Chapter 6

Comparative Hazard Assessment of the Substances Used for Production and Control of Coca and Poppy in Colombia

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Glyphosate and an adjuvant, Cosmo-Flux® are employed for the control of coca and poppy plants used to manufacture the illicit drugs cocaine and heroin in Colombia, Latin America. Other substances, from pesticides to control pests in the coca and poppy fields to substances used in the extraction and refining processes are used by growers and refiners of the drugs. The practice of illicit crop production may have potential adverse effects on human and environmental health due to cut and burn practices and the large quantities of chemicals required to cultivate the crops under the conditions of growth in Colombia. Of the 67 substances used in significant quantities, 20 were selected as high hazard substances and 16 of these were pesticides. A comparative

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approach was used to evaluate the relative hazard from glyphosate as used in the spray eradication program and the 16 pesticides used in the production of coca and poppy. Hazard quotients for the human indicated that several pesticides used in coca and poppy production present much greater hazard to humans than glyphosate. Hazard quotients calculated for the aquatic environments indicated that most of the pesticides used in coca and poppy production present significantly greater hazards to aquatic organisms than glyphosate (and Cosmo-Flux®). Several of the pesticides presented significant hazards to bees and other pollinators, however, the formulation of glyphosate plus Cosmo-Flux® was essentially non-toxic to honey bees. For the earthworm hazard assessment, only diazinon and carbendazim were more hazardous to earthworms than glyphosate.

Introduction

The growing and production of cocaine and heroin in Colombia has significant political, social, and economic implications as well as impacts on human heath and the environment. Coca (*Erythroxylum coca*) and related species are commonly associated with the tropical mountainous regions of South America with temperatures above 25°C and moderate to high rainfall >1,000 mm per year. Historically, coca played an important role in culture of the Incas, Quechuas, and many other Andean peoples. Cocaine, derived from the coca plant, is used in many countries as an illicit addictive drug; global production between 1995 and 2002 was estimated to range from 640 to 950 tonnes used by an estimated 14 million people (*1*).

Opium, morphine, and its derivative, heroin, are produced from the poppy, *Papaver somniferum*, which is primarily grown in Asia. Global production of opium in 2002 was estimated to be 1,586 tonnes, of which about 160 tonnes were produced in South America (*1*), some of this in Colombia. It is estimated that, globally, about 15 million people use opiates and that about 10 million of these use heroin (*1*).

Both coca and poppy are grown intensively in a process that involves the clearing of land, the planting of the crop and its protection against pests such as weeds, insects, and pathogens. Depending on the region, the clearing of the land for production purposes may have large and only slowly reversible effects on the environment. As for other forms of agricultural production, the clear-cutting of forests for the purposes of coca and poppy production reduces biodiversity, contributes to the release of greenhouse gases, increases the loss of soil nutrients, and promotes erosion of soils. As production is illegal, it normally takes place in remote locations that are close to or part of the Andean Biodiversity Hotspot (*2*). As a result, the clearing of land is done with little apparent consideration for the biological and aesthetic value of the ecosystem.

The growing of coca and poppy and the distribution of cocaine and opium/heroin in Colombia has been the focus of a National control and eradication program starting in the 1970s. The program involves a number of Departments and Agencies of the Colombian Government and is coordinated by the Direccion Nacional de Estupefacientes (DNE), an agency of the Ministry of the Interior and Justice. The program has three main foci; the control of production of coca and poppy through aerial spraying of the herbicide glyphosate; the control of the processing, purification, and transport of the cocaine and heroin; and the seizure and forfeiture of the profits of illicit drug production (*3*).

The aerial eradication program for coca and poppy in Colombia is the responsibility of the Antinarcotics Directorate of the Colombian National Police (DIRAN-CNP), supported by data gathering from other nations such those in North America and Europe. The DIRAN reviews satellite imagery and flies over growing regions on a regular basis to search for new coca and opium poppy growth and to generate estimates of the illicit crops through high resolution low-altitude imagery and visual observation. Flights with aircraft that spray coca and opium poppy crops with glyphosate are then conducted. Glyphosate is applied to coca at a rate of 4.9 kg a.e. per ha and to poppy at a rate of 1.2 kg a.e. per ha. An adjuvant, Cosmo-Flux® is added to the spray mixture to increase penetration through cuticular waxes (*4*).

