I. HOW CANNABIS IS PRODUCED

Cannabis the plant

Cannabis is a unique plant. It has been cultivated by mankind for centuries, although it is only fairly recently that its use as a drug has outpaced its other applications. As evidenced by its geographic range, the plant is exceedingly hardy and adaptable, leading to the oft-repeated quip "cannabis can grow anywhere". However, it can only reach its full potential, and thus be of practical use, under certain conditions.

The cannabis plant prefers temperatures of 14°-27° Celsius, but can withstand freezing temperatures for brief periods of time. While it can grow in difficult soil types, such as sand, it prefers loams rich in nitrogen. It has been dubbed a "camp follower", owing to its ability to flourish in human waste dumps and manure, and this may be one reason for its early cultivation [1]. Despite some claims to the contrary [1], the hemp industry literature indicates that the cannabis plant is a "heavy feeder", drawing lots of nutrients (especially nitrogen) from the soil, and that feeding is most intense immediately before and during flowering ([2], p. 72; [3]). It prefers direct sunlight, as much as it can get. After the first six weeks, it can grow with little water, as it possesses a powerful taproot, but it only flourishes with regular moisture.* For drug purposes, however, arid climates seem to favour the production of resin and reduce the risk of fungus and moulds. In addition, the cannabis plant requires well-drained soil or its roots will rot, so it does not grow well in clay.** It can be grown in slightly alkaline soil, but prefers a fairly neutral pH of between 6 and 7.*** It is resistant to many predatory insects and has even been used as a hedge to protect other crops from insects, but it is vulnerable to spider mites, aphids and other pests.

In short, while its feral range is wide, the cannabis plant is like any other crop: its productivity is linked to the amount of care and support it is given. When

*On the other hand, since it appears that one of the functions of cannabis resin is to protect the plant from water loss and that some of the best known strains of cannabis come from arid climates, it has been hypothesized that aridity has a positive effect on the drug potential of the plant.

In an interesting study, Haney and Bazzaz [4] observed the proliferation of cannabis in the United States of America. Aside from noting its extreme adaptability and aggressive nature, the authors point out the areas where cannabis has **not successfully spread. Looking at the state of Illinois, which at that time was considered to be a state in the heart of the "cannabis belt" in the United States, Haney and Bazzaz show that the plant is non-existent in the south-eastern part of the state. This area is characterized by tight soil that is low in nitrogen and high in clay. Of these two factors, the authors reckon that clay is the most important inhibiting factor, as cannabis has been found growing in very sandy soil with low nitrogen content.

***Industrial hemp can be grown in a pH of up to 7.8, according to Cloud ([5], p. 3).

intentionally cultivated, however, it can be grown in most inhabited areas of the world.

Is the cannabis plant one species or several?

The cannabis plant's unique properties have led to much debate concerning the taxonomic classification of cannabis and it was reclassified several times before being given its own family, the *cannabaceae*, shared only with the hops plant. Its wide geographic distribution and extremely adaptive morphology have further confused matters, as plants bred under different conditions can bear little resemblance to one another. Some argue that there are two or three species: "sativa", "indica" and, sometimes, "ruderalis". This breakdown is very popular in the grey literature on cannabis plant cultivation. Even today, there is disagreement about whether *Cannabis* is a genus with only one species or several.*

What is the life cycle of the cannabis plant?

The cannabis plant is an annual, completing its life cycle in a single season and dying after reproduction. When cultivated outdoors in the temperate climates of the northern hemisphere, seeds are traditionally planted between March and May and the plant flowers between September and November, representing about a six-month growth cycle, with only one crop possible.** Closer to the equator, however, it is possible to manage two annual crops from the same plot [8] and it has been claimed that some tropical varieties will experience up to four growth seasons a year ([9], p. 114). Plants harvested for drug use are generally completely destroyed and they would normally die soon after harvest time in any case.***

The cannabis plant is unusual in being "dioecious", which means (with the exception of an odd hermaphrodite)**** each individual plant is either male or female. Males fertilize females by means of wind-borne pollen.

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*See, for example, the ruminations of Richard Evan Schultes [1], in which he illustrates the difficulties in distinguishing whether cannabis is a genus with one, highly varied and adaptable species or several distinct species, before conceding that most botanists feel that cannabis is a monotypic species. Ironically, later in life Schultes served as an expert witness to argue for the defence in cannabis cases on the basis that laws prohibiting the use of specified strains of cannabis species might not apply to others. For a discussion of this debate, which also concludes that cannabis has only one species, see Small [6]. Small notes the argument in support of the position that cannabis is monospecific made by hemp specialist Dewey, who claimed that cannabis seeds planted in a region different from their origin appeared to take on the characteristics of the cannabis native to their new home within a few generations.

**Frank and Roseland, cited in Mignoni ([7], p. 42).

***Indoors, cannabis plants can be kept alive indefinitely, even after harvesting, by reverting back to a vegetative photoperiod, but this practice is rare, as it generally involves more time and effort than starting again from clones.

****Monoecious (hermaphroditic) varieties have been bred for industrial hemp production, as this allows more uniform crops. Hermaphroditism in dioecious plants is often a reaction to stress, as a way of ensuring pollination despite adverse conditions.

The cannabis plant flowers over time or when it detects the coming of autumn, as evidenced in the shortening of days. This allows plants that germinated late to complete their life cycle in an accelerated manner. The exact photoperiod required to induce flowering varies by variety: plants from temperate climates, in their home environment, tend to flower later in the season, whereas plants coming from harsher climes necessarily have to reproduce in a tighter timeframe. A 12-hour night period is enough to induce flowering in most, if not all, varieties.

All of these unusual characteristics (variability, adaptability, dioeciousness, wind-borne pollination and photoperiod-linked fertility) have implications for illicit cannabis production. The genetic diversity of the cannabis plant and the fact that individual plants tend to manifest only one sex makes it well suited for selective breeding to enhance desired qualities. Strains that have evolved under difficult climatic conditions can be bred with those that produce the best quality drug, for example. Plants can be designed to make them more concealable, resilient, productive or potent.

It just so happens that female plants, when unfertilized, produce the best quality drugs and cultivators must work around this fact if they want to aim for the high end of the market. As will be discussed below, this is one of the factors that pushed the production of premium cannabis indoors, in order to avoid undesired pollination. The indoor environment also allows manipulation of the light cycle. Plants can be fooled into thinking that the season has changed and their maturation accelerated as a result. This allows growers to decide when and for how long a plant will be allowed to flower. These matters are discussed further below.

Cannabis the drug

Several drug products can be produced from the cannabis plant, falling into three main categories:

- "Herbal cannabis": the leaves and flowers of the plant
- "Cannabis resin": the pressed secretions of the plant, commonly referred to as "hashish" in the West or "charas" in India
- "Cannabis oil"

For reasons that will be discussed, herbal cannabis is the most popular form in North America and most of the rest of the world, while cannabis resin is the most popular form in much of Europe and in a few regions that traditionally have produced cannabis resin.

Within these categories, a number of different grades and strains are also available in most major market areas. In any large market there are generally cheap and expensive alternatives. In the United States, for example, a distinction is commonly made between "schwag" or "commercial" grade cannabis (typically

field-grown in Mexico or domestically) and higher-grade herbal products, often referred to by the brand name of the cultivar. In France, New Zealand and the United Kingdom of Great Britain and Northern Ireland, especially potent cannabis is often referred to as "skunk", a reference to the result of an important early crossing of plants from different sources, which was perceived as being particularly smelly by users. The variety of cannabis strengths and products in the market may be likened to the range of cigarette or alcohol products and brands. Preferences are influenced by culture, but individual tastes vary.

While there are shadings, the primary product division on the herbal side is between high-grade cannabis produced without seeds and the more mundane product. Known as sinsemilla (from the Spanish *sin semilla*: without seeds), this product is composed entirely of the unfertilized flowers of the female plant and is far more potent than other forms of cannabis herb.

The terminology in this area can become confusing:

- Since most sinsemilla consists of only the flowering tops of the plant, it is sometimes referred to as "buds", but seeded buds are also marketed, of course.
- Today, most sinsemilla is produced indoors, and nearly all cannabis produced indoors on any scale is sinsemilla, so there is a tendency to equate the two, while this may not always be accurate.
- Indoor sinsemilla is often grown using hydroponic (non-soil, discussed below) techniques and nearly all hydroponic cannabis grown is sinsemilla, but many indoor producers favour soil-based (often referred to as "organic") production, so the terms are by no means equivalent.
- Outside the United States, most sinsemilla is produced in the country where it is consumed and in some (particularly European) countries the opportunities for outdoor cultivation may be limited, so some commentators equate "sinsemilla" with "domestically grown", but this may also be inaccurate.

While the term "hashish" has been historically used to describe all sorts of cannabis concoctions, today the word is primarily used to refer to cannabis resin. As the plant flowers, glands called "trichomes" produce a sappy, resinous substance in which much of the cannabinoid content of the plant is concentrated. The purpose of this resin is unclear, but it has been hypothesized that it plays a role in protecting the buds from harsh environmental conditions (for example, ultraviolet light, insect pests and water loss due to wind) or as a means of collecting windborne pollen, as it is in the unfertilized female flowers that the resin is most plentiful and most potent.

The resin is collected wet or after it has dried. Dried resin must be heated or pressed to make it malleable. Sale-ready cannabis resin differs in colour from sandy

to reddish to black. It differs in consistency from putty-like to brittle and dusty. These differences may be attributed to:

- The type of cannabis plant used and the way it was cultivated and cured
- The presence of non-resinous plant matter
- The extent to which the resin has been pressed, heated or otherwise handled
- Age
- Adulterants introduced by manufacturers

Darkening may be due to a kind of oxidation, as resin that has been roughly handled (such as Indian hand rubbed) or left to age (such as traditional Afghan) may appear darker. A green colour may be indicative of unwanted plant material rather than pure resin, but experienced users agree that colour is not a reliable gauge of potency.

