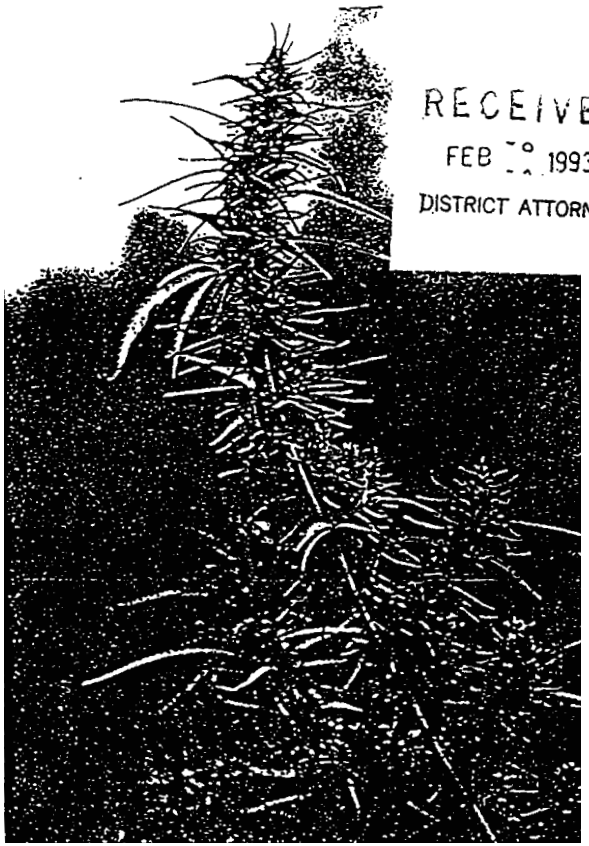
CANNABIS YIELDS



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SUMMARY

Outdoor Cannabis sativa L. (cannabis) yield studies conducted during the summers of 1990 and 1991 have determined that the usable dry weight yield (leaf and bud) for female cannabis plants can be up to 2.3 kilograms (5.1 pounds). Based upon a survey of 15 leading producer states, the average plant yield for mature, domestically grown female cannabis plants in 1991 was 448 grams (1 pound). An accurate yield estimate can be made by weighing the fresh weight of a plant or measuring the plant's diameter at the broadest point in the canopy. A very significant factor affecting yield was planting density.

BACKGROUND

The Drug Enforcement Administration (DEA) during the summers of 1990 and 1991, conducted a detailed cannabis yield measurement program at the University of Mississippi in Oxford. The purpose of the project was to determine the average yield of outdoor cultivated cannabis plants and identify factors to predict usable yield. Prior to the project's initiation, the only quantitative studies undertaken were two studies self-initiated by the University of Mississippi in 1985 and 1986. These two studies made a limited number of observations and did not identify factors influencing plant yield.

METHODOLOGY

The overall intent of the studies was to introduce variation into the research design in order to gain a basic understanding of some of the factors influencing plant yield. The DEA sponsored research used different seed stocks from Mexico, Colombia, Jamaica, and a hybrid of South African-Afghanistan origin.

The 1990 effort consisted of a progressive planting of 3 separate areas at 2 week intervals. Each area was planted with the same seed stock at an identical planting density. The varying of the planting date permitted analysis of the sensitivity of cannabis yield and plant development to planting date. The 1991 effort focused on the relationship between planting density and yield. Three different planting densities of Mexican seed stock were studied. Tables 1 and 2 describe the average plant yields which are associated with specific densities.

Yield measurements were made on 90 days or older female plants, which duplicated the preference of a majority of domestic growers to cultivate the larger yielding females. However, no attempt was made to cultivate unfertilized female plants, commonly known as "sinsemilla". The vast majority of observations were made on the very common, tall, narrow leaflet cannabis variety known as

"sativa". A very limited number of observations were made on the other major variety, "indica". The indica variety is a shorter, more compact, faster maturing plant with larger leaves.

Yield measurements were made on 102 plants during the course of the two year study. Physical measurements were made of the plant's height from ground level and the diameter at the broadest point in the plant's canopy. Upon completion of the physical measurements, the plant was cut at ground level and separated into four component parts - stem/branches, leaves, female flowering tops, commonly known as buds or colas, and seed. The individual components were each weighed to determine a "wet" or "fresh" weight. The material was dried in a convection oven at 70 degrees Celsius. The dried material was reweighed when it had reached a constant weight, typically after 24 to 48 hours. This second measurement is termed the "dry" weight. During both yield surveys, cannabis plants were harvested and measured on a monthly basis to quantify yield throughout the growth cycle. The selection of plants was based upon a determination of their representative physical size, shape, and overall vigor characteristics. The selection process captured the diversity or plant size by including cannabis plants ranging from the larger to the smaller plant specimens. The planting of approximately 100 plants per cultivation area insured that there was a large and representative population from which plants were sampled. If a particular plant was harvested for the measurement program, the neighboring plants were ineligible for future selection which avoided changing the planting density during the study. Similarly, no plants on the outer rows were selected to avoid edge affects which could skew results because of an asymmetrical planting density.