Several concerns have been raised about the use of glyphosate and adjuvants in the eradication of coca and poppy plants. These concerns range from damage to other crops to adverse effects on the environment and human health. In response to this, the Government of Colombia appointed an independent environmental auditor who reviews the spray and no-spray areas with the DIRAN, and regularly monitors the results of spraying through field checks and analysis of data from the computer system. In addition to the internal assessment of the control program, three detailed reviews two on the substances used for production of cocaine and heroin (*5,6*) and one of the use of glyphosate (*4,7*) were conducted for the Inter-American Drug Abuse Control Commission (CICAD) section of the Organization of American States (OAS). These reviews form the basis for this Chapter which is an illustration of a comparative environmental and human health hazard assessment of the processes associated with the production and eradication of coca and poppy in Colombia.

Several pesticides are used in the production of illicit drugs (*7*). Herbicides may be used in the initial clearing of the land and later in the suppression of weeds. Similarly, insecticides and fungicides may be used to protect the illicit crops from pests and diseases. To increase yields, fertilizers and other nutrients may also be used. Large quantities of agrochemicals have been seized and confiscated as part of the program to control the production of illicit drugs (*3*). Although some of these agrochemicals are highly toxic to mammals and may have significant environmental impacts, accurate information on the amounts used, their frequency of use, and the conditions of their use is not available. Because of this, it is not possible to conduct a detailed human health and ecological risk assessment. In addition to the use of agrochemicals in the production of coca and poppy, large amounts of chemicals are used in the processing of the raw product into refined cocaine and heroin (*7*). Processing of the illicit drugs is conducted in remote locations and in the absence of occupational health and environmental regulations and controls. During and after use, these substances may be released into the environment and have significant impacts on human health and the ecosystem (*5*).

A total of 67 substances used in significant quantities for these purposes were reviewed in a Tier-1 assessment (*5*). From this list a detailed hazard ranking scheme was used to select the 20 most hazardous for a more detailed assessment of toxicological properties and their fate in the environment.(*6*). Of the 20, 16 were pesticides. Since no exposure data were available for any of the 16 pesticides, exposure estimates were conducted using the same procedures as were used for worst case estimates of glyphosate exposures during the aerial application of glyphosate and Cosmo-Flux® for the purposes of eradication of coca (*4*). This allowed the exposures to these pesticides to be compared to those of glyphosate as used in the eradication program. These hazards were then compared to those of other activities undertaken in the production of cocaine and heroin.

Methods

Pesticide exposures

Humans

Pesticides are applied with hand-operated backpack sprayers in coca fields (*6*). Formulated products are diluted with local sources of water from a nearby stream, river, or well. Mixing and loading of the sprayer usually takes place close to the water source and empty containers are discarded in the field. Other than anecdotal information, there are little data on the use of protective equipment; however, from field observations it appears not to be widely used.

As for the glyphosate risk assessment (*4*), the most likely scenario is the partially clothed human with a cross-sectional area of 0.25 m^2 exposed to the spray. For the purposes of this assessment, it was assumed that people conducting pesticide applications would be exposed via the same route as a bystander receiving an accidental overspray. However, this is likely an underestimate as an applicator would be handing concentrated material more often. In general, applicators have greater exposures than bystanders (*8*). Total body dose for each of the sixteen pesticides contained in the priority list was calculated from the pesticide application rate, dermal absorption of the pesticide, average human body mass, and surface area exposed. As for glyphosate, body dose calculations were computed using two different surface areas 0.25 m^2 (face, forearms, and hands) and 2 m^2 (face, hands, arms, feet, legs, and torso), which correspond to different clothing coverage scenarios. Pesticide absorption values (expressed as percent absorption) and application rates were obtained from government reports and the primary literature (references in *6*). Body dose was estimated from the equation:

$$Body\ dose = \frac{Application\ rate\,(mg\,/\,m^2) \times surface\ area\,(m^2) \times dermal\ absorption\,(\%)}{body\ mass\,(kg)}$$

Environmental

As for the human exposures, similar procedures to those used to estimate surface water concentrations for glyphosate (*4*) were used to estimate concentrations of pesticides in water. The maximum concentration of pesticide water used for the hazard assessment of surface waters was estimated based on worst-case procedures, where direct overspray of water of different depths is assumed. Three assumptions of water depth were used, the USEPA assumption of a water depth of 2 m (farm pond *9*), the European assumption of a farm pond, 0.3 m, (*10*), and a depth of 0.15 m (forest pool or wetland). For an application rate of 1 kg per ha (1 x 10^{-4} kg/m^2), the assumed maximum concentrations for these three depths are 50, 333, and 670 µg per L, respectively. These base values were adjusted by multiplying the assumed concentration at an application rate of 1 kg per ha by the suggested label rate in order to obtain specific exposure concentrations for individual pesticides.

