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Yield of Illicit Indoor Cannabis Cultivation in The Netherlands

ABSTRACT: To obtain a reliable estimation on the yield of illicit indoor cannabis cultivation in The Netherlands, cannabis plants confiscated by the police were used to determine the yield of dried female flower buds. The developmental stage of flower buds of the seized plants was described on a scale from 1 to 10 where the value of 10 indicates a fully developed flower bud ready for harvesting. Using eight additional characteristics describing the grow room and cultivation parameters, regression analysis with subset selection was carried out to develop two models for the yield of indoor cannabis cultivation. The median Dutch illicit grow room consists of 259 cannabis plants, has a plant density of 15 plants/m², and 510 W of growth lamps per m². For the median Dutch grow room, the predicted yield of female flower buds at the harvestable developmental stage (stage 10) was 33.7 g/plant or 505 g/m².

KEYWORDS: forensic science, illicit cultivation, flower buds, growth conditions, marijuana

Cannabis is the most commonly used drug in the EU and, depending on the country, is used regularly by 1–10% of all adults (1). The denomination cannabis is commonly used to describe the various products of the cannabis plant (*Cannabis sativa* L.), namely the extracted resin (known as hashish) and the dried female flower buds (known as marijuana, grass, “nederwiet”). The most common mode of administration is smoking in cigarettes (with or without tobacco). Hashish is also eaten, e.g., baked in cookies or cakes (2). The psycho-active effects of cannabis are mainly caused by the cannabinoid Δ^9 -tetrahydrocannabinol (THC). The most prominent feature of cannabis use is an initial period of euphoria and relaxation, which is followed by a depressant period (3). Use of cannabis affects the execution of complicated mental tasks that require a concerted action of attention, memory, and control of movement (4).

Except for fiber applications, cannabis cultivation is prohibited in most countries. Nonetheless, many EU countries report the growth of cannabis (1). Until the 1980s, cannabis was mainly cultivated outdoors for the production of female flower buds. Cultivation was strongly influenced by weather conditions and day length. The risks for the grower were high, e.g., due to theft or confiscation by the police. In the 1980s, indoor cultivation of cannabis was initiated in The Netherlands in order to evade law enforcement and to become less dependent on environmental conditions. Indoor cultivation became “professionalized” by the growth of nonpollinated female plants (sinsemilla), the use of cuttings taken from high-quality mother plants, and the use of hydro culture systems (5). Indoor cultivation allowed the growth of cannabis the whole year round, with four to six harvests a year. The use of faster and more controlled plant growth under optimal growing conditions in combination with breeding of new high performing varieties resulted in increased yields of flower buds and increased THC levels. For “nederwiet,” the average THC level was reported to have increased from 9% in 1999/2000 to 15% in 2001/2002 (6). In 1997, The Forensic Science Service

Laboratory in London measured an average THC level in flower buds of 9.4% with extreme levels up to 19% (5).

Little scientific information is available on the yield of female flower buds from cannabis cultivation. In newspaper articles, yields up to 50 g of flower buds per plant have been reported. In 1997, forensic science sources in the U.K. estimated the yield of flower buds at 15–20 g/plant (7). Based on case studies, Huizer and Poortman-van der Meer (8) estimated the yield for “nederwiet” at 22 g/plant in 1995. This yield estimation is used in Dutch court proceedings to determine the potential financial profits of the illicit cannabis grower.

In order to obtain a scientifically determined estimation of the yield of illicit indoor cannabis cultivation in the Netherlands, cannabis plants seized by the police were used to determine the yield of dried female flower buds. The developmental stage of flower buds of the seized plants was described on a scale from 1 to 10, where the value of 10 indicates a fully developed flower bud ready for harvesting. Using eight additional characteristics to describe the grow room and growing conditions, regression analysis with subset selection (9) was carried out to develop two models for the yield of indoor cannabis cultivation. The model for yield per plant gave a prediction of 33.7 g female flower buds per plant. The second model for yield per m² gave a prediction of 505 g flower buds per m² for a median Dutch grow room.

