Resource ID#: 3996

The Health and Safety Concerns of Common Insecticides

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Abstract

The selection of an insecticide that is not only effective but poses the minimum risk to both people and the environment is an important decision best made by an informed environmental health professional. There are three major types of synthetic insecticides: organochlorines, organophosphates and carbamates, each with unique health hazards and environmental concerns. In addition, several naturally prepared products are used as insecticides. Other factors that can influence the hazards of insecticide use are packaging, formulation and application methods. Careful determination of the correct insecticide, although cumbersome, is necessary to avoid the potentially disastrous effects of improper insecticide use.

The safety of insecticides—both in terms of acute toxicity and long term, chronic health effects—has become an important environmental health issue in recent years. The potential hazards that can result from improper use of any insecticide become clearly evident when the consequences of exposure are examined and the need to strictly follow safety precautions must be emphasized whenever insecticides are to be used.

Environmental health professionals can be confronted with the task of recommending the use of one insecticide or another. The question of the comparative safety of different insecticides or classes of insecticides, however, can be difficult to answer. Most often there is a trade-off between safety and effectiveness or cost. The environmental health professional who is knowledgeable of the possible health effects and understands the principles of insecticide action is in a stronger position to recommend the insecticide most suited to a particular need.

It is strongly recommended that information on a specific product be obtained from the manufacturer and toxicological reference books be consulted so that the exact nature of a compound can be determined. The formulation of the specific product that is intended to be used is very important and can greatly influence the impact of the insecticide on its intended target, as well as risk to humans. The percentage of the active ingredient in the formulation is critically important, as is the nature of the carrier. For example, insecticides dissolved in a petroleum base will tend to be persistent in the environment.

When selecting a particular insecticide, the level of expertise of the applicators must also be considered. The use of many commercial insecticide formulations would not be appropriate for anyone other than professionals wearing protective gear. It should also be kept in mind that even professional applicators have been known to unintentionally contaminate the environment. The time invested in choosing the proper insecticide to be used is well worth the effort, considering the extensive and expensive damage that can be caused by the use of the wrong compound and poor application methods.

Synthetic products

Organochlorine insecticides

Organochlorines (OCs) represent the first class of synthetic insecticides developed and fall into three distinct groups, according to both chemical structures and neurological effects. The first type includes DDT and compounds which are derived from it by attaching side chains or chlorine atoms. The second group, cyclodienes, are composed of non-aromatic hydrocarbon ring structures to which a varying number of chlorine atoms have been added. In addition, there are chlorinated cyclohexane compounds which occur in several different isomeric forms.

Organochlorine exposures differ from organophosphate (OP) exposures in several important respects:

- OCs are generally less acutely toxic than OPs and death from overdose is less likely to occur (except in children).
- OCs are not as easily metabolized as OPs, and as a result chronic exposures are cumulative.
- OCs are lipophilic and concentrate in fat, where they can remain for very long periods of time.
- OCs have a different mechanism of action than OPs, in that they do not inhibit cholinesterase; instead, OCs overstimulate the nervous system by interfering with nerve impulses.

Acute exposures to OCs occur through accidents and suicide attempts, while chronic effects are pronounced in the occupational setting. Widespread exposure to the general public from the ingestion of residues is also of concern.

Accidental exposure to OC insecticides can be critical in young children. In a case reported by Garrettson and Curley (1), a four-year-old boy and his two-year-old sister consumed a 5% solution of dieldrin (a cyclodiene insecticide). The girl died before a physician arrived, but the boy was hospitalized in time and survived. The first symptom of the poisoning was heavy salivation followed shortly by convulsions and seizures leading to hypoxia and resultant cyanosis. The child was treated with intravenous anticonvulsants, including phenobarbital. The seizures stopped after seven hours and the boy completely recovered in three days. No further complications due to the exposure were detected after six months follow-up. In adults, severe outcomes are less likely unless very high doses are taken, such as in suicide attempts.

