asthma, and other ailments [see Mechoulam and Hanus (1997) for an authoritative medical review, and Pate (1995) for a guide to the medical literature]. To date, governmental authorities in the US, on the advice of medical experts, have consistently rejected the authorization of medical use of marijuana except in a handful of cases. However, in the UK medicinal marijuana is presently being produced sufficient to supply thousands of patients, and Canada recently authorized the cultivation of medicinal marijuana for compassionate dispensation, as well as for a renewed effort at medical evaluation.

Several of the cannabinoids are reputed to have medicinal potential: THC for glaucoma, spasticity from spinal injury or multiple sclerosis, pain, inflammation, insomnia, and asthma; CBD for some psychological problems. The Netherlands firm HortaPharm developed strains of *Cannabis* rich in particular cannabinoids. The British firm G.W. Pharmaceuticals acquired proprietary access to these for medicinal purposes, and is developing medicinal marijuana. In the US, NIH (National Institute of Health) has a program of research into medicinal marijuana, and has supplied a handful of individuals for years with maintenance samples for medical usage. The American Drug Enforcement Administration is hostile to the medicinal use of *Cannabis*, and for decades research on medicinal properties of *Cannabis* in the US has been in an extremely inhospitable climate, except for projects and researchers concerned with curbing drug abuse. Synthetic preparations of THC—dronabinol (Marinol®) and nabilone (Cesamet®)—are permitted in some cases, but are expensive and widely considered to be less effective than simply smoking preparations of marijuana. Relatively little material needs to be cultivated for medicinal purposes (Small 1971), although security considerations considerably inflate costs. The potential as a "new crop" for medicinal cannabinoid uses is therefore limited. However, the added-value potential in the form of proprietary drug derivatives and drug-delivery systems is huge. The medicinal efficacy of *Cannabis* is extremely controversial, and regrettably is often confounded with the issue of balancing harm and liberty concerning the proscriptions against recreational use of marijuana. This paper is principally concerned with the industrial uses of *Cannabis*. In this context, the chief significance of medicinal *Cannabis* is that, like the issue of recreational use, it has made it very difficult to rationally consider the development of industrial hemp in North America for purposes that everyone should agree are not harmful.

Key analyses of the medicinal use of marijuana are: Le Dain (1972), Health Council of the Netherlands (1996), American Medical Association (1997), British Medical Association (1997), National Institutes of Health (1997), World Health Organization (1997), House of Lords (1998), and Joy et al. (1999).

MINOR USES

Biomass

It has been contended that hemp is notably superior to most crops in terms of biomass production, but van der Werf (1994b) noted that the annual dry matter yield of hemp (rarely approaching 20 t/ha) is not exceptional compared to maize, beet, or potato. Nevertheless, hemp has been rated on a variety of criteria as one of the best crops available to produce energy in Europe (Biewinga and van der Bijl 1996). Hemp, especially the hurds, can be burned as is or processed into charcoal, methanol, methane, or gasoline through pyrolysis (destructive distillation). As with maize, hemp can also be used to create ethanol. However, hemp for such biomass purposes is a doubtful venture in North America. Conversion of hemp biomass into fuel or alcohol is impractical on this continent, where there are abundant supplies of wood, and energy can be produced

Fig. 41. Medicinal tincture of *Cannabis sativa*. (Not legal in North America.)

relatively cheaply from a variety of sources. Mallik et al. (1990) studied the possibility of using hemp for "biogas" (i.e. methane) production, and concluded that it was unsuitable for this purpose. Pinfold Consulting (1998) concluded that while there may be some potential for hemp biomass fuel near areas where hemp is cultivated, "*a fuel ethanol industry is not expected to develop based on hemp.*"

Essential Oil

Essential (volatile) oil in hemp is quite different from hempseed oil. Examples of commercial essential oil product products are shown in Fig. 42. The essential oil is a mixture of volatile compounds, including monoterpenes, sesquiterpenes, and other terpenoid-like compounds that are manufactured in the same epidermal glands in which the resin of *Cannabis* is synthesized (Meier and Mediavilla 1998). Yields are very small—about 10 L/ha (Mediavilla and Steinemann 1997), so essential oil of *C. sativa* is expensive, and today is simply a novelty. Essential oil of different strains varies considerably in odor, and this may have economic importance in imparting a scent to cosmetics, shampoos, soaps, creams, oils, perfumes, and foodstuffs. Switzerland has been a center for the production of essential oil for the commercial market. Narcotic strains tend to be more attractive in odor than fiber strains, and because they produce much higher numbers of flowers than fiber strains, and the (female) floral parts provide most of the essential oil, narcotic strains are naturally adapted to essential oil production. Switzerland has permitted strains with higher THC content to be grown than is allowed in other parts of the world, giving the country an advantage with respect to the essential oil market. However, essential oil in the marketplace has often been produced from low-THC *Cannabis*, and the THC content of essential oil obtained by steam distillation can be quite low, producing a product satisfying the needs for very low THC levels in food and other commercial goods. The composition of extracted essential oil is quite different from the volatiles released around the fresh plant (particularly limonene and alpha-pinene), so that a pleasant odor of the living plant is not necessarily indicative of a pleasant-smelling essential oil. Essential oil has been produced in Canada by Gen-X Research Inc., Regina. The world market for hemp essential oil is very limited at present, and probably also has limited growth potential.