Any place that produces cannabis could produce cannabis resin ("hashish"), although in practice only a few do. Today, for example, the single largest producer of "hashish" is the Ketama region of Morocco. While Morocco has a long-standing cannabis ("kif") culture, it is only since around 1970 that the country began producing "hashish", a practice allegedly introduced by foreigners. Historically, there have been two means of collecting cannabis resin: hand-rubbing and sieving.

In hand-rubbing, workers remove the gummy resin from the living plants by running their hands over the flowering tops. The resin adheres to the skin and has to be removed by forcefully peeling it away and rubbing it into little balls, which are combined and moulded into shapes for marketing. Hand-rubbed cannabis resin may have been the first way cannabis was consumed and it represents a rather inefficient and labour-intensive means of gathering the drug. Hand-rubbing today is concentrated in India and Nepal.*

*India has traditionally produced at least three standard cannabis products: "bhang", which is chopped cannabis leaves, usually consumed as a drink, often with other psychoactive ingredients added; "ganja", which is herbal cannabis; and "charas", which is hand-rubbed cannabis resin. "Charas" is generally dark and somewhat pliable when heated. Indian "charas" was rediscovered by the West when hippies in the 1960s made pilgrimages to India in search of enlightenment and started what is known as the "hashish trail". Exporting hand-rubbed cannabis resin is problematic, as the rough handling causes the product to age quickly: tetrahydrocannabinol (THC) degrades into other cannabinoids and the drug then produces a less desirable mental state. Moisture is often captured in the mix during manual handling and this can lead to moulding. If stored on site, however, it can last for years and local users tend to age their "charas" for a year before smoking it. This, as well as the time-consuming labour required to gather the drug, has limited its presence in international trafficking and most "charas" is consumed domestically. "Charas" from Nepal is considered to be of an even higher quality than "charas" from India, although lower grades are also produced. It is often smoothed into balls ("temple balls") or "fingers" and may have a shiny or waxy appearance. There are persistent claims that temple balls are treated with opium or some by-product of the opium refining process ("first water") but these claims are difficult to substantiate.

Hand-rubbing is not to be confused with hand-pressing. The dust-like product produced by sieving becomes malleable when heat and pressure are applied and this can be done by hand or by machine in order to prepare it for storage and shipping.

Sieving requires the plants to be dried first, which means an arid climate is essential. The resin and trichomes become powdery and brittle and can be removed from the bulk of the plant matter by use of a screen and some percussive force. Traditionally, fabric is used as a screen and a basin or pot as a collection device. Light tapping produces the purest cannabis resin, but greater quantities (including quite a lot of relatively inert plant matter) can be gathered by the application of more force. The powdery resin that is produced is either gently heated or manually or mechanically pressed to make it malleable. Lower grades may be adulterated with a range of oils and inert or active bulking agents.

As with cannabis herb, there are grades to cannabis resin, which vary depending on the country of origin. Much like olive oil, cannabis resin made from the first sifting is rated highest, as it contains the maximal amount of resin with minimal impurities. Producing 10 grams of top grade cannabis resin (such as the Moroccan "zero-zero") requires about 1 kilogram of plant material (i.e. a 1 per cent, or 100 to 1, extraction ratio) and some premium varieties have even lower ratios. Often, the residue is used to produce additional resin of a lower quality. Lower quality cannabis resin may be produced at ratios of up to 50 grams per kg or more.

Manual preparation processes are highly labour intensive and somewhat wasteful, so it is not surprising that modern consumers of cannabis resin have devised more efficient technologies. Many of these were piloted in the Netherlands. The potency of the cannabis resin they produce (*nederhasj*) is much higher than the resin produced through traditional methods, although the yield is not as great. Sinsemilla cannabis plants are generally used for *nederhasj*, further enhancing potency.

A third sort of cannabis resin ("jelly hash") has also emerged in recent years. This appears to be a combination of *nederhasj* and cannabis oil, with a soft consistency and very high THC levels. Cannabis oil itself may be making a comeback, as new processes are developed that reduce the risk of solvent impurities. There have also been other cannabinoid concentrates developed, such as the Vancouver product known as "budder". The proponents of these products argue that they will be easier for medical cannabis patients to consume, without the necessity of smoking plant matter.

Despite these technological developments, there are many people in Europe who prefer traditionally made cannabis resin. They face problems of quality in their supply, however. Morocco dominates the European market and all but the highest grades of its output of cannabis resin appear to have declined in quality in recent years. Particularly worrying are the adulterants said to be used to bulk up lower grades, producing products such as "soap bar" in the United Kingdom and "Chernobyl" in France. These have been persistently alleged to contain all sorts of additives over the years, including the highly unlikely claim that they are made with an unspecified, addictive animal tranquillizer. Despite these claims, in its review of

cannabis potency, the European Monitoring Centre for Drugs and Drug Addiction (EMCDDA) asserts that, in Europe, "resin is rarely adulterated" ([10], p. 40).

Cannabis resin is smoked like cannabis herb, but can also be used in cooking and eaten. It can be vaporized or smoked in a range of ways, which include pressing a small amount between two hot knives and inhaling the fumes. It is often added to a medium such as tobacco before consumption.

What are the psychoactive components of cannabis?

Cannabis contains over 400 chemicals, of which more than 60 are chemically unique and are collectively referred to as cannabinoids. Delta-9 THC is believed to be responsible for most of the psychoactive effects of cannabis, although related chemicals are believed also to play a role. The precise way in which the various components of cannabis interact and influence the physiological and subjective effects of cannabis is a topic of ongoing research.

Much of the THC in a plant is in acid form or in a less potent variant and the application of heat is essential to make all of the THC accessible. Chemically synthesized delta-9 THC is known as dronabinol (marketed as Marinol).

One of the most important secondary chemicals is cannabidiol (CBD), the biosynthetic precursor of THC, which converts to THC as the plant matures. It has been argued, particularly by users, that this chemical alters the subjective perception of the effects of THC, enhancing the sedative effect. This claim is the subject of ongoing research [11]. At least one study has concluded, on the contrary, that the psychoactive effects of cannabis are mainly due to THC [12]. Some research exists on the independent muscle relaxant and anti-psychotic properties of CBD [11]. If these investigations are borne out, they may challenge the notion that the quality of cannabis can be reduced to its THC content. Numerous forensic studies have found that different varieties of cannabis contain different ratios of cannabinoids. For example, some South African varieties have been found with virtually no CBD [13, 14]. Most plants used to make cannabis resin have a high CBD content, although whether this is a result of historic accident or more deeply related to the nature of the drug remains unclear [15]. These variations could possibly provide some explanation for the different subjective effects of different cultivars, a topic widely discussed by cannabis users.*

*Users say that "sativa" varieties produce more of a "cerebral high", while "indicas" produce more of a "body stone". The grey literature often argues that "sativas" have large amounts of THC compared to CBD, while "indicas" are relatively CBD-rich. Smokers of high THC "sativas" say they become more energetic and creative, while those who consume varieties where CBD is relatively high talk about falling into a physically relaxed "couch lock". For a discussion of the different subjective effects of different cultivars of cannabis, see, for example, Drake ([16], p. 25). One of the challenges breeders pose for themselves is capturing the preferred qualities of each strain. There is also variation in the proportions of other cannabinoids in local cannabis products, such as cannabinol and tetrahydrocannabivarin, and the processing and age of the sample can have an effect on cannabinoid content. Finally, different methods of ingestion result in different levels and combinations of cannabinoids being absorbed. Heat is required to decarboxylate THC acid to THC, and this affects the potency of cannabis when it is eaten.

THC is found in most parts of the plant aside from the stems and seeds, but is most plentiful in the flowers and small leaves surrounding them. This is where the glandular trichomes (the tiny, mushroom-shaped glands that produce resin) are most prominent. A positive correlation has been found between the number of stalked capitate glandular trichomes and THC content [17]. Some commentators dispute that either trichome numbers or resin quantity are reliable indicators of potency. The quality (THC level) rather than the quantity of resin is emphasized [18].

Other cannabinoids are of use to forensic researchers. For example, cannabinol (CBN) is a mildly psychoactive product of THC degradation and is not found in the fresh plant. The ratio of THC to CBN can thus be an indicator of the age of a sample of cannabis [19].

Cannabis resin is a concentrated product and it is therefore remarkable that, in major markets such as Germany and the United Kingdom, the cannabis herb available locally is actually more potent than the cannabis resin that is consumed. In 2002, low average resin potency levels were found in countries as diverse as Norway (5 per cent), Latvia (4.5 per cent), Portugal (2.6 per cent) and Hungary (2 per cent) ([7], p. 31). Some of this may be because of the presence of low quality Albanian cannabis resin in the market. For countries whose cannabis comes from Morocco, the differences could be due to divergence in sampling and testing, or they could be due to lower quality or diluted products being shipped to certain markets.

The potency of sinsemilla is much higher than that of the seeded product, with a 2004 average of about 10.5 per cent in the United States (as compared with 2.5 per cent for low-grade cannabis herb)* and close to 18 per cent in the Netherlands [20] (as compared with about 6 per cent for imported cannabis) [10]. Individual samples have exhibited THC levels in excess of 30 per cent, although this is extremely rare. As will be discussed further below, sinsemilla is distinct enough in appearance and potency to be considered a separate drug product, like "hashish". There has even been discussion of scheduling sinsemilla as a "hard drug" in countries that have liberalized their cannabis policies.** Making the distinction between sinsemilla and other herbal cannabis products in the official statistics is important for public education, trend monitoring and market valuation.