Organochlorine insecticides have been

implicated in several mass poisonings due to contamination of food stuffs. In 1954 in a rural area of Wales, bags of flour were contaminated with endrin (a cyclodiene insecticide) while being transported in a railway car. More than 150 people who ate bread baked from the contaminated flour were affected. The severity of symptoms varied according to the amount ingested: convulsions were seen in most exposed people; dizziness, weakness in the legs, abdominal discomfort and nausea were observed at lower exposures. No deaths or permanent injuries were reported (2).

Studies of workers in plants producing cyclodiene insecticides have uncovered neurological disturbances. In a Dutch plant manufacturing aldrin, dieldrin and endrin, it was documented that 17 workers had experienced convulsions. Electroencephalographic (EEG) anomalies were also twice as common in insecticide exposed workers studied as controls. Removal from exposure resulted in recovery without long term impairment (3).

Severe intoxications of workers and catastrophic contamination of the nearby James River estuary occurred when a Virginia plant which manufactured chlordecone (Kepone) operated without proper protective controls. The plant was permanently closed by the Virginia State Health Department in July 1975. By then more than half of the workers (76 of 133) were at least moderately ill from chlordecone exposure. The major neurological symptoms were a disabling tremor and a visual problem, *opsoclonia*, characterized by uncontrollable rapid eye movements. Other symptoms found included headache, walking difficulties and weight loss. In many cases, full recovery required more than a year. Massive pollution of the James River necessitated a ban on eating fish and crabs and drastically reduced bluecrab populations by 90% (4).

Mortality of workers employed in chlordane and heptachlor manufacture was studied by Wang and MacMahon (5). Although chlordane is considered to be carcinogenic in mice, deaths due to cancer (and circulatory disease) were not elevated in this study (6). However, a highly significant excess of deaths from cerebrovascular disease was found. Additional evidence on the relationship of insecticide exposure to hypertension and cerebrovascular disease is needed to properly assess this problem.

OC insecticides have resulted in persistent environmental contamination for two reasons. The synthetic nature of these compounds makes them resistant to microbial breakdown in most environmental media. Secondly, because they are very lipophilic, they accumulate in adipose tissue in humans, livestock and even wildlife. Once dissolved in fat, an OC insecticide such as DDT will remain in storage almost indefinitely.

A recent Canadian study measured OC residues in adipose tissue, mothers' milk and blood. Detectable levels of DDT and its metabolites were found in all of the 570 adipose tissue samples, demonstrating the ubiquitous nature of OC insecticide contamination. DDT was also detected in all but three of 348 human milk samples. Several other OC insecticides such as chlordane, dieldrin and mirex were also detected at lower levels. Since this study lasted for nine years, the persistence of these residues could be gauged. A slow decline in adipose tissue DDT levels was observed; residues of DDT in human milk declined markedly after DDT was banned in 1970, but then reached a steady state in subsequent years. OC insecticide levels in blood did, however, decline in many individuals. Disappearance of these OC insecticide residues from the human tissue pool is predicted to take several decades (7).

Organophosphate insecticides

Organophosphates (OPs) were originally developed by Germany as part of the World War II effort. They were to be used as a substitute for nicotine and as nerve gas in chemical warfare (8).

Parathion was synthesized in 1944 for agricultural use. It was designed to be less toxic to mammals, but sufficiently stable under environmental conditions to be used on crops as an insecticide. Parathion remains in wide use to this day, and is more toxic than most of the other OPs since developed. There are many other commonly used OPs, including malathion, diazinon and chorpyrifos (9).

Acute exposure to OPs can easily become life-threatening if left untreated. Numerous deaths related to OP exposure have been reported (10). Ingestion is the most common non-occupational route of exposure; however, critical cases of overexposure through skin contact also have been documented (11). Acute exposures usually occur in one of three ways: careless handling of the chemical leading to a spill (11); improper storage of the chemical in a container normally used for drinking; or by deliberate ingestion as a suicide or homicide attempt (12).

Symptoms of exposure that can readily be identified include salivation, nausea, headache, blurred vision, miosis, cyanosis and uncontrollable muscle twitches followed by muscular weakness (13). Overexposure to OPs can become life-threatening if respiratory failure occurs (14). Another serious consequence that may occur is cardiac arrest (12).