Bees and other pollinating insects are important in agriculture and in the survival of many insect-pollinated plants. For this reason, they are tested for sensitivity to pesticides as part of the registration process. A general guideline has been suggested for assessing hazard of pesticides to honeybees (*11*). This is based on empirical observations in field tests with a number of pesticides. To use this, the rate (g AI) applied per ha of field is divided by the topical LD50 for the pesticide in µg per bee as determined in laboratory tests. The quotient is then compared to the hazard ratio criteria and the risk estimated. A hazard ratio of < 50 indicates low risk; 50 - 2,500 indicates moderate risk; and > 2,500 indicates large risk. Exposures to bees were determined from the recommended application rates. Concentrations of pesticides in soil were estimated using the assumptions based on a rate of application of 1 kg per ha to soil with a bulk density of 1.5 kg per L. For even distribution in the top 2.5 and 5.0 cm, this would give concentrations of 2.67 and 1.34 mg per kg soil, respectively. These values were adjusted for recommended application rates (*6*).

Human hazards

The exposure value obtained from calculations divided by the effects value from experimental data, results in a Hazard Quotient (HQ). A HQ which exceeds one indicates a potential for toxicity; values less than one indicate toxicity is not likely to occur. For the human assessment, hazard quotients were computed by dividing the Reference Dose (RfD, obtained from the EPA IRIS database or other EPA sources) by the calculated body dose. The RfD (also known as the Acceptable Daily Intake or ADI) is a commonly-used criterion for judging exposure to a number of substances, especially pesticides. The RfD is the estimated maximum amount of an agent or pesticide, expressed on a body mass basis, to which an individual in a (sub) population may be exposed daily over their lifetime without appreciable health risk (*12*). This is used to assess chronic risk and therefore provides a conservative estimate of risk. It is the same estimator that was used to assess risks of glyphosate exposures that result from spray eradication (*4*) and thus serves as a useful criterion for comparative assessment of hazard. The data used in the calculation of the hazard quotients for humans are reported in (*6*). Toxicity and estimated exposure data for glyphosate in humans were included in for the purpose of comparison.

Most of the more hazardous pesticides (Figure 1) have hazard quotients (HQs) greater than 1, are insecticides, are toxic to mammals, and other wildlife, as well as to insects. It should be noted that the HQs are shown on a logarithmic scale to allow presentation in a small graph. These insecticides are organophosphorus compounds which are frequently associated with human poisonings and adverse effects in wildlife (*6*). The HQ for glyphosate was less than 1, as were those for carbendazim, cypermethrin, lambda cyhalothrin, and paraquat. Carbendazim is a fungicide and would not be expected to be hazardous to mammals. Cypermethrin and lambda cyhalothrin are pyrethroid insecticides, are moderately toxic to mammals, and are used at small rates of application. The small HQ for paraquat is reflective of its poor penetration through skin, the basis for the calculation of these hazards. In fact, paraquat can be much more hazardous if there are cuts or abrasions in the skin that facilitate penetration (*6*). If consumed orally, paraquat is very hazardous and is responsible for many human deaths, particularly where it is not used and stored properly (*6*).