Pesticide and Repellent Potential

McPartland (1997) reviewed research on the pesticide and repellent applications of *Cannabis*. Dried plant parts and extracts of *Cannabis* have received rather extensive usage for these purposes in the past, raising the possibility that research could produce formulations of commercial value. This possibility is currently hypothetical.

Non-Seed Use of Hemp as Livestock Feed

As noted above, hemp seed cake makes an excellent feed for animals. However, feeding entire plants is another matter, because the leaves are covered with the resin-producing glands. While deer, groundhogs, rabbits, and other mammals will nibble on hemp plants, mammals generally do not choose to eat hemp. Jain and Arora (1988) fed narcotic *Cannabis* refuse to cattle, and found that the animals "*suffered variable degrees of depression and revealed incoordination in movement.*" By contrast, Letniak et al. (2000) conducted an experimental trial of hemp as silage. No significant differences were found between yield of the hemp and of barley/oat silage fed to heifers, suggesting that fermenting hemp plants reduces possible harmful constituents.

Fig. 42. Bottles of hemp fragrance (left) and essential oil (center), and pastilles flavored with hemp essential oil (right).

Hemp as an Agricultural Barrier

One of the most curious uses of hemp is as a fence to prevent pollen transfer in commercial production of seeds. Isolation distances for ensuring that seeds produced are pure are considerable for many plants, and often impractical. At one point in the 1980s, the only permitted use of hemp in Germany was as a fence or hedge to prevent plots of beets being used for seed production from being contaminated by pollen from ruderal beets. The high and rather inpenetrable hedge that hemp can produce was considered unsurpassed by any other species for the purpose. As well, the sticky leaves of hemp were thought to trap pollen. However, Saeglitz et al. (2000) demonstrated that the spread of beet pollen is not effectively prevented by hemp hedges. Fiber (i.e. tall) cultivars of hemp were also once used in Europe as wind-breaks, protecting vulnerable crops against wind damage. Although hemp plants can lodge, on the whole very tall hemp is remarkably resistant against wind.

Bioremediation

Preliminary work in Germany (noted in Karus and Leson 1994) suggested that hemp could be grown on soils contaminated with heavy metals, while the fiber remained virtually free of the metals. Kozłowski et al. (1995) observed that hemp grew very well on copper-contaminated soil in Poland (although seeds absorbed high levels of copper). Baraniecki (1997) found similar results. Mölleken et al. (1997) studied effects of high concentration of salts of copper, chromium, and zinc on hemp, and demonstrated that some hemp cultivars have potential application to growth in contaminated soils. It would seem unwise to grow hemp as an oilseed on contaminated soils, but such a habitat might be suitable for a fiber or biomass crop. The possibility of using hemp for bioremediation deserves additional study.

Wildlife Uses

Hemp is plagued by bird predation, which take a heavy toll on seed production. The seeds are well known to provide extremely nutritious food for both wild birds and domestic fowl. Hunters and birdwatchers who discover wild patches of hemp often keep this information secret, knowing that the area will be a magnet for birds in the fall when seed maturation occurs. Increasingly in North America, plants are being established to provide habitat and food for wildlife. Hemp is not an aggressive weed, and certainly has great potential for being used as a wildlife plant. Of course, current conditions forbid such usage in North America.

Ornamental Forms

Hemp has at times in the past been grown simply for its ornamental value. The short, strongly-branched cultivar 'Panorama' (Fig. 43) bred by Iván Bósca, the dean of the world's living hemp breeders, was commercialized in Hungary in the 1980s, and has been said to be the only ornamental hemp cultivar available. It has had limited success, of course, because there are very few circumstances that permit private gardeners can grow *Cannabis* as an ornamental today. By contrast, beautiful ornamental cultivars of opium poppy are widely cultivated in home gardens across North America, despite their absolute illegality and the potentially draconian penalties that could be imposed. Doubtless in the unlikely event that it became possible, many would grow hemp as an ornamental.

Fig. 43. 'Panorama,' the world's only ornamental cultivar, with the breeder, Ivan Bócsa. (Courtesy of Professor Bócsa.)

AGRONOMY

The following sketch of hemp cultivation is insufficient to address all of the practical problems that are encountered by hemp growers. Bócsa and Karus (1998) is the best overall presentation of hemp growing available in English. The reader is warned that this book, as well as almost all of the literature on hemp, is very much more concerned with fiber production than oilseed production. McPartland et al. (2000) is the best presentation available on diseases and pests, which fortunately under most circumstances do limited damage. The resource list presented below should be consulted by those wishing to learn about hemp production. Provincial agronomists in Canada now have experience with hemp, and can make local recommendations. Particularly good web documents are: for Ontario (OMAFRA Hemp Series, several documents): www.gov.on.ca/OMAFRA/english/crops/hort/hemp.html); for Manitoba (several documents): www.gov.mb.ca/agriculture/crops/hemp/bko01s00.html; for British Columbia: (BC Ministry of Agriculture and Foods Fact Sheet on Industrial Hemp, prepared by A. Oliver and H. Joynt): www.agf.gov.bc.ca/croplive/plant/horticult/specialty/specialty.htm

In the US, extension publications produced up to the end of World War II are still useful, albeit outdated (Robinson 1935; Wilsie et al. 1942; Hackleman and Domingo 1943; Wilsie et al. 1944).