When OPs are the cause of a poisoning, treatment with the antidotes atropine and pralidoxime (2-PAM) should be started as soon as possible. Full recovery is usually possible within several days, unless central nervous system effects and delayed neurotoxicity occur (15).

Exposures to lower levels of OPs that occur over long periods of time are also common. These exposures are usually occupational in nature. The groups most often affected are insecticide sprayers, fruit pickers and other agricultural workers. The inhalation route figures prominently in this type of exposure, followed by the dermal route and the ingestion of contaminated food. Symptoms are similar to those of acutely exposed people, but are less marked. Exposure of workers can be monitored by measuring plasma or red blood cell (preferred) cholinesterase levels and by the detection of p-nitrophenol, a metabolite of parathion in the urine (16). Residues of OP insecticides on fruits and vegetables in the market place can also result in human exposure (17).

Lingering central nervous system effects after OP poisoning have been reported (18). Although symptoms can vary and are often ill defined, the overall pattern resembles acute cholinergic symptoms. Commonly this includes muscle aches and pains, numbness, irritability, fatigue and nervousness. These symptoms can last from six to 12 months after an exposure (12).

There is a second type of delayed OP toxicity which may have debilitating and

irreversible consequences. After exposure, nerve degeneration begins at the distal ends of large and long axons in conjunction with breakdown of the myelin sheath. Axonal degeneration slowly advances toward the nerve cell body. Fortunately, gradual regeneration is possible unless extensive damage has occurred to the neural body (19).

An early prototype of today's OPs, triorthocresyl phosphate (TOCP), readily produces this form of delayed toxicity and was responsible for several major tragedies earlier in this century. TOCP was ingested with certain lots of Jamaican ginger, resulting in a great number of paralysis cases in the U.S. (20). In Morocco in 1959, a mixture of olive oil and aircraft lubricant oil containing TOCP was sold for food, poisoning approximately 10,000 people (21). Although many OP insecticides that produce delayed toxicity have been removed from the market, two compounds, methamidophos and trichlorphon that had been considered safe were later found to cause delayed toxicity in humans (22).

Carbamate insecticides

Carbamates, developed after the hazards of organochlorines and organophosphates had become evident, are variations of an alkaloid, physostigmine, found in the African calabar bean. Carbamates are easily metabolized and excreted and do not bioaccumulate like organochlorines. Although their mechanism of action is essentially the same as organophosphates (cholinesterase inhibition), the action of carbamates is more readily reversible. Another great advantage is that the delayed neurotoxicity seen with some organophosphates is not found with carbamates.

The acute toxicity of carbamates varies greatly from more toxic compounds, such as aldicarb and oxamyl, to less toxic forms, such as carbaryl. Human exposure to carbamates can occur during the manufacturing process, through agricultural use and by accident or suicide. Adverse effects have also been recorded in consumers of carbamate treated fruits and vegetables.

Workers in a factory producing carbaryl were studied and substantial uptake of carbaryl was indicated because high levels of a breakdown product, 1-naphthol, were found in their urine. Plasma cholinesterase was also found to be depressed. However, no overt clinical disease attributable to carbaryl exposure was reported (23). Published information on long term exposure to carbaryl is limited, but adverse effects have not been identified (24).

The seriousness of acute poisoning by carbamates is determined by several major factors: the toxicity of the specific compound, the amount ingested, the age of the person and the promptness of antidote administration. Two fatal cases illustrate how serious poisoning by carbamates can be. In 1965, a 17-year-old boy took a solution of 22% Zectran (an extremely toxic carbamates insecticide) from the nursery where he worked. With intention to commit suicide, he drank up to 8 ounces of the insecticide preparation. When he arrived at the hospital he was in a coma, had pin-point pupils, an irregular heartbeat and pulmonary edema. He died about four to four-and-a-half hours after ingestion of the insecticide. There is no mention in the case report whether the antidote atropine was administered (25).