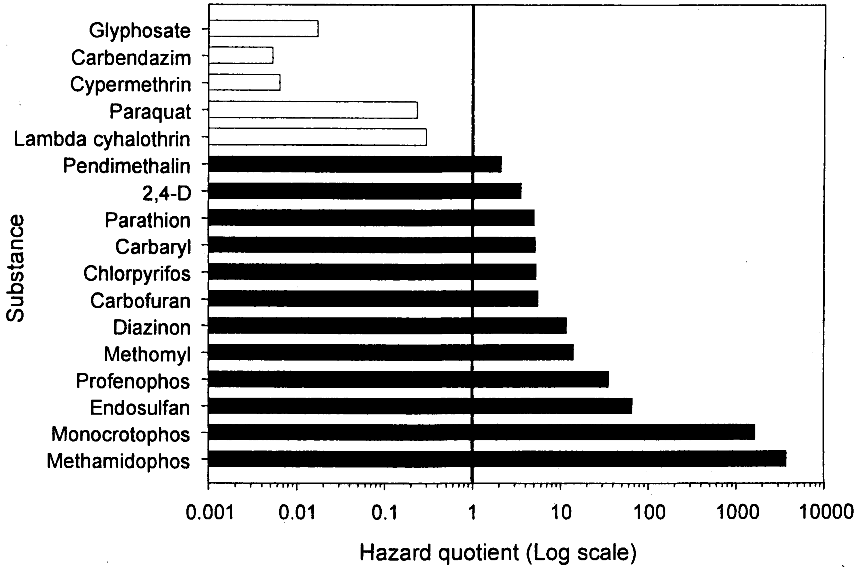

Figure 1. Graphical illustration of the huma health hazard quotients of pesticides used in the production of coca and poppy. Quotients based on estimated body does as compared to the RfD.

Hazards to aquatic organisms

The environmental HQ was calculated by dividing maximum estimated concentration in surface water by the lowest acute toxicity value for aquatic organisms (*6*). Again, this is a conservative estimate but is similar to that used for the assessment of the risk of glyphosate to non-target aquatic organisms (*4*) and allows for a comparative assessment of hazard. The hazard assessment data for exposures in 30 cm-deep surface water are shown in Figure 2. Toxicity and estimated exposure data for glyphosate and for the mixture of glyphosate and Cosmo-Flux® as used in Colombia are included for the purposes of comparison.

The hazard quotients calculated from environmental exposures in surface waters and the effect measure for the most sensitive aquatic organisms were also greater than 10 for several pesticides. In fact, for shallow waters (15 cm, data not shown), only pendimethalin and glyphosate (plus Cosmo-Flux®) had HQs less than 10. The HQ for endosulfan was, by comparison, 41,000 (*6*). Once again, most of the other pesticides used in the production of coca and poppy present a significantly greater hazard to aquatic organisms than glyphosate (and Cosmo-Flux®). Again, whether this represents a significant risk to the environment is uncertain as the frequency of use is not known. However, proximity of coca and poppy fields to surface waters is a constant with respect to use of pesticides by growers or eradication spraying from aircraft. Although not known exactly, the likelihood of contamination by pesticides used by coca and poppy growers and that from the use of glyphosate for eradication spraying is the same and these hazards can be used for compareative purposes.

Hazards to bees

Several of the pesticides used in the production of coca and poppy have high hazard to bees, and by extension, to other pollinators (Figure 2). This is not surprising as these pesticides are insecticides and are very toxic to insects. Compared to these substances, glyphosate is essentially non-toxic to honey bees (Figure 2). Tests conducted with the formulation of glyphosate plus Cosmo-Flux® as used in the spray program in Colombia showed that it was also non-toxic to honey bees with no observed effects at exposures ≤ 58 μg per bee (*4*).