Hemp does best on a loose, well-aerated loam soil with high fertility and abundant organic matter. Well-drained clay soils can be used, but poorly-drained clay soils are very inappropriate because of their susceptibility to compaction, which is not tolerated. Young plants are sensitive to wet or flooded soils, so that hemp must have porous, friable, well-drained soils. Sandy soils will grow good hemp, provided that adequate irrigation and fertilization are provided, but doing so generally makes production uneconomical. Seedbed preparation requires considerable effort. Fall plowing is recommended, followed by careful preparation of a seedbed in the spring. The seedbed should be fine, level, and firm. Seed is best planted at 2–3 cm (twice as deep will be tolerated). Although the seedlings will germinate and survive at temperatures just above freezing, soil temperatures of 8°–10°C are preferable. Generally hemp should be planted after danger of hard freezes, and slightly before the planting date of maize. Good soil moisture is necessary for seed germination, and plenty of rainfall is needed for good growth, especially during the first 6 weeks. Seeding rate is specific to each variety, and this information should be sought from the supplier. Fiber strains are typically sown at a minimum rate of 250 seeds per m^2 (approximately 45 kg/ha), and up to three times this density is sometimes recommended. In western Europe, seeding rates range from 60–70 kg/ha for fiber cultivars. Recommendations for seeding rates for grain production vary widely, from 10–45 kg/ha. Densities for seed production for tall, European, dual-purpose cultivars are less than for short oilseed cultivars. Low plant densities, as commonly found in growing tall European cultivars for seed, may not suppress weed growth adequately, and under these circumstances resort to herbicides may pose a problem for those wishing to grow hempseed organically. Hemp requires about the same fertility as a high-yielding crop of wheat. Industrial hemp grows well in areas that corn produces high yields. Growing hemp may require addition of up to 110 kg/ha of nitrogen, and 40–90 kg/ha of potash. Hemp particularly requires good nitrogen fertilization, more so for seed production than fiber. Adding nitrogen when it is not necessary is deleterious to fiber production, so that knowledge of the fertility of soils being used is very important. Organic matter is preferably over 3.5%, phosphorus should be medium to high (>40 ppm), potassium should be medium to high (>250 ppm), sulfur good (>5,000 ppm), and calcium not in excess (<6,000 ppm).

Finding cultivars suited to local conditions is a key to success. Hemp prefers warm growing conditions, and the best European fiber strains are photoperiodically adapted to flowering in southern Europe, which provides seasons of at least 4 months for fiber, and 5.5 months for seed production. Asian land races are similarly adapted to long seasons. In Canada, many of the available cultivars flower too late in the season for fiber production, and the same may be predicted for the northern US. Fiber production should also be governed by availability of moisture throughout the season, and the need for high humidity in the late summer and fall for retting, so that large areas of the interior and west of North America are not adapted to growing fiber hemp. The US Corn Belt has traditionally been considered to be best for fiber hemp. There are very few cultivars dedicated to oilseed production (such as 'Finola' and 'Anka') or that at least are known to produce good oilseed crops (such as 'Fasamo' and 'Uniko-B'). Oilseed production was a specialty of the USSR, and there is some likelihood that northern regions of North America may find short-season, short-stature oilseed cultivars ideal.

Although hemp can be successfully grown continuously for several years on the same land, rotation with other crops is desirable. A 3- or preferably 4-year rotation may involve cereals, clover or alfalfa for green manure, maize, and hemp. In Ontario it has been recommended that hemp not follow canola, edible beans, soybeans or sunflowers. However, according to Bócsa and Karus (1998), "*it matters little what crops are grown prior to hemp.*"

For a fiber crop, hemp is cut in the early flowering stage or while pollen is being shed, well before seeds are set. Tall European cultivars (greater than 2 m) have mostly been grown in Canada to date, and most of these are photoperiodically adapted to mature late in the season (often too late). Small crops have been harvested with sickle-bar mowers and hay swathers, but plugging of equipment is a constant problem. Hemp fibers tend to wrap around combine belts, bearings, indeed any moving part, and have resulted in large costs of combine repairs (estimated at $10.00/ha). Slower operation of conventional combines has been recommended (0.6–2 ha/hour). Large crops may require European specialized equipment, but experience in North America with crops grown mainly for fiber is limited. The Dutch company HempFlax has developed or adapted several kinds of specialized harvesting equipment (Fig. 44, 45).

Retting is generally done in the field (Fig. 46, 47). This typically requires weeks. The windrows should be turned once or twice. If not turned, the stems close to the ground will remain green while the top ones are retted and turn brown. When the stalks have become sufficiently retted requires experience—the fibers should have turned golden or grayish in color, and should separate easily from the interior wood. Baling can be done with any kind of baler (Fig. 48). Stalks should have less than 15% moisture when baled, and should be allowed to dry to about 10% in storage. Bales must be stored indoors. Retted stalks are loosely held together, and for highest quality fiber applications need to be decorticated, scutched, hackled, and combed to remove the remaining pieces of stalks, broken fibers, and extraneous material. The equipment for this is rare in North

Fig. 44. A John Deere Kemper harvester, with circular drums that cut and chop hemp stalks, shown in operation in southern Ontario. (Courtesy of Kenex Ltd., Pain Court, Ontario.)

Fig. 45. A hemp harvester operated by HempFlax (Netherlands), with a wide mowing head capable of cutting 3 m long stems into 0.6 m pieces, at a capacity of 3 ha/hour. (Courtesy of HempFlax, Oude Pekela, The Netherlands.)

Fig. 46. Windrowed fiber hemp in process of dew retting. Photograph taken in 1930 on the Central Experimental Farm, Ottawa, Canada.