Materials and Methods

Samples

Samples of cannabis plants were collected by the police during house searches in buildings or houses that were used for illicit cultivation of cannabis. Grow rooms containing less than 12 plants were excluded from the survey because these rooms cannot supply the minimum sample size of 12 plants. In total, 86 samples of plants in different stages of flower development were collected in 10 different police regions in The Netherlands. The police filled in a form to describe the situation encountered in the grow room. This form requested information on the number of plants, the size of the growing area, the size of the growing area occupied with plants, the type of substrate (soil/potting compost, rockwool,

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TABLE 1—Morphological characteristics of the female flower buds used to determine their developmental stage.

Developmental Stage	Morphological Characteristics
1	Onset of flowering
2	Small green female flower
3	Developing green flower
4	Developed green flower
5	Onset of drying
6	Color transition of hairs to red-brown
7	Onset of resin formation
8	Progression of resin formation
9	Almost fully developed flower
10	Fully developed flower, much resin, harvest stage

hydro-culture, or other), the type of heating (no heating, heating, or thermostat-controlled heating), the presence of sticky traps to indicate the presence of insect pests, the type of ventilation (no ventilation, ventilation without aspiration, or ventilation with aspiration to the outside), the type of growth lamps, the wattage of the lamps and the number of lamps in the grow room, the application of additional CO₂, and the presence of fertilizers and additives.

The growth area was sampled randomly according to a defined protocol: cannabis plants were taken along the legs of a virtual X laid over the area occupied with plants. Border plants were excluded from sampling because these have a comparative advantage over other plants and will not reflect the average yield adequately.

Each sample of 12 plants was packed in paper bags and delivered to the laboratory of Plant Research International within 24 h. Upon arrival, the developmental stage of the female flower buds was determined based on morphological characteristics (Table 1). Each sample of twelve plants was randomly separated into two duplicate batches and dried at 35°C for 3 days. From each batch of six plants, the female flower buds were plucked and weighted, resulting in two weight values per sample.

Statistical Analysis

The reliability of the duplicate batches was determined by comparison of the two weight values of each sample. If duplicate values differed by more than three times the standard deviation of the differences of the duplicate values, analytical data were checked for inconsistencies. On the basis of these analyses, three samples were omitted from the analysis. Six additional samples were omitted from the analysis because the accompanying forms lacked essential information.

Linear regression models for yields of female flower buds per plant as well as flower bud yield per m² were developed by subset selection (Genstat 7.2 for Windows, VSN International). The value for yield of flower buds per confiscated plant used in the model was calculated by taking the average of the 12 plants in the two batches of six confiscated plants from one sample. The explanatory variables of the model are described in Table 2.

Results

Eighty-six samples of 12 *Cannabis* plants each were collected in 10 different police regions in The Netherlands. The stage of female flower bud development was determined based on the morphological description in Table 1. To predict the yield of female flower buds at the various stages of development, two linear regression models were developed based on 77 of the 86 samples

TABLE 2—Description of the explanatory variables used for model selection.

Explanatory Variables	Description
Developmental stage	See Table 1 for description
Plant density	Calculated by dividing the number of plants per grow room by the size of the growing area occupied with plants
Wattage of growth lamps per m ²	Calculated by multiplying the total number of lamps with the wattage of the lamps and dividing this by the size of the growing area occupied with plants
Type of growth lamps	Brand and type of the growth lamps
Type of substrate	Soil/potting compost, rockwool, hydro-culture, or other
Type of heating	No heating, heating, or thermostat-controlled heating
Type of ventilation	No ventilation, ventilation without aspiration, or ventilation with aspiration to the outside
Presence of sticky traps	Not present or present
Presence of additional CO ₂	Not present or present
Presence of fertilizer and additives	Not present or present

The size of the growing area was not included in the explanatory variables.

(nine samples were omitted from the analysis due to inconsistencies in the duplicate values or missing data) using the subset selection method described by Furnival and Wilson (9).