YIELD RESULTS

All measurements recorded in 1990 or 1991 are contained in Attachment 1. Table 1 depicts the average yield for all mature (120 days or older) cannabis plants grown using a dense planting pattern of either 9 square feet per plant or 18 square feet per plant. At this relatively high planting density, the lateral branches of adjacent cannabis plants were touching by the middle of July. Thereafter, the horizontal growth rate decreased in relation to the vertical rate of growth. The results were tall, narrow plant canopies.

Table 1
Average Cannabis Yields at
Maturity for High Planting Densities

SPONSOR	YEAR	DENSITY	YIELD*	SEED STOCK
Univ. of MS	1985	9 ft. sq.	222 grams	Mexico
Univ. of MS	1986	9 ft. sq.	274 grams	Mexico
DEA	1990	18 ft. sq.	233 grams	Colombia
DEA	1991	9 ft. sq.	215 grams	Mexico

*Yield = oven dry weight of usable leaf and bud from mature 120 day or older plants.

The similarity of plant yields contained in Table 1 is remarkable considering the variation in seed stock, year of cultivation, and other factors. However, if the planting density is decreased, the plants have more room to laterally branch out. The additional space allows the plant to assume a natural canopy shape, somewhat similar to a Christmas tree. The larger branching structure coupled with increased available sunlight, soil nutrients, and water resulted in significantly greater plant yields. Table 2 displays the yields for cannabis at maturity for identical seed stocks at three low planting densities and for different planting dates and years.

Table 2
Average Cannabis Yields at
Maturity for Low Planting Densities

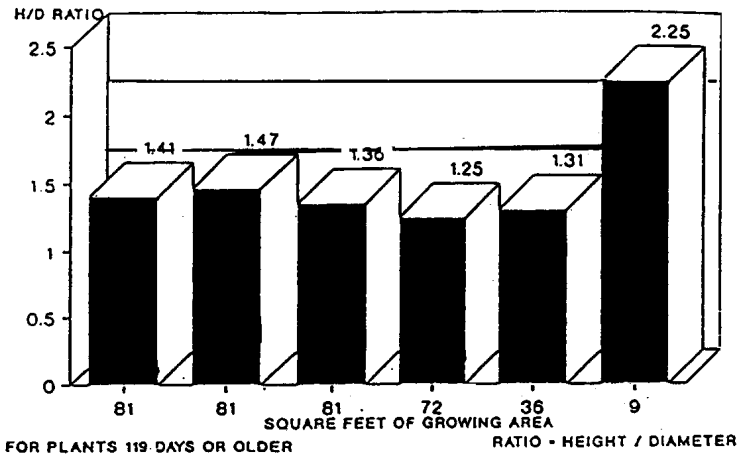
SPONSOR	YEAR*	DENSITY	YIELD	SEED STOCK
DEA-A	1990	81 ft. sq.	777 grams	Mexico
DEA-B	1990	81 ft. sq.	936 grams	Mexico
DEA-C	1990	81 ft. sq.	640 grams	Mexico
DEA	1991	72 ft. sq.	1015 grams	Mexico
DEA	1991	36 ft. sq.	860 grams	Mexico

*Seedlings for the 1990 measurement program were planted at two week intervals: DEA-A was planted on 4/17, DEA-B was planted on 5/8, and DEA-C was planted on 5/17. The 1991 plantings were made during the first week of June.

Figure 1 reports select plant height-diameter ratios for the planting densities used in 1990 and 1991. The noticeably high ratio for the 9 foot square planting density confirms that this plant canopy shape is different than all of the other observations which had relatively large amounts of space in which to grow. The height-diameter graph of Figure 1 shows that planting density is a significant factor affecting plant canopy shape, which in turn affects plant yield. The significance of the relationship between planting density and plant yield will be

discussed later in this paper.