In another case, a 53-year-old woman working in a tobacco field drank "a swallow" of oxamyl (a very toxic carbamate insecticide), thinking that it was water. Despite reasonably prompt medical attention, she died within 12 hours (26).

Aldicarb, a very popular but extremely toxic carbamate insecticide-nematocide, has been implicated in both public health and environmental problems. Aldicarb, which is very stable in water, has caused widespread contamination of groundwater aquifers, most notably on Long Island in New York State where it was extensively used by potato farmers. In this area alone, more than 1,100 wells were affected by the late 1970s (27). Since then, aldicarb contamination of groundwater has been detected in many other states as well (28). The potential health concerns from drinking aldicarb-tainted water are not known, but alterations of the immune system have been demonstrated in both humans and animal models (29).

The other problem with aldicarb is that certain plants, such as melons and cucumbers, concentrate aldicarb and its toxic breakdown products in the edible portion of their fruit. Although the use of aldicarb is forbidden on these types of crops, massive episodes of aldicarb poisoning have still occurred in recent years in the western United States. The most extensive outbreak took place in the summer of 1985, when more than a thousand cases of aldicarb related poisonings from eating contaminated watermelon occurred (30). A recent re-evaluation of aldicarb toxicity seems to indicate that it is considerably more toxic than previously thought, and that levels in produce which could cause an adverse reaction in people may not be detected by current inspection methods (31).

These events have led to a call for tighter restrictions on the use of aldicarb and greater fines for misuse (32).

Natural products

Nicotine

Nicotine is an alkaloid found in the tobacco plant. It is an extremely toxic compound, at least as potent as most OP insecticides. Nicotine is present in low to moderate concentrations in tobacco products and is concentrated into insecticides that are used in agriculture or horticulture. Exposure to nicotine can occur to a variety of people: field workers harvesting tobacco leaves; smokers inhaling tobacco products; florists and farmers using nicotine insecticides and accident or suicide victims. Severe exposure can occur by both the dermal and ingestion routes. Nausea generally discourages overexposure by inhalation of smoke.

Field workers harvesting tobacco leaves often develop "green tobacco sickness," especially if they harvest wet, uncured leaves. Dermal absorption from the fluid on the leaves is the most important exposure route, but inhalation of aerosols may also occur. Symptoms take several hours to manifest themselves and include headache, nausea, dizziness, abdominal cramps and vomiting. Recovery usually takes place within one day. Smoking tobacco affords some protection, most likely because a tolerance to nicotine develops (33).

When nicotine is concentrated into an insecticide, accidental dermal exposure becomes a significant concern which can warrant hospitalization. Faulkner (34) described the case of a florist who sat in a chair where a nicotine-based insecticide had been spilled. Within 15 minutes, he was overcome with nausea, fainting and vomiting. On the way to the hospital he lost consciousness and became semi-comatose. He regained consciousness three hours later, but still exhibited other symptoms such as

pin-point pupils, weak pulse and cold extremities until the next day.

Due to the extreme toxicity of nicotine and lack of a specific antidote, ingestion of nicotine insecticides can be fatal (35). Nicotine is especially toxic to children (36). Poisonings usually occur because of improper storage in a beverage container or because of suicide (37).

Strychnine

Strychnine, another alkaloid, is found in the plant species *strychnos nox vomica*. The acute toxicity of strychnine is similar to nicotine and the more potent OP insecticides. There are two main types of commercial products which may contain strychnine: tablets used as a "tonic" (although of no real medicinal value), and preparations such as bait used to kill rodents or larger animals which are considered to be a nuisance.

Poisonings are almost always by the ingestion route and the onset of severe symptoms occurs rapidly. Lovegrave (38) describes an incident where three small boys ate strychnine bait. All three exhibited much the same symptoms, including pupillary dilation, muscular spasms and a characteristically abnormal breathing pattern known as Cheyne Stokes breathing. One boy who presumably ate the most strychnine died, while the other two recovered.

Barbiturates have been successfully used as an antidote in strychnine poisoning, but potential barbiturate overdose makes this treatment risky (39). For this reason the tranquilizer diazepam (Valium), which is also effective against strychnine, is considered a much safer choice for an antidote (40).