The main characteristics of the grow rooms are shown in Fig. 1. In 42 grow rooms, plants were grown in pots with potting soil while in 35 grow rooms hydro culture systems with rockwool were applied. Most grow rooms (23) contained 100–200 plants, while nine grow rooms contained over 1000 plants (Fig. 1a). On average, a grow room contained a total of 549 plants, and the median was 259 plants. Thirty grow rooms had a plant density of 9–16 plants/m² and in 20 cases the plant density was 17–24 plants/m² (Fig. 1b). Of the 77 samples analyzed, the average plant density was 18.1 plants/m² and the median was 15.3 plants/m².

In all grow rooms, horticultural growth lamps of 400 W or 600 W were present. The majority of the lamps were Philips (Master SON-T) lamps. The wattage of the growth lamps was between 500 and 600 W/m² in 17 grow rooms and between 300 and 400 W/m² in 15 others (Fig. 1c). The average wattage was 569 W/m², and the median was 510 W/m².

Based on these data, the median illicit Dutch grow room consists of 259 plants, with a plant density of 15 plants/m² and a wattage of 510 W/m². The developmental stage of the confiscated plants varied between developmental stages 2 and 8.5 (Fig. 1d).

As input for the models to predict the yield of female flower buds per plant or per m², the explanatory variables described in Table 2 were used. The combination of the variables that can predict the yield has been analyzed using subset selection. For both models, yield per plant and yield per m², 37% of the variance was accounted for by three explanatory variables: developmental stage, plant density, and wattage per m² (Table 3). The model for yield of flower buds per plant with three explanatory variables is described by the following formula:

$$\begin{aligned} \text{yield of flower buds per plant} = & - 8.06 \\ & + 4.261[\text{developmental stage}] \\ & - 0.482[\text{plant density}] \\ & + 0.01242[\text{wattage of growth lamps per m}^2] \end{aligned}$$