Fig. 47. Shocked fiber hemp in process of dew retting. Photograph taken in 1931, near Ottawa, Canada. The shocks shed water like pup-tents, providing more even retting than windrows.

America, and consequently use of domestically-produced fiber for high quality textile applications is extremely limited. However, as described above relatively crude fiber preparations also have applications.

Harvesting tall varieties for grain is difficult. In France, the principal grower of dual-purpose varieties, the grain is taken off the field first, leaving most of the stalks for later harvest (Fig. 49). Putting tall whole plants through a conventional combine results in the straw winding around moving parts, and the fibers working into bearings, causing breakdown, fires, high maintenance, and frustration. Following the French example of raising the cutting blade to harvest the grain is advisable. Growing short varieties dedicated to grain production eliminates many of the above problems, and since the profitability of hemp straw is limited at present, seems preferable. Grain growers should be aware that flocks of voracious birds are a considerable source of damage to hempseed, particularly in small plantations.

ECOLOGICAL FRIENDLINESS OF HEMP

Although the environmental and biodiversity benefits of growing hemp have been greatly exaggerated in the popular press, *C. sativa* is nevertheless exceptionally suitable for organic agriculture, and is remarkably less "ecotoxic" in comparison to most other crops (Montford and Small 1999b). Figure 50 presents a comparison of the ecological friendliness of *Cannabis* crops (fiber, oilseed, and narcotics) and 21 of the world's major crops, based on 26 criteria used by Montford and Small (1999a) to compare the ecological friendliness of crops.

The most widespread claim for environmental friendliness of hemp is that it has the potential to save trees that otherwise would be harvested for production of lumber and pulp. Earlier, the limitations of hemp as a pulp substitute were examined. With respect to wood products, several factors appear to favor increased use of wood substitutes, especially agricultural fibers such as hemp. Deforestation, particularly the destruction of old growth forests, and the world's decreasing supply of wild timber resources are today major ecological concerns. Agroforestry using tree species is one useful response, but nevertheless sacrifices wild lands and biodiversity, and is less preferable than sustainable wildland forestry. The use of agricultural residues (e.g. straw bales in house construction) is an especially environmentally friendly solution to sparing trees, but material limitations restrict use. Another chief advantage of several annual fiber crops over forestry crops is relative productivity, annual fiber crops sometimes producing of the order of four times as much per unit of land. Still another

Fig. 48. Baled, retted hemp straw. (Courtesy of Kenex Ltd., Pain Court, Ontario.)

Fig. 49. Harvesting hemp in France. (Courtesy of La Chanvrière de l'Aube, Bar sur Aube, France.)

important advantage is the precise control over production quantities and schedule that is possible with annual crops. In many parts of the world, tree crops are simply not a viable alternative. "*By the turn of the century 3 billion people may live in areas where wood is cut faster than it grows or where fuelwood is extremely scarce*" (World Commission on Environment and Development 1987). "*Since mid-century, lumber use has tripled, paper use has increased six-fold, and firewood use has soared as Third World populations have multiplied*" (Brown et al. 1998). Insofar as hemp reduces the need to harvest trees for building materials or other products, its use as a wood substitute will tend to contribute to preserving biodiversity. Hemp may also enhance forestry management by responding to short-term fiber demand while trees reach their ideal maturation. In developing countries where fuelwood is becoming increasingly scarce and food security is a concern, the introduction of a dual-purpose crop such as hemp to meet food, shelter, and fuel needs may contribute significantly to preserving biodiversity.

The most valid claims to environmental friendliness of hemp are with respect to agricultural biocides (pesticides, fungicides, herbicides). *Cannabis sativa* is known to be exceptionally resistant to pests (Fig. 51), although, the degree of immunity to attacking organisms has been greatly exaggerated, with several insects and fungi specializing on hemp. Despite this, use of pesticides and fungicides on hemp is usually unnecessary, although introduction of hemp to regions should be expected to generate local problems. *Cannabis sativa* is also relatively resistant to weeds, and so usually requires relatively little herbicide. Fields intended for hemp use are still frequently normally cleared of weeds using herbicides, but so long as hemp is thickly seeded (as is always done when hemp is grown for fiber), the rapidly developing young plants normally shade out competing weeds.