Hazards to soil organisms

Soil organisms such as earthworms are important in maintaining soil quality

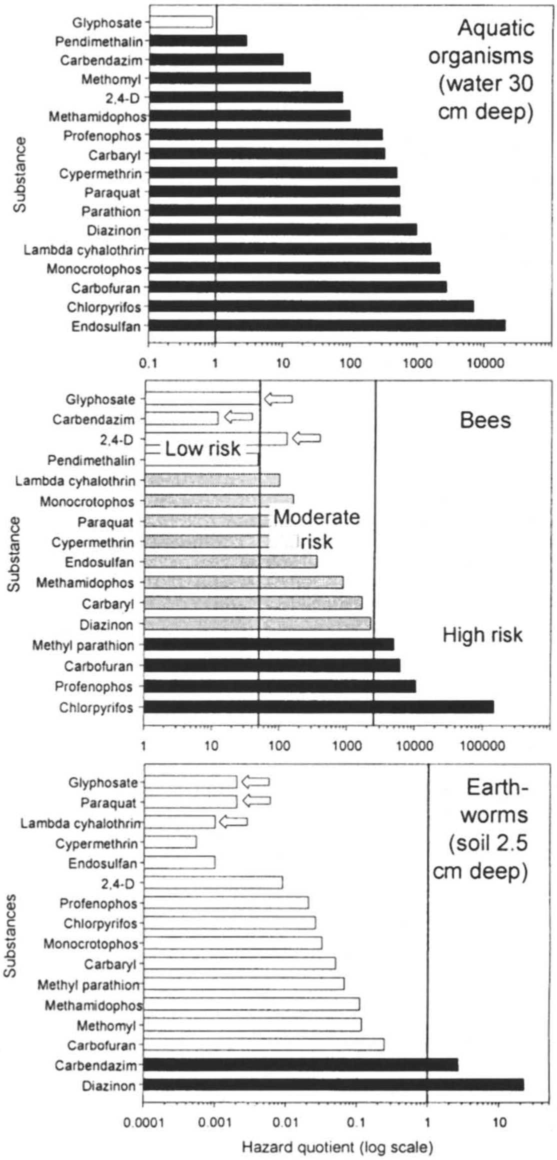

Figure 2. Hazard quotients for aquatic organisms, bees, and earthworms for pesticides used in the production of coca and poppy. Arrows indicate that the HQs were based on toxicity data that were greater than the largest tested concentration.

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and are routinely tested in the registration of pesticides. To assess hazards to earthworms, the data for the most sensitive soil organism (*6*) were compared to the concentration that would result if the soil was sprayed directly with the substance and it was evenly distributed in the top 2.5 or 5 cm of soil. Hazard ratios are shown in Figure 2. From these results, it is clear that a number of other pesticides that are used in the production of coca have greater hazards to earthworms than glyphosate. Diazinon and carbendazim both have hazard quotients greater than 1, suggesting that they may be hazardous to earthworms when used in coca and/or poppy production.

Comparative hazards from all activities in production and eradication of coca and poppy

There are a number of other activities associated with the process of cocaine and heroin production that result in risks to human health and the environment. While data were not available to quantify all the risks of these activities, some may be estimated on the basis of other knowledge and expert judgment. This was done using an adaptation of a risk prioritization scheme that has been used in ecological risk assessment (*13*). For the purposes of this ranking process for human hazards, the intensity score ranged from 0 to 5, with 5 being a severe effect such as a physical injury or toxicity. The recovery score also ranged from 0 to 5 and was based on the potential for complete recovery from the adverse effect. Frequency was based on an estimate of the proportion (%) of the total number of persons involved in coca and poppy cultivation, production, and the refinement of cocaine and heroin. The score for impact was the product of the individual scores and the percent impact is based on the sum of the impact scores (Table I).

Risks to humans and human health from the use of glyphosate and Cosmo-Flux® in the eradication of coca and poppy in Colombia were minimal (*4*). The acute toxicity of the formulated product and Cosmo-Flux® to laboratory animals was very small, the likely exposures were small, and the exposures were infrequent. When these risks are compared to other risks associated with clearing of land, the uncontrolled and unmonitored use of other pesticides to protect the coca and poppy, and exposures to substances used in the refining of the raw product into cocaine and heroin, they are essentially negligible. Compared to glyphosate exposures resulting from the eradication program, risks from potential misuse of and exposure to pesticides used in production were large.

A similar procedure to that described above was used for ranking ecological risks associated with the cycle of coca and poppy production. The intensity score was ranked from 0 to 5, with 5 being most intense, such as the total destruction of the habitat by clear-cutting and burning when clearing a natural area. Intensity of effects in this case also included off-field effects such as on non-target animals and plants.