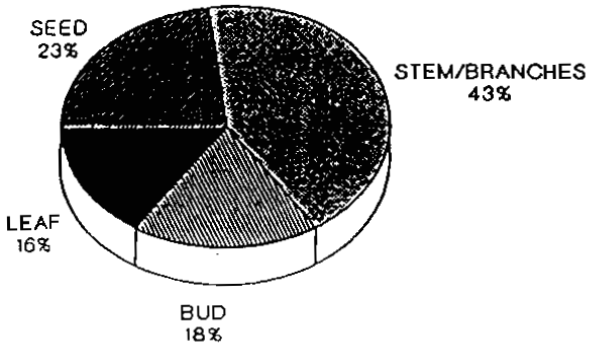
FIGURE 1
HEIGHT AND DIAMETER RATIOS



During both growing seasons, only standard irrigation, fertilization, and weeding activity were rendered as required. However, two plants, identification numbers 107.01 and 103.01 in the 1991 low planting density plots, had extremely high yields in comparison to neighboring plants. The dry weight yield for plant 107.01 was 2,086.9 grams (4.6 pounds) and plant 103.01 yielded 2,308.4 grams (5.1 pounds). These two plants were located in a low area. It is believed that the natural slope of the land caused these plants to receive additional water and possibly additional fertilizer through run on water. The significance of these yields is that they demonstrate that certain agronomic practices can produce higher average yields than those reported in Table 2.

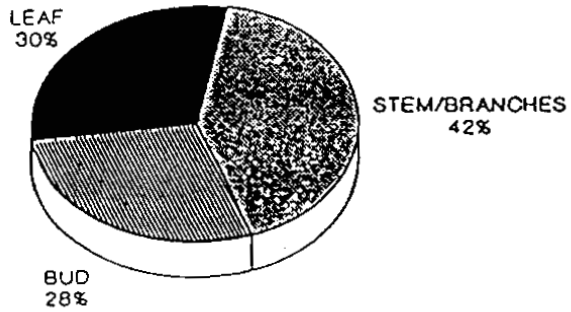
Analysis of the combined 1990 and 1991 DEA yield data shows that usable oven dry weight material (leaf and bud) in a mature cannabis plant is 14.4% of the plant's total (roots excluded) fresh weight. A break down of the four types of material found in a mature female cannabis plant is presented in Figure 2.