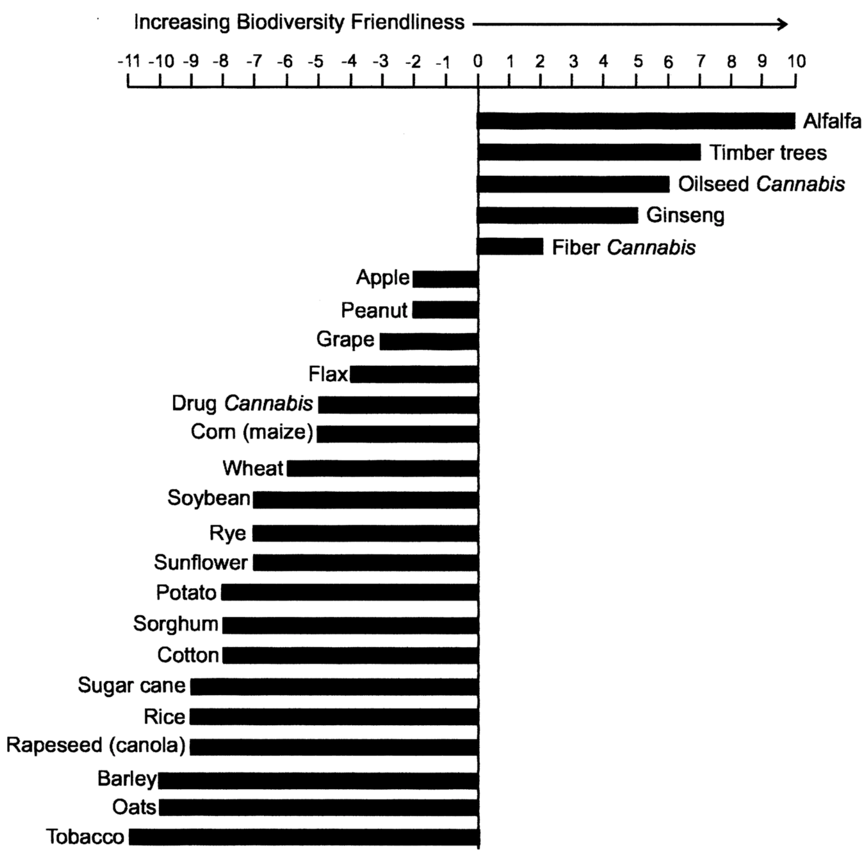

Fig. 50. A crude comparison of the biodiversity friendliness of selected major crops and three *Cannabis sativa* crops (fiber, oilseed, drug) based on 26 criteria (after Montford and Small 1999a).

BREEDING HEMP FOR NORTH AMERICA

The basic commercial options for growing hemp in North America is as a fiber plant, an oilseed crop, or for dual harvest for both seeds and fiber. Judged on experience in Canada to date, the industry is inclined to specialize on either fiber or grain, but not both. Hemp in our opinion is particularly suited to be developed as an oilseed crop in North America. The first and foremost breeding goal is to decrease the price of hempseed by creating more productive cultivars. While the breeding of hemp fiber cultivars has proceeded to the point that only slight improvements can be expected in productivity in the future, the genetic potential of hemp as an oilseed has scarcely been addressed. From the point of view of world markets, concentrating on oilseed hemp makes sense, because Europe has shown only limited interest to date in developing oilseed hemp, whereas a tradition of concentrating on profitable oilseed products is already well established in the US and Canada. Further, China's supremacy in the production of high-quality hemp textiles at low prices will be very difficult to match, while domestic production of oilseeds can be carried out using technology that is already available. The present productivity of oilseed hemp—about 1 t/ha under good conditions, and occasional reports of 1.5 to 2 t/ha, is not yet sufficient for the crop to become competitive with North America's major oilseeds. We suggest that an average productivity of 2 t/ha will be necessary to transform hempseed into a major oilseed, and that this breeding goal is achievable. At present, losses of 30% of the seed yields are not uncommon, so that improvements in harvesting technology should also contribute to higher yields. Hemp food products cannot escape their niche market status until the price of hempseed rivals that of other oilseeds, particularly rapeseed, flax, and sunflower. Most hemp breeding that has been conducted to date has been for fiber characteristics, so that there should be considerable improvement possible. The second breeding goal is for larger seeds, as these are more easily shelled. Third is breeding for specific seed components. Notable are the health-promoting gamma-linolenic acid; improving the amino acid spectrum of the protein; and increasing the antioxidant level, which would not only have health benefits but could increase the shelf life of hemp oil and foods.

Germplasm Resources

Germplasm for the improvement of hemp is vital for the future of the industry in North America. However, there are no publicly available germplasm banks housing *C. sativa* in North America. The hundreds of seed collections acquired for Small's studies (reviewed in Small 1979) were destroyed in 1980 because Canadian government policy at that time envisioned no possibility that hemp would ever be developed as a legitimate crop. An inquiry regarding the 56 United States Department of Agriculture hemp germplasm collections supplied to and grown by Small and Beckstead (1973) resulted in the reply that there are no remaining hemp collections in USDA germplasm holdings, and indeed that were such to be found they would have to be destroyed. While hemp has been and still is cultivated in Asia and South America, it is basically in Europe that germplasm banks have made efforts to preserve hemp seeds. The Vavilov Institute of Plant Research in St. Petersburg, Russia has by far the largest germplasm collection of hemp of any public gene bank, with about 500 collections. Detailed information on the majority of hemp accessions of the Vavilov Institute can be found in Anon. (1975). Budgetary problems in Russia have endangered the survival of this invaluable collection, and every effort needs to be made to find new funding to preserve it. Maintenance and seed generation issues for the Vavilov hemp germplasm collection are discussed in a number of articles in the Journal of the International Hemp Association (Clarke 1998b; Lemeshev et al. 1993, 1994). The Gatersleben gene bank of Germany, the 2nd largest public gene bank in Europe, has a much smaller *Cannabis* collection, with less than 40 accessions

Fig. 51. Grasshopper on hemp. Most insects cause only limited damage to hemp, and substantial insect damage is uncommon, so the use of insecticides is very rarely required.

(detailed information on the hemp accessions of the Gatersleben gene bank are available at fox-serv.ipk-gatersleben.de/). Because hemp is regaining its ancient status as an important crop, a number of private germplasm collections have been assembled for the breeding of cultivars as commercial ventures (de Meijer and van Soest 1992; de Meijer 1998), and of course these are available only on a restricted basis, if at all.