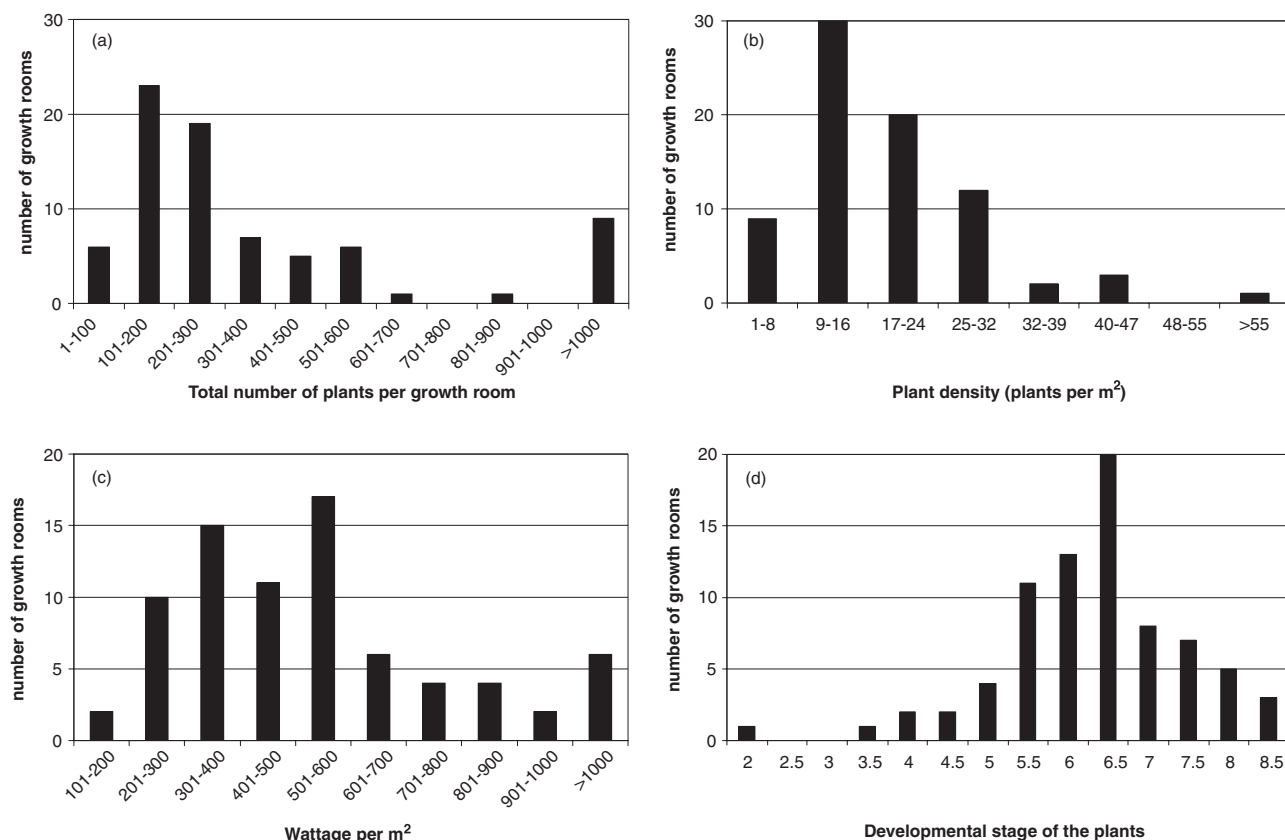


FIG. 1—Overview of the distribution of the main characteristics of the 77 grow rooms. The distribution of (a) the total number of plants per grow room, (b) the number of plants per m² (plant density), (c) the wattage of growth lamps per m², and (d) the developmental stage of the plants are shown.

The model for yield of flower buds per m² with three explanatory variables is described by the following formula:

$$\begin{aligned} \text{yield of flower buds per m}^2 = & -386 + 69.8 * [\text{developmental stage}] \\ & + 6.5 * [\text{plant density}] \\ & + 0.1838 * [\text{wattage of growth} \\ & \text{lamps per m}^2] \end{aligned}$$

Table 4 shows the regression coefficients, standard errors, *t*-values, and *p*-values for both models. On the basis of these models, the yield of female flower buds per plant or per m² can be predicted for each developmental stage, given the plant density and wattage of growth lamps per m². Table 5 shows the predicted yields for the median Dutch grow room (15 plants/m², 510 W/m²) with the lower bound of the one-sided 95% confidence interval for developmental stages 8–10 where stage 10 represents the fully mature flower buds, ready for harvesting.

Inclusion of the variable ventilation in the models further increased the percentage of variation accounted for to about 41% for both models. Compared with the reference situation with the parameter “ventilation with aspiration to the outside,” the parameter “ventilation without aspiration” led to a decrease in yield. The parameter “no ventilation” only applied to one sample and was not significantly different from the reference situation.

Discussion

In order to predict the yield of illicit indoor cannabis cultivation in the Netherlands, data from 77 samples seized by the police were analyzed statistically. The median Dutch illicit grow room consists of 259 plants, has a plant density of 15 plants/m², and 510 W of growth lamps per m². Based on regression analysis with subset selection, models were developed to predict the yield of female flower buds per plant and per m². For both yield of flower buds per plant and yield of flower buds per m², the model with three

TABLE 3—Model selection for the response variables yield of female flower buds per plant and yield of flower buds per m².

	Explanatory Variable(s)	Adjusted R ²	
		Yield per Plant	Yield per m ²
1	Developmental stage	22.53	17.89
2	Developmental stage, plant density	28.25	32.52
3	Developmental stage, plant density, wattage per m ²	36.56	37.15
4	Developmental stage, plant density, wattage per m ² , ventilation	40.74	41.54
5a	Developmental stage, plant density, wattage per m ² , ventilation, fertilizer	43.69	—
5b	Developmental stage, plant density, wattage per m ² , ventilation, presence of sticky traps	—	41.54

The best subset with 1–5 explanatory variable(s) based on adjusted percentages of variance accounted for (adjusted R²) is indicated.

TABLE 4—Regression coefficients with standard error (SE), *t*-value (*t*(73)), and *p*-value (*p*) for the variables of the models that predict the yield of female flower buds per plant and the yield of flower buds per m².