FIGURE 2
NON-SINSEMILLA CANNABIS COMPONENTS



PERCENT OVEN DRY WEIGHT 120 DAYS OR OLDER PLANTS

SINSEMILLA CANNABIS COMPONENTS

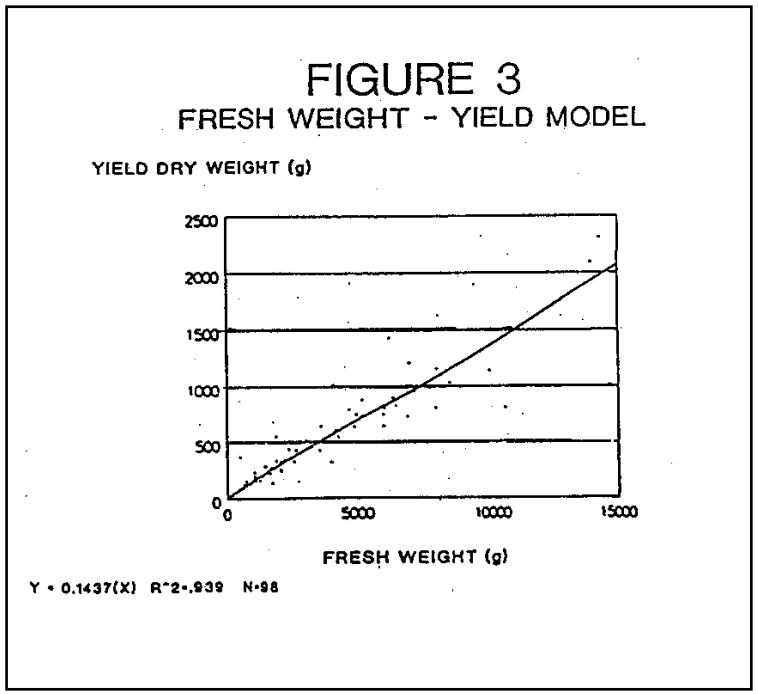


PERCENT OVEN DRY WEIGHT 90 DAY OR OLDER PLANTS
WHICH DID NOT HAVE ANY SEED DEVELOPMENT

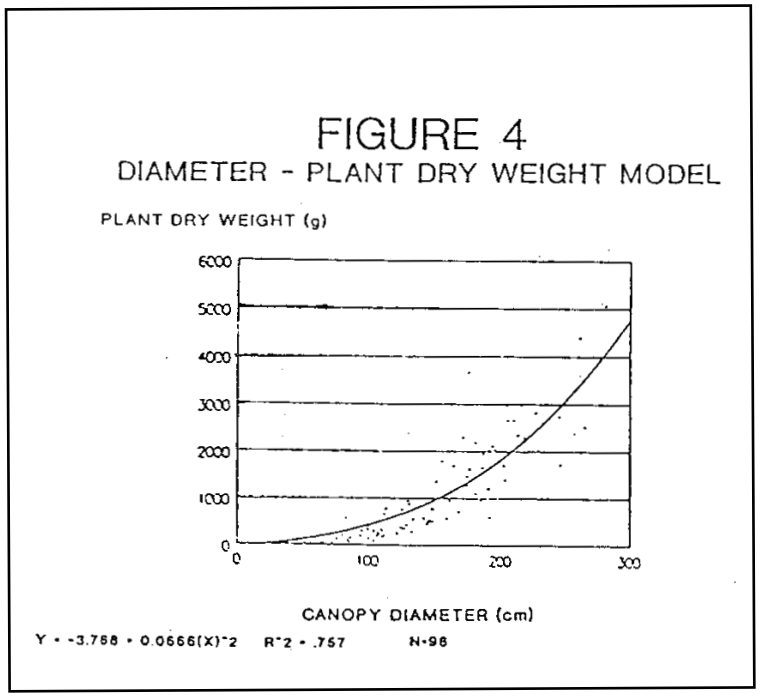
YIELD PREDICTION

The plant growth and yield data collected throughout the 1990 and 1991 growing seasons shows that plant yield can be accurately predicted from simple field measurements. Several field measurement techniques were assessed including plant height, diameter, fresh weight, and the number of grow days. The predictive models developed are valid for any sativa variety plants regardless of plant age or planting density.

The best predictor of plant yield was measurement of the plant's fresh weight. Figure 3 depicts the linear relationship between plant fresh weight and yield dry weight. The only required measurement is the weighing of the plant at the time of seizure in a timely fashion to avoid excessive loss of plant water. That fresh weight would not include the plant roots or any soil adhering to the plant. The fresh weight multiplied by the number 0.1437 would result in an estimate of usable dry weight material. This estimating technique is extremely accurate.



Another accurate method for predicting plant yield is based upon measurement of the diameter of the plant at the broadest point in the canopy. Figure 4 depicts the curvilinear relationship between plant canopy diameter and the plant dry weight. The measurement of a plant canopy diameter is simpler than the measurement of the plant's fresh weight. However, the calculation of a yield estimate requires a two step process. First, the measured diameter is entered into the equation: Dry Weight = -3.76786 + (0.06666 * (Diameter ^2)). This first equation estimates the plant's total dry weight. Usable yield is then calculated using the percentages of bud and leaf described in Figure 2.



Neither plant height data or the number of grow days were as accurate a predictor of plant yield as were fresh weight or diameter measurements. However, weight was a good indicator of plant age and this relationship may be useful in estimating planting date. The correlation matrix included in Attachment 1 reports on the degree of association among 13 different plant measurements.

MISCELLANEOUS DATA ANALYSIS

Air Dry Weight

The use of oven dry weights, although scientifically acceptable because it can be reproduced, under-represents the amount of usable material in the illicit market. Most illegal material is air dried or at the time of sale, is in equilibrium with surrounding atmosphere which contains a certain amount of moisture. It is estimated based upon the DEA studies that the leaf and bud material of cannabis would weigh an additional 10% to 20% if allowed to air dry naturally and equalize with the surrounding atmosphere.

Water Content

In addition to the yield measurements, the amount of water contained in each plant was measured. A mature cannabis plant has, on a fresh weight basis, 66% water and 34% dry plant matter (leaves, buds, seeds, stems/branches). Plant water content can vary with plant age. Young plants less than 55 days old have a water content ranging from 75% to 82%. Older plants have water content ranging from 60% to 70%.

Plant Height

The average height of a mature cannabis plant was between 270 cm and 350 cm (8.6 - 11.5 feet). A few cannabis plants were measured in excess of 400 cm (13.1 feet). The tallest plant recorded was 430 cm (14.1 feet). Height was determined not to be very sensitive to planting density factors.