The most pressing need of the hemp industry in North America is for the breeding of more productive oilseed cultivars. At present, mainly European cultivars are available, of which very few are suitable for specialized oilseed production. More importantly, hempseed oil is not competitive, except in the novelty niche market, with the popular food oils. As argued above, to be competitive, hemp should produce approximately 2 t/ha; at present 1 t/ha is considered average to good production. Doubling the productive capacity of a conventional crop would normally be considered impossible, but it needs to be understood just how little hemp has been developed as an oilseed. There may not even be extant land races of the kind of hemp oilseed strains that were once grown in Russia, so that except for a very few very recent oilseed cultivars, there has been virtually no breeding of oilseed hemp. Contrarily, hemp has been selected for fiber to the point that some breeders consider its productivity in this respect has already been maximized. Fiber strains have been selected for low seed production, so that most hemp germplasm has certainly not been selected for oilseed characteristics. By contrast, drug varieties have been selected for very high yield of flowers, and accordingly produce very high yield of seeds. Drug varieties have been observed to produce more than a kilogram of seed per plant, so that a target yield of several tonnes per hectare is conceivable (Watson and Clarke 1997). Of course, the high THC in drug cultivars makes these a difficult source of germplasm. However, wild plants of *C. sativa* have naturally undergone selection for high seed productivity, and are a particularly important potential source of breeding germplasm.

Wild North American hemp is derived mostly from escaped European cultivated hemp imported in past centuries, perhaps especially from a revival of cultivation during World War II. Wild Canadian hemp is concentrated along the St. Lawrence and lower Great Lakes, where considerable cultivation occurred in the 1800s. In the US, wild hemp is best established in the American Midwest and Northeast, where hemp was grown historically in large amounts. Decades of eradication have exterminated many of the naturalized populations in North America. In the US, wild plants are rather contemptuously called "ditch weed" by law enforcement personnel. However, the attempts to destroy the wild populations are short-sighted, because they are a natural genetic reservoir, mostly low in THC. Wild North American plants have undergone many generations of natural adaptation to local conditions of climate, soil and pests, and accordingly it is safe to conclude that they harbor genes that are invaluable for the improvement of hemp cultivars. We have encountered exceptionally vigorous wild Canadian plants (Fig. 52), and grown wild plants from Europe (Fig. 53) which could prove valuable. Indeed, studies are in progress in Ontario to evaluate the agronomic usefulness of wild North American hemp. Nevertheless, present policies in North America require the eradication of wild hemp wherever encountered. In Europe and Asia, there is little concern about wild hemp, which remains a valuable resource.

Fig. 52. Wild female hemp plant collected Oct. 17, 2000 near Ottawa, Canada. This vigorous plant had a fresh weight of 1.5 kg.

HARD LESSONS FOR FARMERS

It is clear that there is a culture of idealistic believers in hemp in North America, and that there is great determination to establish the industry. As history has demonstrated, unbridled enthusiasm for largely untested new crops touted as gold mines sometimes leads to disaster. The attempt to raise silk in the US is probably the most egregious example. In 1826 a Congressional report that recommended the preparation of a practical manual on the industry resulted in a contagious desire to plant mulberries for silk production, with the eventual collapse of the industry, the loss of fortunes, and a legacy of "Mulberry Streets" in the US (Chapter 2, Bailey 1898). In the early 1980s in Minnesota, Jerusalem artichoke was touted as a fuel, a feed, a food, and a sugar crop. Unfortunately there was no market for the new "wonder crop" and hundreds of farmers lost about $20 million (Paarlberg 1990). The level of "hype" associated with industrial hemp is far more than has been observed before for other new crops (Pinfold Consulting 1998). Probably more so than any plant in living memory, hemp attracts people to attempt its cultivation without first acquiring a realistic appreciation of the possible pitfalls. American presidents George Washington and Thomas Jefferson encouraged the cultivation of hemp, but both lost money trying to grow it. Sadly in Canada in 1999 numerous farmers contracted to grow half of Canada's crop area for hemp for the American-based Consolidated Growers and Processors, and with the collapse of the firm were left holding very large amounts of unmarketable grain and baled hemp straw. This has represented a most untimely setback for a fledgling industry, but at least has had a sobering effect on investing in hemp. In this section we emphasize why producers should exercise caution before getting into hemp.

In Europe and Asia, hemp farming has been conducted for millennia. Although most countries ceased growing hemp after the second word war, some didn't, including France, China, Russia, and Hungary, so that essential knowledge of how to grow and process hemp was maintained. When commercial hemp cultivation resumed in Canada in 1997, many farmers undertook to grow the crop without appreciating its suitability for their situation, or for the hazards of an undeveloped market. Hemp was often grown on farms with marginal incomes in the hopes that it was a savior from a downward financial spiral. The myth that hemp is a wonder crop that can be grown on any soil led some to cultivate on soils with a history of producing poor crops; of course, a poor crop was the result.

Market considerations also heavily determine the wisdom of investing in hemp. Growing hemp unfortunately has a magnetic attraction to many, so there is danger of overproduction. A marketing board could be useful to prevent unrestrained competition and price fluctuations, but is difficult to establish when the industry is still very small. As noted above, unwise investment in Canada produced a glut of seeds that resulted in price dumping and unprofitable levels for the majority. Cultural and production costs of hemp have been said to be comparable to those for corn, and while the truth of this remains to be confirmed, the legislative burden that accompanies hemp puts the crop at a unique disadvantage. Among the problems that Canadian farmers have faced are the challenge of government licensing (some delays, and a large learning curve), very expensive and sometime poor seed (farmers are not allowed to generate their own seed), teenagers raiding fields in the mistaken belief that marijuana is being grown, and great difficulties in exportation because of the necessity of convincing authorities that hemp is not a narcotic. Unless the producer participates in sharing of value-added income, large profits are unlikely. The industry widely recognizes that value added to the crop is the chief potential source of profit, as indeed for most other crops.