While the cannabinoid profile of sinsemilla is partly determined by its genetics, sinsemilla samples tend to be very high in THC and very low in CBD ([22], p. 10). As suggested above and discussed below, this means that the difference between smoking sinsemilla and other forms of cannabis is more than just how quickly the user gets intoxicated: it may be a qualitatively different experience.

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*Data from the University of Mississippi Cannabis Potency Monitoring Project.

**For example, the Home Secretary of the United Kingdom, Charles Clarke, recently asked the Advisory Council on Misuse of Drugs to consider whether "skunk" should be excepted from the downgrading of cannabis from a class B to a class C drug. See Travis [21].

Cultivation techniques

The cannabis market today is quite different from that of just 40 years ago. First, the market definition of the drug itself has changed. After the massive growth of the Western market in the 1960s and 1970s, users' tastes have grown increasingly sophisticated. The market for high quality cannabis has expanded and many users today insist on smoking only the unfertilized buds of the female plant,* as opposed to the mixed matter that was considered standard in the past. Even low-grade cannabis today is likely to contain more flowers than during the early years of the modern cannabis boom.

Secondly, the plant has been improved. Since the early 1970s, cannabis production has been revolutionized by breeders and cultivators working in Canada, the Netherlands and the United States. Selective breeding has resulted in plants that are more potent, faster maturing, hardier and more productive.** Cultivation techniques have been refined to increase yields dramatically. Using the best plants and the best technology, growers can now harvest up to six crops a year indoors, producing far more cannabis in a smaller space than ever before. Even casual outdoor cultivation has benefited from a growing base of knowledge on how to produce the best cannabis.

In the past decade, the spread of new cannabis technology has been facilitated by the information revolution and its impact on globalization. Technical know-how is now disseminated through a large number of websites and chat groups where growers exchange experiences and tips. Seed "banks" are some of the prime sources of this information and their sales though the Internet allow growers worldwide to access the best new strains.

Technologically sophisticated operations are aptly referred to as "cannabis factories". In many ways, cultivation of cannabis in some countries is becoming more like the production of synthetic drugs than the production of other plant-based drugs. While cannabis produced in less sophisticated ways continues to maintain market share, law enforcement pressure may have the unintended side effect of driving production indoors, promoting higher potency products and increasing the share of production occurring in the consumer countries.

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*For example, one survey of regular users in New South Wales, Australia, found that 60 per cent only smoked cannabis buds and that nearly all only smoked cannabis leaf when buds were not available or when they could not afford pure bud cannabis. See Didcott and others ([23], p. 26).

**As will be discussed below, there are methodological problems in respect of time series THC-level data and it is still debated whether global THC levels have increased overall, but there is no doubt that strains available today, cultivated using cutting-edge technology, are more potent than in the past. In addition, as will be demonstrated in the following discussion, yield per unit area per year is about 16 times greater in modern indoor cultivation than in a traditional outdoor farm.

How has cannabis changed in recent years?

As market logic would dictate, the revolution in cannabis production described above was preceded by a revolution in demand. Looking at the largest consumer country, the United States, this history is clear. While cannabis has been consumed throughout the past century (especially after the wave of emigration following the Mexican Revolution of 1910), the drug-fuelled social movements of the 1960s generated an unprecedented proliferation of use. This expanding trend continued to escalate through the 1970s.

After a decline in the 1980s and early 1990s (to a low of about 22 per cent annual use among students in the twelfth grade in 1992), the drug came back into fashion in the United States in the mid-1990s and seems to have reached a plateau of about 35 per cent of students in the twelfth grade in the late 1990s and the early years of the new millennium. This means that there are some lifetime cannabis smokers in the United States who have been consuming the drug for over 40 years, as well as young initiates who continue to try it for the first time every year in large numbers. The presence of long-term users in the market may be fuelling demand for higher potency products. For example, only 3 per cent of all users in Ireland polled in 2002/2003 who had used cannabis in the previous month said they used "skunk" most frequently, rather than more mundane products, but 10 per cent of older adult users (35-64 years of age) did so [24].

The social movements of the 1960s contributed to the cannabis revolution in other ways as well. "Hippies" roaming the globe came into contact with traditional cannabis cultures and brought this knowledge back home with them. Sometimes, they also brought seeds and, working at home, they started breeding North American cannabis. In the early years, "home-grown" was hardly a selling point, as much superior product could be imported from Mexico. Law enforcement crackdowns, including the use of the herbicide "paraquat" in Mexico, however, led to a decline in import quantity and quality in the mid-1970s. While supplies from Colombia eventually filled this void, users were aware of supply vulnerability and many began serious cultivation efforts at home.

Most of the cannabis herb smoked in the 1960s would be maligned as "schwag" today, as it was seeded. In addition to seeds, it included a great deal of leaves, twigs and other material that would be regarded as waste today. Sinsemilla only entered the market some years later. This is not to say that the sinsemilla technique was recently invented. It is said to be traditional in parts of India, where "paddars" ("ganja doctors") were hired to remove male plants from cultivation areas [25]. It has also been present for some time in the Americas. In 1933 in Panama, United States military officers familiar with this practice noted that local cultivators, while aware that male plants were weaker, did not bother weeding them [26]. It would appear that sinsemilla cultivation was far less common in the Americas in the early years of the present boom and a look at early cultivation manuals shows how the

market slowly developed an understanding of the potency of sinsemilla.* Most commentators place the emergence of sinsemilla in the United States around the early to mid-1970s ([28], p. 9) and in Europe at about 1980 [29].

Law enforcement action in the second half of the 1970s to the early 1980s appears to have pushed some domestic production indoors,** and caused growers to focus on producing greater quality rather than quantity in order to evade detection. Producing sinsemilla outdoors can be difficult to do in areas of dense cultivation, because a single male can pollinate downwind females over a very wide radius.*** This reduces local illicit outdoor production to the lowest common denominator and thus sinsemilla can only be grown either in isolated areas or where there are strict cultural controls over how cannabis is grown (something that is difficult to maintain in an illicit market). Outdoor sinsemilla cultivation is impossible in an area where industrial hemp is grown or where wild hemp proliferates. The move towards more indoor cultivation has thus supported the expansion of sinsemilla production.

Weeding the males, aside from being a labour-intensive process if production is done on any scale, means pulling up half the saleable crop**** and interferes with optimal spacing of the plants (since there is no way of predicting which plants will be thinned). In addition, seeds add a lot of weight to the final product, so the price of sinsemilla must outweigh this loss in order for the market to become viable. The move towards starting with cloned plants supported sinsemilla production, as it eliminated the need for weeding males whether the crop was grown indoors or outdoors.

Cloning simply means taking a cutting from a successful mother plant, a technique frequently used in propagating houseplants. This cutting is left to develop roots and then planted. It is a genetic duplicate of its mother and can be used to generate still more cuttings. Eventually, a grower can work with entire crops of genetically identical plants. A square metre of mother plants is said to be capable of producing 100 clones a week [29].

There are several advantages to working with clones. First, the cuttings are guaranteed to be exclusively females. Second, they will be duplicates of a mother proven to be a successful producer and whose life cycle and weaknesses are known. Finally, the clone assumes the stage of the life cycle of the mother and so needs less time to reach flowering than would a similarly sized plant grown from seed.

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*The *Cannabis Underground Library: Seven Rare Classics* [27] includes seven early texts on cannabis growing from the 1970s and 1980s, which illustrate the evolution in understanding over time.

**Bergman, as cited in Jansen [30].

***Cannabis pollen has been found to comprise up to 36 per cent of the total pollen during the peak of cannabis pollination in mid- to late-August in areas where cannabis plants are common [31].

****Despite disinformation to the contrary, male plants have similar levels of THC as female plants [32].

Used in combination with the forced flowering technique described below, clones dramatically accelerate the rate of cannabis production.

How were the modern strains of the cannabis plant developed?

Until the mid-1970s, nearly all the cannabis consumed in North America was a landrace strain of the sativa variety. Landrace strains are those native to a particular geographic region and the early varieties usually contained a geographic designation, for example "Acapulco gold".

A key turning point was reached when plants gathered from different parts of the world were bred. According to the users, this specifically involved the breeding of tropical "sativa" plants and highland "indica" plants. In the user's typology, pure sativas are considered to have good psychoactive effects but are believed to be both late maturing (making them difficult to grow in northerly latitudes) and very tall (making them difficult to conceal outside and problematic to grow inside). They say it was not until seeds from Central Asia and the Middle East were introduced—seeds of plants traditionally used in making cannabis resin—that these problems were overcome. These "indica" genes were said to accelerate the life cycle, boost yields, be more cold resistant, generate a different sort of high and produce more manageably sized (and thus concealable) plants. But some argue that random cross-breeding resulted in the manifestation of some of the less desirable characteristics of "indicas" and that "serious breeders of the 1980s began to view indica with more scepticism" ([28], p. 9).

One of the beneficiaries of seed gathering by "hippies" was a semi-legendary American breeder known as the "Skunkman". The Skunkman is said to be the father of "skunk"—a smelly hybrid of three distinct and previously uncrossed cannabis genetic lines: Colombian, Mexican and Afghan. This hybrid was said to be 75 per cent "sativa" and 25 per cent "indica" and was supposedly among the first to capture the THC "high" of the "sativas" with the rapid growth cycle and yield of the "indicas" ([33], p. 154). It remains one of the cornerstone cultivars used in breeding today and high quality cannabis herb is still referred to as "skunk" in various parts of the world.