Pyrethrum and related compounds

Pyrethrum consists of several related compounds found in chrysanthemum flowers and has become a popular alternative to OP insecticides. The advantage of these compounds is that while being quite toxic to insects, they are of low toxicity to humans and other mammals. This is attributed to the fact that mammals can readily metabolize pyrethrum while insects presumably lack certain critical enzymes and cannot. Very little injury to humans has occurred due to accidental pyrethrum exposure. The health effects, usually seen in workers exposed to pyrethrum, are usually limited to allergenic dermatitis and asthma (13).

The effectiveness of pyrethrum with low human toxicity spurred the development of synthetic analogs called pyrethroids. While early compounds such as allethrin and tetramethrin exhibited excellent insecticidal activity, they shared the environmental instability of the natural compounds. This led to the development of permethrin, the first stable pyrethroid in 1973 and other related compounds that are in widespread use today (41). Pyrethroids are considered relatively safe to humans and non-threatening to the environment; however, massive exposure can lead to respiratory failure. Sensitivity to pyrethroids can also develop in some individuals (42).

Hazards of insecticide preparations

In addition to the innate toxicity of the active compound, there are several other factors that can affect the hazards of insecticide use and the safety of both workers and the environment. These include the packaging of insecticide products, the types of formulations used and the methods of application.

Packaging can create problems if the removal of the product is difficult, leading to spills or aerosol formation. Having to measure the insecticide before mixing can also result in exposure. How to safely dispose of the contaminated waste containers should also be considered. These problems can be eliminated by purchasing insecticides in premeasured, water soluble packets (43).

Since few insecticides can be applied as pure compounds, it is almost always necessary to mix them with some type of carrier before application. The most common types of formulations in use today are solutions, emulsions, powders, dusts and granules.

A few insecticides are soluble enough in water to be used as premixed solutions, or as water soluble powders. However, most insecticides have to be dissolved in a petroleum based solvent to produce a useable solution.

Emulsions are mixtures of insecticide, oil and water and require sophisticated preparation techniques. Wettable powders are prepared from insecticide and inert wetting agents. While easier to transport, inhalable dust can be generated during the mixing process.

Dusts can only be applied in a very dilute form and therefore large, cumbersome quantities are required. Granules, when suitable, can be highly effective and pose less of a hazard to the environment (44).

Microencapsulation and other controlled release methods have two advantages. They can benefit workers by making insecticide exposure less likely during application. Secondly, they deliver the insecticide more efficiently to the target organism, and therefore less of the active compound is needed. The selection of the polymer to which the insecticide is bound determines the rate of release of insecticide to the environment (45).

Although exposure to insecticides can occur during mixing and loading, it is field applicators who generally receive the highest doses. Most of this exposure is through the dermal route rather than by inhalation (43). Protective clothing made of impermeable materials, gloves and head gear specific to the application should be purchased from a knowledgeable vendor.

Conclusion

The toxicity of an insecticide should be evaluated in terms of three factors: acute toxicity, long term chronic effects, and the potential to contaminate the environment. Acute toxicity is most relevant to the applicators of the insecticide and accidental or intentional misuse, which usually occurs by ingestion. Acute toxicity is a function of the specific compound rather than the class to which it belongs. For example, the use of a highly toxic OP, such as parathion, or the compound oxamyl, a very toxic carbamate, would present similar exposure risks.

Long term toxicity and environmental contamination concerns are greatest with OCs, and in fact DDT, which was once widely used, has been banned because of these reasons. In addition, OCs often can have carcinogenic properties.

The substitution of a naturally based product for a synthetic insecticide may make sense in the case of pyrethrum and pyrethroids, which can often be as effective as an OP while being significantly safer to humans.

However, it must be recognized that each specific application of an insecticide

can have unique requirements and the decision of which insecticide to use should be done on a case-by-case basis. Therefore, an informed decision by an environmental health professional is essential in order to minimize the risks to people and the environment, while still managing to accomplish the task at hand.

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