Fig. 53. A wild female hemp plant grown in southern Ontario [accession #16 from Georgia (formerly USSR), reported in Small and Marcus (2000)]. Such highly-branched plants can produce very large quantities of seeds, and may be useful for breeding.

THE POLITICS OF *CANNABIS* WITH PARTICULAR REFERENCE TO THE US

Cannabis has long had an image problem, because of the extremely widespread use of "narcotic" cultivars as illegal intoxicants. The US Drug Enforcement Administration has the man-date of eliminating illicit and wild marijuana, which it does very well (Fig. 54–56). Those interested in establishing and developing legitimate industries based on fiber and oilseed applications have had to struggle against considerable opposition from many in the political and law enforcement arenas. The United States National Institute on Drug Abuse (NIDA) information web site on marijuana, which reflects a negative view of cannabis, is at www.nida.nih.gov/DrugPages/Marijuana.html, and reflects several basic fears: (1) growing *Cannabis* plants makes law enforcement more difficult, because of the need to ensure that all plants cultivated are legitimate; (2) utilization of legitimate *Cannabis* products makes it much more difficult to maintain the image of the illegitimate products as dangerous; (3) many in the movements backing development of hemp are doing so as a subterfuge to promote legalization of recreational use of marijuana; and (4) THC (and perhaps other constituents) in *Cannabis* are so harmful that their presence in any amount in any material (food, medicine or even fiber product) represents a health hazard that is best dealt with by a total proscription.

Ten years ago hemp cultivation was illegal in Germany, England, Canada, Australia, and other countries. Essential to overcoming governmental reluctance in each country was the presentation of an image that was business-oriented, and conservative. The merits of environmentalism have acquired some political support, but unless there is a reasonable possibility that hemp cultivation is perceived as potentially economically viable, there is limited prospect of having anti-hemp laws changed. Strong support from business and farm groups is indispensable; support from pro-marijuana interests and what are perceived of as fringe groups is generally counterproductive. It is a combination of prospective economic benefit coupled with assurance that hemp cultivation will not detrimentally affect the enforcement of marijuana legislation that has led most industrially advanced countries to reverse prohibitions against growing hemp. Should the US permit commercial hemp cultivation to resume, it will likely be for the same reasons.

The US Office of National Drug control Policy issued a statement on industrial hemp in 1997 (www.whitehousedrugpolicy.gov/policy/hemp%5Fold.html) which included the following: "*Our primary concern about the legalization of the cultivation of industrial hemp (*Cannabis sativa*) is the message it would send to the public at large, especially to our youth at a time when adolescent drug use is rising rapidly... The second major concern is that legalizing hemp production may mean the de facto legalization of marijuana cultivation. Industrial hemp and marijuana are the product of the same plant,* Cannabis sa-

Fig. 54. The war on drugs: helicopter spraying of Paraquat herbicide on field of marijuana. (Courtesy US Drug Enforcement Administration.)

Fig. 55. The war on drugs: clandestine indoor marijuana cultivation. (Courtesy US Drug Enforcement Administration.)

Fig. 56. The war on drugs: burning seized marijuana. (Courtesy US Drug Enforcement Administration.)

tiva... *Supporters of the hemp legalization effort claim hemp cultivation could be profitable for US farmers. However, according to the USDA and the US Department of Commerce, the profitability of industrial hemp is highly uncertain and probably unlikely. Hemp is a novelty product with limited sustainable development value even in a novelty market... For every proposed use of industrial hemp, there already exists an available product, or raw material, which is cheaper to manufacture and provides better market results.... Countries with low labor costs such as the Philippines and China have a competitive advantage over any US hemp producer.*"

Recent European Commission proposals to change its subsidy regime for hemp contained the following negative evaluation of hemp seed: "*The use of hemp seed ... would, however, even in the absence of THC, contribute towards making the narcotic use of cannabis acceptable... In this light, subsidy will be denied producers who are growing grain for use in human nutrition and cosmetics.*"

A USDA analysis of hemp, "*Industrial hemp in the United States: Status and market potential*," was issued in 2000, and is available at www.ers.usda.gov/publications/ages001e/index.htm. This is anonymously-authored, therefore presumably represents a corporate or "official" evaluation. The conclusion was that "*US markets for hemp fiber (specialty textiles, paper, and composites) and seed (in food or crushed for oil) are, and will likely remain, small, thin markets. Uncertainty about longrun demand for hemp products and the potential for oversupply discounts the prospects for hemp as an economically viable alternative crop for American farmers.*" Noting the oversupply of hempseeds associated with Canada's 12,000 ha in 1999, the report concluded that the long term demand for hemp products is uncertain, and predicts that the hemp market in the US will likely remain small and limited. With respect to textiles, the report noted the lack of a thriving textile flax (linen) US industry (despite lack of legal barriers), so that it would seem unlikely that hemp could achieve a better market status. With respect to hemp oil, the report noted that hemp oil in food markets is limited by its short shelf life, the fact that it can not be used for frying, and the lack of US Food and Drug Administration approval as GRAS ("generally recognized as safe"). Moreover, summarizing four state analyses of hemp production (McNulty 1995, Ehrensing 1998, Kraenzel et al. 1998, Thompson et al. 1998), profitability seemed doubtful.