Around 1985, during the era when then President Ronald Reagan began a crackdown on illegal drugs in the United States, the Skunkman brought the best in American cannabis breeding to a location where he could experiment with his plants a little more openly: Amsterdam, the Netherlands. At the time, indoor cultivation of cannabis was just starting to take off in the Netherlands, [29, 30] so he joined up with a number of local cannabis experts and the "breeding revolution" in Amsterdam began [33]. Today, there are many cannabis seed companies in the Netherlands, with a growing number of rivals in Canada and other countries around the world.

The creation of premium strains of cannabis has changed the nature of consumer demand. Today's cannabis is clearly graded, with large price differences between "schwag" and name-brand product. Today's premium buyers can read about how their selected strains fared in various international competitions and "harvest festivals" on the Internet or in seed bank promotional materials. They can also learn about the lineage of the plant and perhaps its THC levels and can hear subjective accounts of its taste and effects. This has introduced pretensions to connoisseurship among some cannabis users, with product descriptions involving terminology more commonly associated with wine tasting.

How is the growing cycle accelerated?

In addition to selective breeding for fast maturity, the rate at which cannabis plants come to flower can be increased by manipulation of the light cycle. Outdoors, the success of cannabis plants grown for drug purposes is highly dependent on latitude. This is because most types of cannabis plant only flower when the days grow shorter. At northerly latitudes, this happens before the plant has had a chance to develop fully, or coincides with lethal frosts. This makes outdoor cultivation of drug-quality cannabis plants in much of Europe, for example, very difficult, especially for plants that evolved at lower latitudes. Indoors, these restrictions clearly do not apply and, in addition, the photoperiod (the amount of light received by the plants during the day) can be manipulated to "force" flowering whenever it suits the grower. During the vegetative phase, when the plant is maturing, it is generally exposed to either continuous light, or 18 hours of "daylight" to six hours of darkness.* When the grower is ready for the plants to flower, they are switched to a 12/12 day/night cycle and this is sufficient to induce flowering in most varieties.

In the wild, cannabis plants would normally have several months of vegetative growth before the days grow shorter, but growers may have a different agenda. Some vegetative growth is necessary, obviously, for the plant to produce good flowers, but indoor cultivators often force flowering with only a few weeks of growth, particularly when working from clones.

Forced flowering results in smaller yields per plant than if each plant had been allowed to mature further, but this is more than offset by the faster overall production time and in the greater number of small plants that can be fitted into a given growth area. Whereas traditional outdoor growers are limited to one (in higher latitudes) or perhaps two (nearer the equator) harvests a year, new technology growers can stagger production to produce almost continual harvests. The turnaround time from clone to harvest is generally in the order of 8-10 weeks, allowing between 4 and 6 harvests off the same square metre of floor space. The best-known

*The 18/6 photoperiod appears to be returning to vogue because, while continual light can increase yields, this advantage is offset by the expense of additional lighting.

example of this is the "Sea of Green" technique from the Netherlands, which is discussed below.

Clearly, high-technology indoor cultivation is only one cultivation strategy and it is only available to relatively well-resourced growers, largely in developed countries. Its advantages, including the fact that the drug can be produced in the most profitable consumer countries, might lead one to believe that it will eventually supplant more traditional approaches. But the cannabis market, like the alcohol and cigarette markets, addresses a wide range of consumer tastes and budgets, so it is likely that cheap, lower-potency cannabis will continue to find buyers. Consumer trends are also influenced by product availability, so law enforcement plays a role in the types of cannabis consumed.

What are the main cultivation strategies today?

At present, then, we have a global market with diverse cannabis products on offer. These different cannabis products originate from different cultivation sources and these sources operate differently. Understanding the dynamics behind cannabis production means understanding these different cultivation strategies. While any typology of such a widespread phenomenon as cannabis growing is doomed to overgeneralization, the following are proposed as working categories:

- Feral and semi-cultivated. Some cannabis is gathered from the wild, or seeds are quickly sown and results harvested with very little work invested in between.
- Traditional field cultivation. While this category covers a wide range of practices, it is intended to include all those who farm cannabis as a full-time job, at least seasonally.
- Modern outdoor cultivation. This is field growing utilizing the latest know-how, wherever performed, including "guerrilla" cultivation, that is, when cannabis is grown on land not owned by the cultivator.
- Modern indoor cultivation. Both in soil and hydroponic cultivation, this is the height of high-technology cannabis production.

Each of these production strategies will be discussed in turn.

Feral and semi-cultivated cannabis plant

Since the cannabis plant grows well on its own in some parts of the world, "cultivators" may do little more than drop seeds and harvest whatever comes up, or collect the produce of feral plants. This allows a cash crop to be harvested with little investment, a practice that is very difficult to deter with crop-directed efforts. Indeed, enforcement pressures may make these loose markets more competitive, forcing cultivators to become more efficient. A similar strategy may be employed by

informal growers in developed countries, who plant small patches in vacant or public land on the off chance that they will be able to harvest something with very little risk or effort.

The best known expanses of feral cannabis are in Central Asia, a region that could probably satisfy world cannabis demand if the drug was widely cultivated. But in many parts of the world, including much of Africa, subsistence farmers may keep a small patch of cannabis plants as a source of income for the family. In some instances, these outputs are consolidated by wholesalers for transport to urban areas or even export.

Traditional field cultivation

Table 1 shows the yields of outdoor cannabis cultivation in various parts of the world. Irrigated crops in Morocco provide one example of traditional field production. Cannabis has been grown for some time in Morocco for use in "kif", the local mixture of cannabis and tobacco. Only since the 1960s has cannabis been cultivated to supply the cannabis resin market of Europe, with most of the production occurring in the traditional cannabis-producing region of Ketama, an area where little else grows well.

Cannabis in the Ketama region of Morocco is planted extremely densely in irrigated areas, with 30 or more plants per square metre. This creates a large number of small, unbranched plants, each producing around 4 grams of cannabis resin, which is usually later processed into about 0.04 grams of "hashish". Non-irrigated plots in Morocco perform no better than semi-cultivated areas, such as in Kazakhstan.

Plants in other traditional areas, such as Mexico and South Africa, are not planted as densely and crops are generally smaller and more dispersed, as both countries have active eradication programmes and evasion of law enforcement is an issue.

Table 1. International outdoor yields

Country	*Plant type and cultivation style*	*Yield (grams per square metre)*
Kyrgyzstan (1999)	Outdoor feral	47
Kazakhstan (1999)	Outdoor feral	74
Morocco	Outdoor rain fed	76
Morocco	Outdoor irrigated	127
Mexico	Outdoor mixed; multi-season	180
South Africa	Outdoor mixed	116

Sources: UNODC, except for Mexico, for which information was obtained from the United States Drug Enforcement Administration.

Traditionally, field-grown cannabis is rarely sinsemilla for one obvious reason: it is almost impossible to ensure that male plants do not fertilize crops in areas of intense cultivation. The development of the sinsemilla technique in India may have been the result of the isolated and mountainous areas where the drug was grown. In modern Morocco, in contrast, the male pollen is so thick that clouds of it are said to be visible in Southern Europe [34].

Modern indoor cultivation

Aside from input costs, which, depending on the size of the operation can be substantial, there appears to be little reason for the modern cannabis cultivator to deal with the unpredictability of nature. Climatic problems, plant and animal predators, insect pests and fungi, the non-productive (from a photosynthetic point of view) hours lost to the night and certain aspects of the security risk can be minimized by operating entirely indoors. In addition, growing conditions can be enhanced to a level that cannot be achieved under the best outdoor conditions. For example, carbon dioxide levels can be boosted to a level last encountered on earth in the early years of the planet, but which plant life still "remembers" how to utilize.*

Indoor growing is done on a massive scale both by organized criminal groups and by many cannabis consumers themselves in developed countries. For example, a survey of regular cannabis users in the United Kingdom found that most of the respondents (63 per cent) had tried growing their own cannabis plants. Of these, 34 per cent grew plants from pedigreed seeds exclusively and 43 per cent used pedigreed seeds as at least one of their sources of growing stock. Another 13 per cent used cuttings exclusively and 20 per cent used cuttings as at least one of their sources of growing stock. Only 18 per cent grew outdoors exclusively, compared with 54 per cent who grew indoors exclusively. Just under 10 per cent used hydroponics as one of their cultivation techniques ([35], p. 17).

Of course, not all growers make use of the full range of technologies available to them and some indoor cultivation operations have little to recommend them over the windowsill cultivation of earlier decades. Depending on the segment of the market for which they are growing, some growers may make use of suboptimal technologies in order to keep overheads low. The size of these operations also varies tremendously, from self-contained single-plant units, to closet or bedroom cultivation, to full-scale warehouse-sized operations. In Canada, entire railway cars and shipping containers have been kitted out for indoor production and buried to evade detection. Some cultivation combines indoor and outdoor cultivation at different stages of the life cycle, including the use of greenhouses, thus cutting down on input costs.

*Discussions with cultivators in Amsterdam, the Netherlands, suggest that use of CO^2, while once in vogue, is presently in decline. In order to retain CO^2, grow rooms must be sealed. This produces problems with heat and humidity and additional air conditioners and dehumidifiers are needed. In the end, the increased yields do not seem to justify the expense. Most large-scale growers today emphasize air circulation, rather than adding CO^2.

The cannabis plant requires different conditions, including different nutrient and light conditions, at the various stages of its life cycle. By demarcating separate areas for each stage, crops can be cultivated simultaneously at each point in the growth process. This allows staggered cultivation and, under the Sea of Green method, a harvest every two weeks. The Sea of Green technique involves cultivating a large amount of plants in a given area for a short period of time before flowering. This results in a smaller yield per plant but more plants in a harvest and shorter cultivation periods, which allows for more harvests per year. Different parts of the growing area are used for plants in different stages of their life cycle, staggering production.