Crop Cycle

The crop cycle for the cannabis plants grown at the University of Mississippi was typical of cannabis crops grown in the contiguous states. The crop cycle consists of two stages. The first stage is the vegetative state which is characterized by a 30 to 90 day period of vigorous growth of sexually undifferentiated plants. Typical plantings occur in April or May and the vegetative stage extends until late July or early August. The transition from the vegetative stage to the second stage, known as the flowering or fruiting period, results from the reduction in day length as-

sociated with the photoperiod peaking on the summer solstice of June 21.

The flowering or fruiting stage lasts for the remainder of the plant's life cycle. Beginning in August, male plants form the stamens from which huge amounts of pollen are released. The male plants usually die by the middle of September or soon after they release their pollen. Female plants live a longer time in order to produce seed for the next generation. This reproductive stage is essential for naturally growing cannabis because it is an annual plant and can not survive the winter months. Female plants will produce a protective leafy bud to surround the pistulate reproductive organs and develop seed, if fertilized. The bud structure is highly desired by illicit growers because it contains the highest number of THC producing glands.

Yield Adjustment Factors

There is no need to adjust yield estimations of outdoor mature cannabis crops if at the time of seizure there are no male plants. If male plants are present, then evidence of this fact should be apparent by early August. The estimated yield of a male plant in early August, the point at which it begins to senesce and loose leaf cover, will be approximately 50% of the weight of a female plant of similar age and growth stage. By late September or October, the only harvestable cannabis plants remaining will be female plants.

If the female cannabis plants are unfertilized, then no seed will be produced. The average usable yield (leaf and bud) of a mature female plant will be 57% of the plant's dry weight where as the yield for a typical fertilized, seed bearing cannabis plant will be 34% of the the plant dry weight (Figure 2).

DOMESTIC ESTIMATE

The identification of accurate plant yield estimation methodologies makes possible the opportunity to estimate the average domestic yield using eradication statistics and plant canopy diameter information. A survey of 15 leading producer states was conducted by DEA to determine the average diameter of mature plants eradicated in September 1991. Table 4 lists the average diameter of mature plants observed in that state as reported by the DEA state eradication coordinator. The estimated usable yield for each state's eradicated plant total was cal-

culated using the predictive methodology described in Figure 4. This methodology uses average plant canopy diameter information as the predictor variable to estimate plant dry weight. The plant dry weight is adjusted to estimate usable air dry weight yield by first taking 34% of the dry weight to calculate usable yield, and adding 10% to the oven dry weight to obtain the air dry yield. This estimate is valid for female cannabis plants at maturity which contain seeds. An estimate for seedless cannabis (sinsemilla) is derived by first taking 58% of the plant dry weight, and then adjusting upward by 10% to convert from oven dry weight to an air dry yield.

Table 4
Estimated Cannabis Plant Yields

State	1991 Eradicated Plant Total	Average Diameter*	Estimated Non-Sinsemilla Yield (g)	Estimated Sinsemilla Yield (g)
Alabama	163,294	4 ft.	369	630
Arkansas	106,405	4 ft.	369	630
California	151,529	3.5 ft.	284	484
Florida	92,190	4.25 ft.	420	716
Georgia	300,583	4 ft.	369	630
Illinois	337,730	3.25 ft.	243	414
Indiana	206,494	4 ft.	369	630
Kansas	21,751	4 ft.	369	630
Kentucky	809,366	3.25 ft.	243	414
Louisiana	79,009	3.5 ft.	284	484
Minnesota	191,790	4 ft.	369	630
Missouri	104,493	3.5 ft.	284	484
N. Carolina	198,470	4 ft.	369	630
Tennessee	508,816	4 ft.	369	630
Texas	22,997	4.5 ft.	466	795
AVERAGE:		3.85 ft.	345 grams	589 grams

*Source: DEA Cannabis Investigations Section survey May, 1992.

The average yield for the entire outdoor domestic cultivated cannabis crop can be calculated by averaging the non-sinsemilla and sinsemilla yields in the same proportion as reported in the 1991 end of year eradication program results. The total number of cultivated outdoor cannabis plants eradicated in 1991 was 5,257,486. The number of sinsemilla plants was 2,251,735 or 42.8% of the total, and the number of non-sinsemilla plants was 3,005,751 or 57.2% of the total. A weighted average using the yields reported in Table 4 results in an average domestic plant yield of 448 grams or approximately 1 pound per plant.

CONCLUSIONS

The application of detailed field measurements and mathematical analysis techniques has shown that cannabis plant yields can be accurately estimated. Continued field observations at illicit cultivation locations, both domestically and overseas, will provide the opportunity to further validate the relationships reported. Development of cannabis yield methodologies is essential for understanding of the size of illicit cultivation problem and the drug abuse threat.

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