Table I. Potential human health impacts of activities in the cycle of coca or poppy production

Activity	*Intensity score*	*Recovery score*	*Fre-quency %*	*Impact score*	*% impact*
Clear cutting and burning	5	3	3	45	16.7
Planting the coca or poppy	0	1	100	0	0.0
Fertilizer inputs	0	0.5	10	0	0.0
Pesticide inputs	5	3	10	150	55.6
Eradication spray	0	0	10	0	0.0
Processing and refining	5	3	5	75	27.8

Recovery time in this scheme is the estimated time for the impacted area to recover to a state similar to the initial condition. In the case of the clear cutting and burning, it is recognized that succession will begin immediately; however, full recovery to a mature and diverse tropical forest may take considerably more than the 60 years estimated here. Similarly, in the absence of cultivation, it was estimated that invasive and competitive species will displace coca and poppy in several years and an estimate of four years was used in this case. Given the need to apply fertilizer and pesticides frequently because of utilization of nutrients and resurgence of pests, the recovery time for these ecological impacts was judged to be small. The scores were multiplied to give the impact score and the percent impact was based on the sum of the impact scores (Table II).

Risks to the environment from the use of glyphosate and Cosmo-Flux® in the eradication of coca and poppy in Colombia were small in most circumstances (*7*). Risks of direct effects in terrestrial wildlife such as mammals and birds were judged to be negligible as were those to beneficial insects such as bees. Moderate risks to some aquatic wildlife may exist in some locations where shallow and static water bodies are located in close proximity to coca fields and are accidentally over-sprayed. However, when taken in the context of the environmental risks from other activities associated with the production of coca and poppy, in particular, the uncontrolled and unplanned clearing of pristine lands in ecologically important areas for the purposes of planting the crop, the added risks associated with the eradication spray program are small.

Table II. Potential environmental impacts of the cycle of coca or poppy production

Activity	*Intensity score*	*Recovery time (y)*	*Impact score*	*% Impact*
Clear cutting and burning	5	60	300	96.9
Planting the coca or poppy	1	4	4	1.3
Fertilizer inputs	1	0.5	0.5	0.2
Pesticide inputs	5	0.5	2.5	0.8
Eradication spray	1	0.5	0.5	0.2
Processing and refining	2	1	2	0.6

Uncertainties

There were significant data gaps and uncertainties related to the rates of application, the frequency of the application, and the protective equipment used by the applicators working in coca and poppy fields. Additional uncertainties relate to other routes of exposure in bystanders and other workers who may re-enter the fields shortly after application of chemicals. Biomarkers of exposure, such as concentrations of pesticides and metabolites in urine and blood or inhibition of red blood cell acetylcholinesterase would be more appropriate indicators of exposure but are almost impossible to obtain for logistical reasons. A general uncertainty related to the use of chemicals in the refining and production of cocaine and heroin is the purity of these substances. In some cases, impurities may increase toxicity and hazard to humans and the environment.

Additional uncertainties result from some of the conservative assumptions used in the characterizing of exposures and toxicity. For environmental exposures, it was assumed that direct overspray of water or soil occurred. If surface water was not over-sprayed and the only contamination was from drift, concentrations would be smaller. Similarly, soil concentrations were calculated without factoring in interception of the plant canopy which may reduce deposition on soil to less than 50% if plants are mature and the canopy is closed. For the environmental hazard assessment, toxicity values for the most sensitive organism were used. This organism may not be present in Colombia but, as is the case with all hazard and risk assessments, these organisms are surrogates for those that may be present and that have not been tested for sensitivity. In assessing human health hazards, the reference dose was used. This reference dose is based on daily exposure to the chemical for a lifetime and is somewhat conservative for assessing risks from single and infrequent exposures.

For these reasons, it was not possible to estimate risks with any certainty and was the reason for the use of HQs. Although the HQ is not an accurate indicator or predictor of risk from a substance, they may be compared on the basis of the relative HQs. In all cases, these substances presented greater hazards to humans and the environment than glyphosate, whether this herbicide is used in spray eradication or in the production of coca and/or poppy.

General conclusions

In general, many of the substances used in cocaine and heroin production and refining are potentially hazardous to human and environmental health. Comparatively, several of the short-listed pesticides are considerably more toxic to humans and nontarget organisms in the environment than glyphosate (plus Cosmo-Flux®). Most of the more hazardous pesticides were found to be insecticides, which are toxic to mammals and other wildlife, as well as to insects. With the exception of endosulfan, these chemicals are registered in Colombia for use in agriculture and their inclusion in this chapter does not imply that they should be further restricted or banned. However, if used improperly, such as in the production of coca and heroin, these compounds have the potential to present significant hazards to human and environmental health, much more so than the hazards identified for glyphosate as used in the eradication of illicit crops.

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