The first stage could be loosely termed "germination" and can include sprouting and planting of seeds or the rooting of new cuttings (clones). Here, continuous light is desirable, with no break or night-time cycles, as cannabis grows best when it is allowed to photosynthesize without interruption. Metal halide bulbs are preferred for this stage, but cheaper lights (using fluorescent bulbs) are often substituted. Plants can be placed closely, at four plants per square foot (about 36 per square metre). Germination of seeds or cuttings to viability generally takes two to three weeks.

The second stage is vegetative growth, in which the plant achieves the size and maturity it needs to allow it to flower successfully. Here again, the plants are exposed to continuous light. Plants require more space at this stage, but can still be spaced at one plant per square foot (about nine per square metre). It is in the vegetative stage that methods like Sea of Green cut down on production time—Sea of Green plants may be vegetated for as little as two weeks. Of course, a longer vegetative period has a positive effect on yield per plant, but plants can grow quite large and space considerations may be as much of an issue as individual plant yield.

As the first and second stages require much the same conditions, they may be combined in the same location with the seedlings occupying a shelf above the vegetative growing area. Or, if the vegetative growing area will also be used for flowering, then a curtain is required to shield the mature plants from the light needed by the seedlings.

The flowering stage requires manipulation of the light cycle, so plants in this stage cannot be housed in the same lighting area with seedlings and vegetative plants. High-pressure sodium lights are preferred for this stage, which are also energy efficient in terms of light output. Flowering takes some time and this is often the cultivation time quoted by seed banks: usually about one and a half to three months.

The final stage is harvesting and curing. This takes at least two weeks. The total process, from seeds to sale, can take about 16-18 weeks.

In order to avoid detection through excessive electricity bills, many indoor growers around the world steal their electricity. For example, in a Canadian police

operation conducted in January 2002 ("Operation Green Sweep I") electrical theft was found in 99 of 189 indoor cultivation operations searched [36].

Indoor operations can be massive. In Canada, every year two or three indoor plots with between 10,000 and 20,000 plants are found [36]. At 100 grams per plant and four harvests a year, such an operation can produce up to eight tons of cannabis annually. In 1999, Canadian authorities unearthed eight railway cars that had been buried to create an underground cannabis factory. On certain streets, half the houses have been found to grow cannabis plant [36].

Modern outdoor cultivation

While indoor cultivation seems to be gaining an increasing share of overall cultivation, there has also been a reaction in the opposite direction, perhaps due to enforcement efforts that include asset forfeiture. Since the mid-1980s in the United States, "guerrilla" cultivation, in which cannabis plants are grown on land not owned by the cultivator, has constituted an increasing share of total outdoor domestic cultivation. This can include private property, but has increasingly included public lands, such as the parks in the states of California and Kentucky. In Daniel Boone National Park in Kentucky alone, over 200,000 plants were eradicated in 2003, and more than twice that many are destroyed in the parks of California each year [37]. Many of the Californian operations are controlled by Mexican organized criminal groups [37].

Cultivation on public lands is not limited to the United States, but has been found in Canada and Colombia and in other parts of the world. While some "guerrilla" growers select sites they can access from their homes, some spend the entire growing season camped out by their plot for security reasons.

Yield

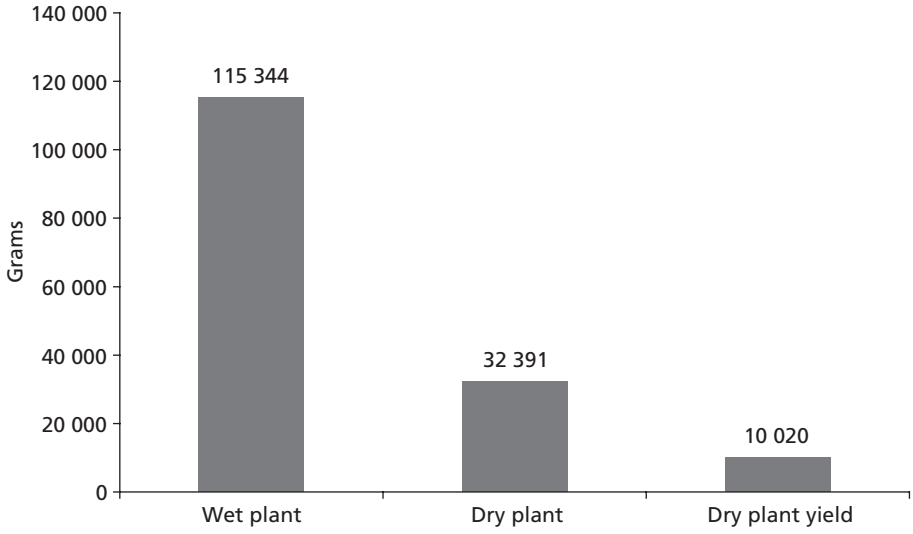
Coming to grips with the scale and variety of cannabis production operations around the globe requires some discussion of yield. Given the variability of the plant and the range of cultivation techniques employed, coming up with precise figures such as yield to plot area ratios can be difficult. Poorly cultivated or feral plants may produce small buds, while those with the benefit of the best genetics and the latest growing technology can produce massive ones.

Clearly, from a consumption perspective, plant yields are tied to the type of drug product desired. Low-grade herbal cannabis contains seeds and large leaves, whereas sinsemilla consists entirely of the buds and small leaves surrounding them. On the other hand, sinsemilla is often grown indoors using forced flowering techniques, which can result in an exaggerated flower to plant ratio. According to the United States Drug Enforcement Administration, 34 per cent of a non-sinsemilla cannabis plant contains useable material (the leaf and bud components) and 58 per

cent of a sinsemilla plant contains useable material (as it contains no seeds) [38]. It would appear that no sinsemilla plants were examined for that determination, however, and that the seeds were simply removed from field-grown plants to create different ratios. This does not mean that sinsemilla plants produce more saleable crop than non-sinsemilla plants, because the seeds (which constitute 23 per cent of the weight of the entire plant) ([39], p. 5) are included in the commercial product. "Useable" does not mean "saleable" in this context: low-grade cannabis is sold with seeds and other unusable plant matter.

The United States Drug Enforcement Administration reports that a cannabis plant loses two thirds of its weight in water during the drying process and the wet plant to dry product ratio is said to be 14 per cent ([39], p. 4). With regard to the latter assertion, at least one cultivation expert agrees: "[Dried] [l]eaves and flowers constitute from ten to twenty per cent of the harvested [wet] weight of the [outdoor] crop" ([16], p. 52).

Figure I. Ratio of wet plant to dry plant to yield



Source: Data supplied by the Office of Medical Cannabis, the Netherlands.

Empirically based figures for sinsemilla can be drawn from the medical cannabis industry, where a scientific approach is taken in order to produce maximal yields of good potency under controlled indoor conditions with minimized input costs. The Office of Medical Cannabis (Bureau voor Medicinale Cannabis) in the Netherlands is one such facility. A recent harvest of 115,344 grams of wet plant was dried to 10 per cent moisture content to produce about 32,391 grams of dried plant, a ratio of about 28 per cent, or between one quarter and one third. From this, a net yield of 10,020 grams was achieved after the bulk quantity was cleaned of twigs, stems and seeds (a process known as "manicuring"), with 21,219 grams of waste and

1,048 grams of spillage. This would suggest that saleable material represents about 30 per cent of dried plant weight and about 8 per cent-10 per cent of wet plant weight. This is easily summarized in the ratio 10-3-1 and is on the low end of the figures cited above [40]. One analyst notes: "About 75 per cent of the fresh weight is moisture that is lost in the drying process. Almost half of the dried plant matter is stem; only about a quarter (18 per cent-28 per cent) remains after the herb is cured and manicured into medical-grade bud" ([41], p. 3). This would correspond to a ratio of 10-2.5-0.7, a slightly lower yield ratio.

Given the expertise of the medical producers, these figures should thus be regarded as optimal (high end) sinsemilla yields. In contrast, street product will usually contain more plant bulk; this is obvious in the case of non-sinsemilla products, because seeds are the densest part of the plant. Medical cannabis producers, concerned about fungal and mould growth, also tend to dry their product more than illicit producers, typically to about 10 per cent moisture content. Street samples generally contain more moisture (giving more bulk for sales purposes), ranging from 12 per cent to 16 per cent, but the impact on total bulk is minimal: 100 kilograms dried to 7 per cent moisture content yields about 27.5 kilograms dried plant, whereas the same material dried to 15 per cent yields about 29.55 kilograms ([41], p. 3). In the end, the 10-3-1 ratio (wet weight of plant—dry weight of plant—dry weight of product) is probably a good average of reasonable values for sinsemilla.

For low-grade cannabis, most of the seeds (and perhaps more stems and leaves) are included. One recipient of medical grade cannabis in the United States reported cleaning even this product to the extent that 25 per cent of the material was lost ([42], p. 20). Seeds make up 23 per cent of the dry weight of the entire plant and stems 43 per cent ([39], p. 5). Most of the stem weight is not included in the street product, but most of the seeds are. Even if all of the stem were removed, seeds would still make up about 40 per cent of the dry product by weight. Allowing for some stem, it can be concluded that about half of the weight of low-grade cannabis is unusable. The ratio between leaf, bud and stem in sinsemilla and non-sinsemilla plants is about the same, so the product outputs (though not the useable amounts) should be about the same.