Without arguing the merits of the above contentions, we point out that the legitimate use of hemp for non-intoxicant purposes has been inhibited by the continuing ferocious war against drug abuse. In this atmosphere, objective analysis has often been lacking. Unfortunately both proponents and opponents have tended to engage in exaggeration. Increasingly, however, the world is testing the potential of hemp in the field and marketplace, which surely must be the ultimate arbiters. De Guzman (2001), noting the pessimistic USDA report, observed that "*Nevertheless, others point to the potential of [the] market. Hemp products have a growing niche market of their own, and the market will remain healthy and be well supported with many competing brands.*"

A wide variety of hemp clothing, footwear, and food products are now available in North America. Some American manufacturers and distributors have chosen to exploit the association of hemp products with marijuana in their advertising. Such marketing is unfortunate, sending the message that some in the industry are indifferent to the negative image that this generates in the minds of much of the potential consuming public. Admittedly, such advertising works. But marketing based on the healthful and tasteful properties of hemp food products, the durable nature of hemp textiles, and the environmental advantages of the crop has proven to be widely acceptable, and is likely to promote the long term development of hemp industries.

Will hemp commercial cultivation resume in the US in the foreseeable future? This is difficult to judge, but the following considerations suggest this might occur: (1) increasing awareness of the differences between industrial hemp and marijuana; (2) growing appreciation of the environmental benefits of hemp cultivation; (3) continuing demonstration of successful hemp cultivation and development in most of the remaining western world; all the G8 countries, except the US, produce and export industrial hemp; and (4) increasing pressure on state and federal governments to permit hemp cultivation by farmers, particularly wheat, corn, and tobacco farmers in desperate need of substitute crops, but also for rotation crops to break pest and disease cycles.

More than a century ago, an expert on hemp concluded his manual on hemp-growing in the US by stating "*There is no question that when the inventive genius, comprehension and energies of the American people become interested, another grand source of profitable employment and prosperity will be established*" (Boyce 1900).

MARKET DEVELOPMENT

Individual entrepreneurs, and indeed whole industries, as a matter of economic survival need to adopt a clear investment policy with respect to whether their market is to be output-driven or demand-led. From the individual producer's perspective, the old adage "*find your market before you plant your seed*" remains sound advice.

In the mid 1990s, the EU provided subsidization for hemp cultivation of ca. $1,050/ha. This support was instrumental in developing a hemp industry in western Europe. However, no comparable support is available in North America, and indeed those contemplating entering into hemp cultivation are faced with extraordinary costs and/or requirements in connection with licensing, security, THC analysis, and record keeping. Those involved in value-added processing and distribution are also faced with legal uncertainties and the regular threat of idiosyncratic, indeed irrational actions of various governments. Simply displaying a *C. sativa* leaf on advertising has led to the threat of criminal charges in the last decade in several G8 countries. Attempting to export or import hemp products among countries is presently a most uncertain activity.

It often takes 10 to 15 years for the industry associated with a new agricultural crop to mature. While it is true that foreign imports have been the basis for hemp products in North America for at least a decade, North American production is only 4 years of age in Canada, and farming of hemp in the US has not even begun. Viewed from this perspective, the hemp industry in North America is still very much in its infancy. Varieties of hemp specifically suited to given products and regions have only started to be developed in North America. There is considerable uncertainty regarding yields, costs of production, harvesting and processing equipment, product characteristics, foreign competition, governmental support, and the vagaries of the regulatory environment. Hemp is not presently a standard crop, and is likely to continue experiencing the risks inherent in a small niche market for some time. Hemp is currently a most uncertain crop, but has such a diversity of possible uses, is being promoted by extremely enthusiastic market developers, and attracts so much attention that it is likely to carve out a much larger share of the North American marketplace than its detractors are willing to concede.

Given the uncertainties and handicaps associated with hemp, it is fortunate that there are compensating factors. As noted, as a crop hemp offers some real environmental advantages, particularly with regard to the limited needs for herbicides and pesticides. Hemp is therefore pre-adapted to organic agriculture, and accordingly to the growing market for products associated with environmentally-friendly, sustainable production. Hemp products are an advertiser's dream, lending themselves to hyperbole ("healthiest salad oil in the world," "toughest jeans on the market"). While the narcotics image of *C. sativa* is often disadvantageous, advertisers who choose to play up this association do so knowing that it will attract a segment of the consuming population. In general, the novelty of hemp means that many consumers are willing to pay a premium price. It might also be said that those who have entered the hemp industry have tended to be very highly motivated, resourceful, and industrious, qualities that have been needed in the face of rather formidable obstacles to progress.

INFORMATION RESOURCES

Organizations

North American Industrial Hemp Council Inc.: www.naihc.org
Hemp Industries Association: www.thehia.org
International Hemp Association: mojo.calyx.net/~olsen/HEMP/IHA/
Hemp Food Association: hempfood.com/
Ontario Hemp Alliance: www.ontariohempalliance.org
International Association for Cannabis as Medicine: www.acmed.org/english/main.htm

Web

The Hemp Commerce & Farming Report: www.hempreport.com
Industrial hemp information network: www.hemptech.com

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