Variables	Yield per Plant				Yield per m ²			
	Coefficient	SE	<i>t</i> (73)	<i>p</i>	Coefficient	SE	<i>t</i> (73)	<i>p</i>
Constant	−8.06	5.99	−1.35	0.183	−386	114	−3.38	0.001
Developmental stage	4.261	0.857	4.97	<0.001	69.8	16.3	4.27	<0.001
Plant density	−0.482	0.117	−4.13	<0.001	6.5	2.22	2.95	0.004
Wattage per m ²	0.01242	0.00380	3.27	0.002	0.1838	0.0724	2.54	0.013

TABLE 5—Prediction of the yield of female flower buds per plant and per m² for the median Dutch grow room (median value of 15 plants/m² and 510 W/m²) for developmental stages 8–10 with a one-sided (*p*) 95% confidence interval.

Developmental Stage	Yield per Plant			Yield per m ²		
	Predicted Yield of Flower Buds (g)	SE	Lower Bound of One-Sided 95% Confidence Interval (g)	Predicted Yield of Flower Buds (g)	SE	Lower Bound of One-Sided 95% Confidence Interval (g)
8	25.1	1.76	22.2	365	33.6	309
9	29.4	2.51	25.2	435	47.7	355
10	33.7	3.31	28.1	505	63.1	399

explanatory variables (developmental stage, plant density, and wattage per m²) accounted for 37% of the variance. For both models, the percentage of variance accounted for was increased to about 41% by adding the variable ventilation. However, this variable was not included in the model because the parameter “ventilation with aspiration to the outside” was only significantly different from the parameter “ventilation without aspiration,” while it was not significantly different from the parameter “no ventilation.” The type of growth lamps used in the different grow rooms was very similar and, therefore, did not influence the percentage of variance accounted for. Also, the type of substrate used did not influence the yield significantly.

It could be possible to further improve the models by incorporating other explanatory variables. Variables like the genotype of the plant, the quality of the starting material (cuttings or seeds), and the presence of diseases may have a significant effect on flower bud yield. Also, other, more difficult to define variables, such as the skill of the grower, may influence the yield of flower buds. Including these factors in the analysis could increase the percentage of variation accounted for and further improve the predictive value of these explanatory models.

There is little scientific information about illicit cannabis cultivation in The Netherlands. No central registration of dismantled grow rooms is carried out. The only data available are from a number of case studies by Bovenkerk and Hogewind (10).

The study described in this paper shows a large variation in the size of grow rooms (from 12 to 7800 plants per grow room). The relatively small number of large grow rooms strongly influenced the average size as shown by the average of 549 plants per grow room compared with a median of 259 plants per grow room. In 2001, a total of 2012 grow rooms were dismantled and 884,609 “nederwiet” plants were confiscated by Dutch police (1). This corresponds to an average of 440 plants per grow room. A case study in Utrecht (The Netherlands) (10) showed a distribution of the size of the grow rooms that is comparable to the distribution shown in Fig. 1*a*, with an average of about 280 plants per grow room. It has to be noted that all data available are based on data from police confiscations and that the actual average number of plants per grow room might differ from the above values. This has to do with the fact that police searches are probably not random. Searches are initiated based on internal police strategies or carried

out after reports e.g., by neighbors. Professionally equipped grow rooms with high-quality air filtering or large grow rooms in the country-side might be detected less frequently.

The yield of female flower buds at a given developmental stage is described by the models as a function of the plant density and the wattage of growth lamps per m². In 1999, Forensic Services in the U.K. estimated that the buds of a female plant can produce 10–15 g of marketable cannabis (7). In The Netherlands, Huizer and Poorter-van der Meer (8) estimated the yield for “nederwiet” at 22 g/plant. In popular cannabis cultivation literature, average yields of 366–610 g/m² are described (11). For the median Dutch grow room with 15 plants/m² and 510 W of growth lamps per m², the models developed here estimate the yield at the harvestable developmental stage 10, at 33.7 g/plant or 505 g/m².

Implementation of these numbers in case law will be the responsibility of the public prosecutor. For The Netherlands, the Dutch Criminal Assets Deprivation Bureau advises to comply to the lower limit of the one-sided 95% confidence interval. In that case, the minimal yield for a median Dutch grow room is 28.1 g/plant or 399 g/m² (12).

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