As discussed above, some cultivation styles emphasize dense plantings, while others focus on a smaller number of highly productive plants. It has been argued that, for the average home garden plot, cultivating a large number of small plants or a small number of large plants results in roughly the same yield ([43], p. 5). Many indoor growers discuss their yields in terms of wattage: one pound for each 600-watt high-pressure sodium bulb being a common rule of thumb. But this is not much help in comparing indoor and outdoor yields. The following discussion concludes that yields should be expressed per unit area (square metre or hectare) rather than per plant.

For example, the United States Drug Enforcement Administration, in cooperation with the National Center for Natural Products Research at the School of

Pharmacy of the University of Mississippi, undertook a study of outdoor cannabis yields in 1990 and 1991 using different (mainly "sativa") seed stocks and planting at different densities [39]. Plants grown at "dense" spacings (between 0.91 and 1.28 metres between plants) produced between 215 and 274 grams per plant, while plants given more room (up to 2.74 metres between plants) produced higher yields, including one plant that produced 2.3 kilograms of cannabis. The study concluded that "a very significant factor affecting yield was planting density". Indeed, squaring the space per plant resulted in per plant yields increasing as much as fourfold. However, this increase does not represent the most efficient use of land area, as the yield per unit area, calculated from the various plantings by the United States Drug Enforcement Administration, shows (see table 2). On average, the densest plantings were more than twice as productive per unit area as the most widely spaced.

Table 2. Cannabis yields at various planting densities

Density (number of plants per square foot)	*Yield (grams)*	*Yield per square foot (grams)*
9	222	25
9	274	30
9	215	24
18	233	13
36	860	24
72	1 015	14
81	777	10
81	640	8
81	936	12
Average yield per square foot for densest plantings		26
Average yield per square foot for most widely spaced plantings		10
Average yield per square foot		14
Average yield per square metre		150

Source: United States Drug Enforcement Administration, 1992.

While individual plants may be spaced three metres apart in some "guerrilla" cultivations, most clandestine growers do not have the luxury of such space* and the size of the resulting plants (some over three metres tall in the University of Mississippi study) would make them difficult to conceal. Furthermore, as table 2 shows, low planting densities quickly reach the point of diminishing returns for growers. All this suggests that using average, low-density, per-plant yields as a rule of thumb is likely to produce inflated estimates and that laws that seek to regulate the number of plants grown, rather than the land area under cultivation, may be misguided.

In practice, traditional growers use much greater planting densities. In Morocco, to cite an extreme case, about 30 plants are cultivated per square metre in irrigated areas, not one [8]. Similar densities are used in Sea of Green indoor operations, where

*For example, the National Organization for the Reform of Marijuana Laws in the United States argues, ". . . most US marijuana is grown densely in gardens of nine square feet or less" [44].

per-plant yields are in the neighbourhood of 10 grams apiece, [45] far from the "pound a plant" rule formerly used by the United States Drug Enforcement Administration.*

In addition to plant density, cultivation style is clearly relevant in determining yield. Dense, indoor, high-technology plantings are more productive than dense, outdoor, traditional ones. Looking at some 35 yield estimates given by a wide range of different sources, a degree of consensus is discernable on the yields per square metre of the various cultivation strategies [47]. Table 3 shows figures derived from a wide range of sources of varying reliability. Still, a considerable amount of consistency can be discerned, with the exception of a few outliers.

Looking first at the outdoor situation, yields vary from as low as 47 grams per square metre for feral or semi-cultivated varieties grown without irrigation in difficult climates, to as high as 500 grams per square metre in well-tended gardens. A modal value of around 75 grams per square metre could be hypothesized for low-end operations, with quite a bit more variation on the upper end of the scale. An average of about 200 grams per square metre outdoors has been said to be consistent with figures gathered in court cases in the United States ([41], p. 2). Throughout the present review, a figure of 100 grams per square metre (or one ton per hectare) will be used for outdoor crops when cultivation style is unspecified.

All this highlights that cannabis is an extremely productive drug crop. One square metre of outdoor cultivation space is sufficient to supply a user with one 0.27 gram cannabis cigarette a day (a reasonable size for a European user) for a year. A hectare could produce enough cannabis to supply 10,000 light daily users. If all 162 million annual users smoked this amount (which is clearly not the case), global demand could be met by a production area of 162 square kilometres (about 100 square miles), an area about the size of Liechtenstein. Of course, this area is presently spread all over the Earth.

There is one important complicating factor, however. In some parts of the world, multiple cannabis seasons are claimed and there is considerable confusion about this matter.** Yields in off-seasons may be considerably less. Weather is also an extremely important factor for rain-fed crops.

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*The Drug Enforcement Administration's figure also conflicts with the 100 grams a plant later affirmed by the United States Sentencing Commission as appropriate when looking at mixed gender crops. "The one plant = 100 grams of marihuana equivalency used by the Commission for offences involving fewer than 50 marihuana plants was selected as a reasonable approximation of the actual yield of marihuana plants taking into account *(a)* studies reporting the actual yield of marihuana plants . . . ; *(b)* that all plants regardless of size are counted for guideline purposes while, in actuality, not all plants will produce useable marihuana . . . ; and *(c)* that male plants, which are counted for guideline purposes, are frequently culled because they do not produce the same quality of marihuana as do female plants". *Federal Register* 60 (10 May 1995): 25078, as quoted by the National Organization for the Reform of Marijuana Laws [44]. This figure was extended to all crops, including those involving more than 50 plants. See also the 1995 annual report of the United States Sentencing Commission ([46], p. 148).

**In Lesotho, for example, it has traditionally been said that there are two harvests, but the first one appears to be simply the culling of male plants to make the inferior *majat* grade cannabis herb, used primarily in combination with methaqualone. More recent reports suggest three harvests are made, with substantial variability in yield between each.

Table 3. Cannabis yields as reported by various sources

Source	*Plant and cultivation style*	*Output per plant (grams)*	*Plants per square metre*	*Weight per square metre (grams)*	*Seasons per year*	*Output per square metre per year (grams)*	*Cost per square metre per year at $400 per ounce (US dollars)*
United States Drug Enforcement	Sinsemilla outdoor	560	. .	. .	. .	. .	. .
UNODC (1999) Kyrgyzstan	Outdoor feral	. .	. .	47	1	47	671
UNODC (1999) Kazakhstan	Outdoor feral	. .	. .	74	1	74	1 056
UNODC Morocco	Outdoor rain-fed	76	1	76	2	152	2 171
UNODC Morocco	Outdoor irrigated	4	30	127	2	254	3 629
Government of Mexico (as cited by the United States Department of Homeland Security)	. .	. .	. .	. .	. .	180	. .
Government of Trinidad and Tobago (UNODC annual reports questionnaire)	Outdoor	100	. .	. .	. .	. .	. .
Government of Colombia (UNODC 2004 annual reports questionnaire)	. .	. .	. .	100	1	. .	. .
Government of South Africa	. .	. .	. .	. .	. .	212	. .
R. Clarke (1998) ([47], p. 189)	Outdoor	. .	. .	100-200 (flowers only 15-30)	. .	. .	. .
M. Starks (1990) [48]	Unspecified outdoor	227-454	Less than 4 ft apart (0.66)	152-304	1	152-304	2 171-4 344
J. Gettman and P. Armentano (1998) [44], citing Urbanek	Outdoor	412	. .	. .	. .	. .	. .
British Columbia Compassion Club Society	Outdoor	250	. .	. .	. .	. .	. .

Table 3 *(continued)*

Source	*Plant and cultivation style*	*Output per plant (grams)*	*Plants per square metre*	*Weight per square metre (grams)*	*Seasons per year*	*Output per square metre per year (grams)*	*Cost per square metre per year at $400 per ounce (US dollars)*
United States Drug Enforcement Administration [38]	Non-sinsemilla outdoor	336 (0.75 lb)	. .	. .	. .	. .	. .
United States Drug Enforcement Administration [38]	Sinsemilla outdoor	560 (1.25 lb)	. .	. .	. .	. .	. .
M. Thomas (2002) [45]	Outdoor	About 500 (1.1 lb)	1	500	1	500	6 400
B. Drake (1986) [16]	Outdoor	. .	1-2 (60-80 cm apart)	. .	. .	. .	. .
W. Scholten [40]	Indoor scientific	100	4-6	400-600	4	1 600-2 400	23 000-34 000
British Columbia Compassion Club Society	Indoor	. .	. .	180-700	. .	. .	. .
R. Clarke (2002) ([47] p. 9)	Indica/sativa 1 m indoor	100	Assume 4	400	3-4	1 200-1 600	17.000-23 000
R. Clarke (1998) ([47], p. 189)	Indoor (“Skunk #1”)	. .	. .	150-300 (flowers only)	3	. .	. .
M. Thomas (2002) [45]	Indoor Sea of Green	9-14 (0.5 oz)	36 (2 per sq ft)	324-504	4	1 296-2 016	18 514-28 800
M. Thomas (2002) [45]	Indoor Screen of Green	84 (3 oz)	9	756	3	2 268	32 400
G. Green (2003) [49]	Indoor Screen of Green	56 (2 oz)	9	504	3	1 512	21 600
J. Gettman and P. Armentano (1998) [44]	All	280	. .	. .	. .	. .	. .

United States Sentencing Commission [46]	Unspecified	100 (37.5-412)	. .	. .	. .	. .	. .
Onlinepot.org website	Unspecified indoor	170	16 plants per 1 000 watts, 2 ft plants: assume 4	680	4-52 (with CO^2)	720-3 400	39 000-49 000
A. C. M. Jansen (2002) [30]	. .	. .	. .	. .	. .	1 000	14 285
Overgrow.com website	Indoor soil	57	. .	. .	4	. .	. .
Overgrow.com website	Indoor hydroponics	99	. .	. .	4	. .	. .
J. Gettman and P. Armentano (1998) [44], citing Urbanek.	Indoor	177	. .	. .	. .	. .	. .
High Times.com website, "Max Yields"	Indoor		. .	126 (0.5 oz sq ft)	. .	. .	. .
High Times.com website, "Max Yields"	Indoor	. .	. .	1 008 (0.25 lb sq ft)	. .	. .	. .
Nirvana Seeds [50]	Indoor Sea of Green	. .	9	. .	3	. .	. .
J. Cervantes (1993) [51]	Indoor hydroponics	7	4	28	4	112	1 600
Cannabis-seedbank.nl website	Outdoor	10-200 g per plant	40 x 10 g	300-600	. .	. .	. .
Cannabis-seedbank.nl website	Greenhouse	. .	1-10	50-250	2-3	100-750	. .
Cannabis-seedbank.nl website	Indoors	. .	. .	300-600	3-6	. .	. .

Note: Two dots (. .) indicate that data are not available or are not separately reported.

Indoors, yields vary from a low of just over 300 grams per square metre to a high of just under 800 grams per square metre. These yields are produced by a number of different strategies, with considerable debate as to which is the most productive. Individual plants can be freakishly productive and this can be perpetuated, to some extent, by cloning. Overall, an average of about 500 grams per square metre seems to be confirmed by several sources. Of course, the real productivity of indoor plots is determined by the number of harvests that can be produced in a year. As discussed above, a four-stage cultivation system allows three to six harvests per unit of floor area per year. Thus, indoor crops are between 15 and 30 times as productive per square metre of cultivation space as are outdoor crops.

Why make cannabis resin?

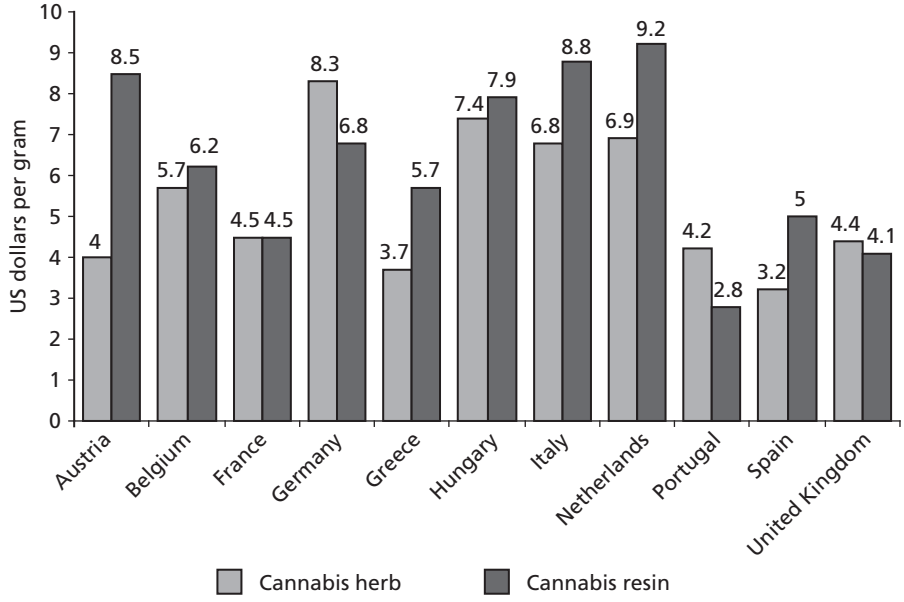
The production of cannabis resin requires considerable additional processing of a plant that is, essentially, ready to use. Yields are only about 4 per cent of herbal yields and prices per gram are nowhere near 25 times higher. Indeed, while cannabis resin is more potent than the herbal product from which it is made, it is not 25 times more potent; thus, making cannabis resin results in a net loss of consumable THC. A pertinent question is: why make cannabis resin?

There are several possible historical explanations for why production of cannabis resin emerged over the years and has retained some popularity, most of which relate to the commercialization of the plant. Cannabis resin is much less bulky than cannabis herb, lacks the overwhelming odour of the herbal plant and is highly malleable. This makes it easier to transport. This may be one reason why cannabis resin is popular where consumer markets are in different countries from production sites, as is the case in Europe, but is less common in areas where cannabis is grown locally, such as North America.

Sieved cannabis resin also stores better than herbal cannabis [52]. While the outside layer of a piece of cannabis resin loses potency through exposure to light and air, the inside can retain its quality over extended periods, especially if stored carefully [53]. Storage is particularly important in the arid areas where much cannabis resin has traditionally been produced, as it ensures a supply even during periods of drought.

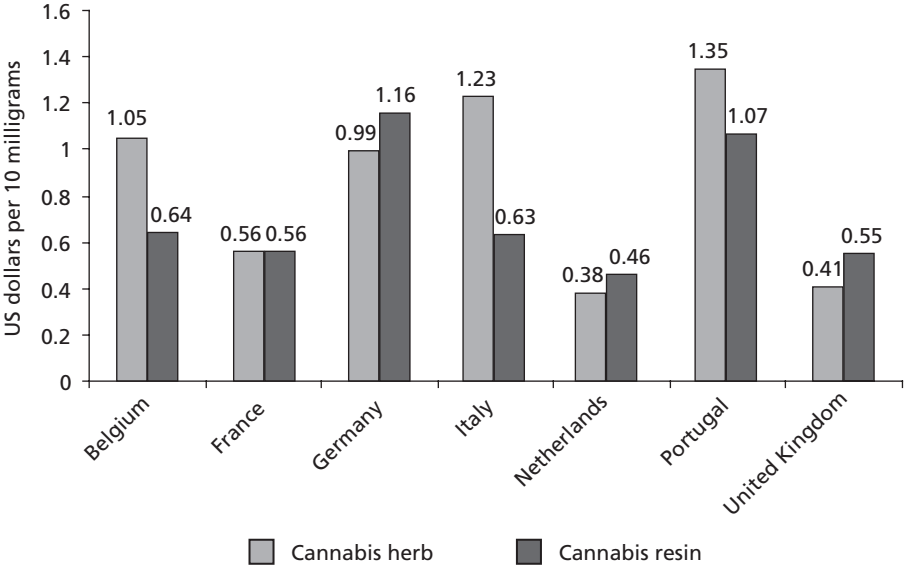
But these factors alone cannot override the fact that, per unit of land and per worker hour, cannabis resin is a lot less profitable than cannabis herb. In some European countries, cannabis resin is more expensive than cannabis herb, but this is not always the case (see figure II). In Belgium, for example, the typical cost of cannabis herb and cannabis resin are nearly the same: $5.70 a gram for cannabis herb and only $6.20 a gram for cannabis resin. Of course, this is a reflection of the fact that most of the cannabis resin in Belgium comes from Morocco and most of the cannabis herb is produced locally or in the Netherlands, with high input costs.

Figure II. Relative prices of cannabis herb and cannabis resin in markets in Europe



Source: United Nations Office on Drugs and Crime, annual reports questionnaire.

Figure III. International price per milligram of tetrahydrocannabinol

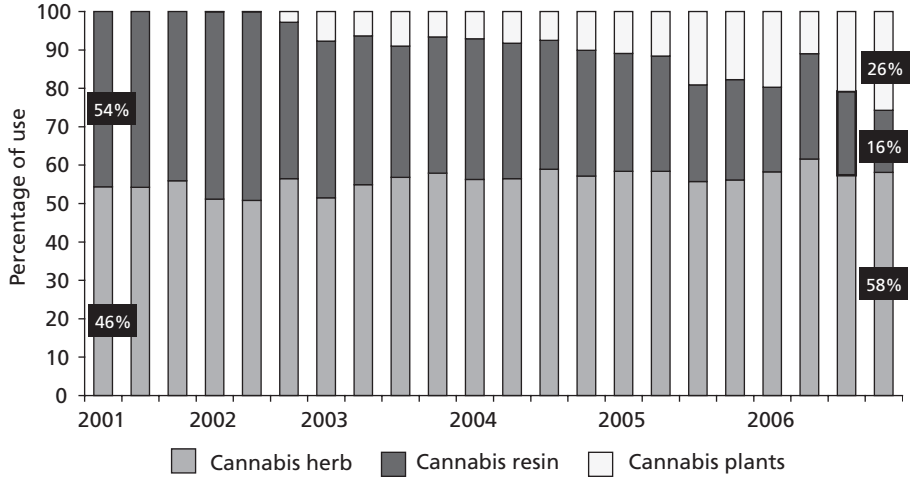


Source: European Monitoring Centre on Drugs and Drug Addiction.

Still, from the perspective of the producer of cannabis resin in Morocco, the amount of land area dedicated to producing one gram of "hashish" is at least 25 times greater than that needed to produce one gram of cannabis herb outdoors, and the increase in potency is not commensurably large: typically, herbal cannabis from Morocco contains about 2 per cent THC and cannabis resin from Morocco contains about 8 per cent THC, when tested on site [54]. If, as EMCDDA has suggested, prices vary linearly with potency in Europe [10], this represents a lot of additional work for relatively little additional profit.

Of course, the price per unit of THC is not always consistent, either within countries or between them. Figure III shows the price in United States dollars per 10 milligrams (mg) of THC in cannabis herb and cannabis resin for various markets in Europe. In Belgium, cannabis resin remains a good deal from the perspective of psychoactive content: potencies are 6 per cent for cannabis herb and 10 per cent for cannabis resin, while the price is essentially the same. In markets where herbal cannabis is a cheaper source of THC (Germany, the Netherlands and the United Kingdom) there are indications that resin is losing market share, being displaced by domestic or imported sinsemilla. For example, in the United Kingdom the share of all cannabis seizures that were resin seizures has declined significantly, from 46 per cent in the first quarter of 2001 to only 16 per cent in the second quarter of 2006. The greater share of herbal cannabis seizures includes a growing number of whole plant seizures, indicating increasing local production. If domestic production expands in other European countries, Moroccan suppliers may face the loss of a major export market.

Figure IV Breakdown of cannabis seizures in the United Kingdom by quarter, 2001-2006



Source: United Kingdom, Forensic Science Service [55].

In the end, the persistence of use of cannabis resin in Europe may be related to the facts of the local market. The cannabis that is grown in Morocco is of a low quality and therefore not competitive as a herbal product. Europeans consume cannabis with tobacco and cannabis resin is well suited to that combination. Moreover, Europe has a long-standing tradition of consumption of cannabis resin and such traditions die hard. As a result, the suppliers in Morocco are bound to continue to produce cannabis resin, despite its lower profitability.

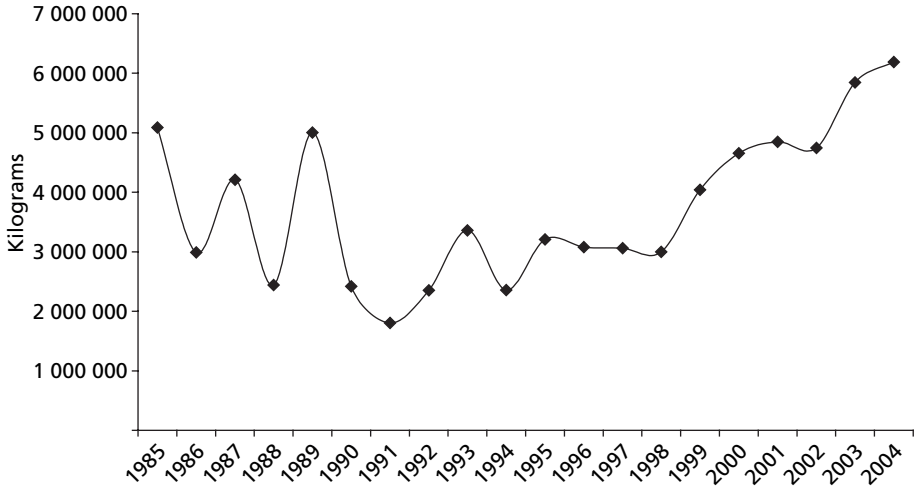
Supply-side global estimates

There are two primary ways to estimate the amount of cannabis produced and consumed in the world based on supply-side information:

- Total global reported seizures and eradication figures can be multiplied by an estimated rate of interdiction.
- An estimate of the total number of hectares under cultivation can be multiplied by an estimate of yield per hectare.

Both approaches have specific problems. Interdiction multipliers are most appropriate with drugs that have clear production sites and transport corridors and that face steady enforcement pressures. Cannabis has none of these characteristics. Global cannabis seizures show high rates of variability with little connection to what is known about global use patterns. While the trend has been upwards since 1998, consistent with the expanding cannabis market indicated by other data

Figure V. Global cannabis herb seizures, 1985-2004



Source: United Nations Office on Drugs and Crime, Database for Estimates and Long-term Trend Analysis (DELTA).

sources, seizures more than doubled between 1998 and 2004 and there is no indication that global use levels doubled during that time. It is far more likely that the rate of interdiction has increased dramatically, but this variability itself calls into question the validity of any proposed multiplier.

Furthermore, this aggregated trend masks tremendous local variability. It is not unusual for developed countries, where interdiction pressures should be fairly consistent, to experience year-on-year variations in annual cannabis seizures of 100 per cent or more. It is unlikely that cannabis production or consumption varies commensurably.

On the other hand, per hectare estimates suffer from the following deficiencies:

- There is no direct way to determine the number of hectares under cultivation and, as has been demonstrated above, crop yields would have to be tied to the cultivation technique used.
- Outdoor per-hectare productivity would be subject to the impact of local weather patterns (especially precipitation for rain-fed crops) and pest problems.
- Areas under cultivation are likely to vary substantially in places where active eradication programmes are in effect.

Conducting an empirical survey of global cannabis production would be nigh on impossible. Cannabis can be grown indoors or outdoors, in small plots or on large plantations and in most inhabited areas of the world. Over the period 1994-2004, 82 countries provided UNODC with cannabis production estimates. In comparison, only six provided estimates for coca leaf production. But the fact that a country did not provide an estimate does not mean that no cultivation exists, as some countries simply lack the capacity to come up with accurate estimates. Fortunately, there are other ways of identifying countries where cannabis is produced.

Member States were also asked to identify the national source of the cannabis consumed in their country. On that basis, a second list of 142 producer countries can be identified. A third list of producer countries can be generated by singling out those countries which report the seizure of whole cannabis plants. It is extremely inefficient to transport whole plants internationally, as only certain parts are useable as a drug. Thus, when a whole plant is seized, it is very likely that it was locally grown. Seizures of whole cannabis plants were reported in 141 countries during the period 1994-2004.

Combining these three lists results in the identification of some 176 countries and territories where cannabis is produced, out of 195 Member States reporting to UNODC (representing a response rate of 90 per cent).

Thus, conducting a comprehensive empirical survey would require observation in at least 176 countries and territories around the world. This is clearly infeasible. Even with a sampling approach, the costs of such an undertaking would be prohibitive.

The UNODC annual reports questionnaire* asks Member States to estimate the number of hectares under cannabis cultivation in their respective countries, but most respondents do not fill out this section. In fairness, most States would have little knowledge of how to make such an estimate. Given that most consumption is domestic and many societies do not regard cannabis as particularly problematic, most would have little incentive to invest much time in making such a calculation.

Table 4. Cannabis production estimates for major countries of production, 2003

Country	*Area under cultivation (hectares)*	*Area eradicated (hectares)*	*Estimated production in herbal equivalent[a] (tons)*	*Total seizures in herbal equivalent[a] (tons)[b]*
Morocco	134 000	. .	98 000	21 000[c]
Afghanistan	52 000	. .	(50 000)	6 432[d]
Mexico	29 500	22 000	10 400	2 160
Paraguay	5 500	753[e]	(15 000)	257[f]
Colombia	5 000	—	4 000	134
United States	(4 500)	365[g]	4 455	1 224
Total	**231 000**	**23 118**	**181 885**	**31 207**

Notes:

Figures in parenthesis are estimates based on data from other sources.

Cannabis resin data are converted into "herbal equivalent" by multiplying by 25.

Two dots (. .) indicate that data are not available or are not separately reported.

A dash (—) indicates that the amount is nil.

Some of the information on production reflected in this table was derived from sources other than the respective Governments and should therefore be treated with caution. For example, the Government of Brazil maintains that Paraguay is the source of most of the cannabis seized in Brazil but there is evidence of substantial cultivation of cannabis plant within Brazil.

[a]The "herbal equivalent" figure is used because seizures of cannabis resin actually represent at least 25 times the land area needed to produce the same weight of cannabis herb.

[b]Assuming a 4 per cent yield.

[c]Assuming that 80 per cent of the cannabis resin seized in Belgium, Denmark, France, Germany, Ireland, Italy, Norway, Portugal, Spain, Sweden and the United Kingdom emanated from Morocco.

[d]Assuming that 100 per cent of the cannabis resin seized in Pakistan (based on that country's response to the annual reports questionnaire) and the Islamic Republic of Iran emanated from Afghanistan; the supply of cannabis resin from Afghanistan to Europe is not included.

[e]Data from 2004.

[f]Assuming that 80 per cent of the cannabis herb seized in Argentina and Brazil (based on those countries' responses to the annual reports questionnaire) emanated from Paraguay.

[g]Total plants converted to 1 plant per square metre outdoor equivalents.

*The UNODC annual reports questionnaire is the mechanism through which Member States report to the United Nations on the drug control situation in their respective countries. The questionnaire is an integral part of UNODC's data collection activities. It is completed annually by Member States and consists of three parts: Legislative and administrative measures (part I); Extent, patterns and trends of drug abuse (part II); and Illicit supply of drugs (part III).

However, it is possible to combine the information available about the biggest markets and seizure data to come up with some idea of the number of hectares under cannabis plant cultivation, at least for those markets for which reliable estimates exist. Table 4 sets out the main producing countries about which information is available. Together, these countries are the source of at least 78 per cent of global cannabis seizures. The largest missing piece of the puzzle is Africa where, for reasons discussed below, data on production and seizures are difficult to reconcile with other available information.

All this suggests that the bulk of global cannabis production occurs in an area of about 231,000 hectares, of which more than half are in Morocco. This is a small area, about the size of the Comoros Islands. The estimated seizure rate for these main producing countries shown in table 4 is about 17 per cent. In other words, after eradication, four fifths of the cannabis produced in the six main producing countries gets past law enforcement.

This rate of interdiction refers to some of the most developed markets for cannabis in the world and it is likely that the corresponding figure in places like Africa is probably much lower. The application of this rate should therefore be considered as a low-end estimate. Global cannabis seizures in 2003 amounted to 5,845 tons of cannabis herb and 1,361 tons of cannabis resin (about 34,000 tons of herbal equivalent) for just under 40,000 tons of global cannabis production seized. If this is about a fifth of true production, about 200,000 tons were produced in 2003. However, most of this (85 per cent) was reduced to cannabis resin. Total cannabis product output should be about 30,000 tons of cannabis herb and just under 7,000 tons of cannabis resin.