From the Toxipedia website in original form. Last updated by Toxipedia in 2014.
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Pesticides

Overview

Definition

The purpose of a pesticide is usually to kill or repel some form of life. The US Environmental Protection Agency's definition of a pesticide is as follows: "A pesticide is any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest. Though often misunderstood to refer only to insecticides, the term pesticide also applies to herbicides, fungicides, and various other substances used to control pests." Pesticide formulations contain both "active" and "inert" ingredients. Active ingredients are what kill the pest, and inert ingredients help the active ingredients to work more effectively.

Types

The two largest classes of synthetic pesticides are insecticides, which are designed to kill insects, and herbicides, which are designed to kill plants. Other classes of pesticides include fungicides (for molds and fungi), rodenticides (for mammals), and antimicrobials (for microorganisms such as bacteria and viruses). Antimicrobial pesticides are used as preservatives, sterilizers, and disinfectants in home, institutional, and commercial environments. (For more information on antimicrobial pesticides, see this EPA website. Note that pharmaceuticals intended to kill organisms in the body, such as bacteria and parasitic worms, are not defined as pesticides and are regulated as drugs.)

How Pesticides Work

Pesticides work by interfering with an essential biological mechanism in the pests, but because all living organisms share many biological mechanisms, pesticides are never specific to just one species. While pesticides may kill pests, they may also kill or harm other organisms that are beneficial or at least not undesirable. They may also harm people who are exposed to pesticides through occupational or home use, through eating foods or liquids containing pesticide residue, or through inhaling or contacting pesticide-contaminated air. The ideal pesticide would be highly specific to only the target organism, be quick acting, and would degrade rapidly to harmless, inert materials in the environment.

(Photo: pesticide application in Canada. Source: Wikimedia.)

Literature Review of Pesticides' Impact on Human and Environmental Health

In the Fall of 2009, Toxipedia was hired by the King County Local Hazardous Waste Management Program to do a literature review of published journal articles examining the impacts of pesticides on human and environmental health. We summarized fifteen articles to provide quick, easy-to-understand accounts of each study and its findings. Articles are separated into five categories as seen below. Each category contains an introduction and three article summaries.

Pesticides - History

Minerals and Metals

One of the first pesticides was sulfur, used by the Chinese in around 1000 BC to control bacteria and mold (fungus). Sulfur is still widely used today. For example, it is used in fungides to control diseases on both agricultural and ornamental plants, and in the wine industry, sulfur is used to control unwanted bacterial growth in empty wine barrels and is commonly added to wine to kill unwanted yeast. The Chinese also pioneered the use of arsenic-containing compounds to control insects. Arsenic has a long history of use both as an insecticide and herbicide, and also as a medicine. Arsenic trioxide was used as a weed killer (herbicide) in the late 1800s, and lead arsenate, containing both lead and arsenic, was used as an insecticide, particularly in orchards, prior to the development of synthetic pesticides following WWII. Some of the first concerns about pesticide safety were raised over lead arsenate residue on fruit and in orchards, and to this day, some orchard soils remain contaminated with lead and arsenic. Arsenic in the form of chromated copper arsenate (CCA) is used today as a wood preservative (to keep wood in contact with soil or moisture from rotting).

Plant-based Pesticides

Plants have provided several other important nonsynthetic pesticides. In the late 1600s nicotine, an extract from tobacco leaves, was recognized as a potent insecticide and is now in limited use as a pesticide. Another group of nonsynthetic insecticides is pyrethrums, which are harvested and refined from chrysanthemums. The Strychnine tree, *Nux vomica*, contains strychnine used to kill rodents. Finally, rotenone, an insecticide and fish poison, is extracted from the root of *Derris elliptica*, a climbing plant from Southeast Asia. Plant extracts are useful for controlling pests, but they are often difficult to purify and produce in large quantities. Consequently, the modern use of plant-based pesticides didn't significantly increase until advances were made in synthetic chemistry and pest biology.

Synthetic Pesticides

Synthetic chemistry advanced rapidly in the 1930s and by the early 40s, a range of new pesticides had been developed, including organochlorine insecticides like DDT. In 1937 the first organophosphate compounds were synthesized by a group of German chemists. These very potent compounds were kept secret during World War II and were originally developed as potential chemical warfare agents. After the war, these organophosphate compounds were re-purposed as insecticides, and many organophosphate insecticides continue to be used today.

Herbicides were developed after WWII in order to increase food production and create possible warfare agents. In 1946, the first commercially available chlorine-based herbicides were marketed to kill broadleaf plants. This class of compounds includes 2,4-D (2,4-Dichlorophenoxyacetic acid) and 2,4,5-T(2,4,5-Trichlorophenoxyacetic acid), synthetic auxins (plant hormones) that disrupt plant growth. These herbicides have been extensively utilized in agriculture and to clear roadsides and rights of way. 2,4,5-T was used extensively during the Vietnam War to defoliate jungle plants. During the manufacturing process, 2,4,5-T was often contaminated with the persistent and very toxic dioxin, TCDD (2,3,7,8-tetrachlorodibenzo-p-dioxin). Dioxins, like other chlorinated compounds including DDT, bioaccumulate in body fat and persist in the environment for many years (the soil half-life is 10 to 12 years). Dioxins are classified as carcinogens and are also known to affect the reproductive and immune systems.

The U.S. EPA cancelled the use of 2,4,5-T because of the dioxin contamination, but 2,4-D is still one of the most widely used herbicides. (Photo: A UH-1D helicopter from the 336th Aviation Company sprays a defoliation agent on a dense jungle area in the Mekong Delta. *26 July 1969/National Archives photograph.)*

U.S. Pesticide Regulation

In the United States, regulation initially focused on protecting the consumer from pesticide residue on food, but it became apparent that protection was needed for workers applying or working near pesticides. Congress passed the first federal act specifically dealing with pesticides in 1947. This act, the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), allowed the U.S. Department of Agriculture to regulate appropriate labeling of pesticides. Unfortunately, this law did not provide sufficient protection for consumers or workers. Rachel Carson's *Silent Spring*, published in 1962, explored the harmful effects of pesticides, especially DDT, on people, wildlife, and the environment and marked a turning point in our understanding of the effects of chemicals on human and environmental health.

In 1972 the U.S. Environmental Protection Agency was formed and given authority to register pesticides based on evaluating and weighing estimated risks and benefits. Subsequent revisions to FIFRA greatly expanded the testing requirements companies must comply with before pesticides could be registered for use. Current requirements include acute toxicity testing of full formulations (including inert ingredients); however, chronic and sub-chronic testing is only required for the active ingredients. Results of these tests, which are conducted by manufacturers and submitted to EPA, are used to estimate potential risks to human health and the environment. There is also an international effort to harmonize regulatory standards between the United States, Europe, and Japan.

In 1996 the Food Quality Protection Act passed by Congress required that special consideration be given to children's exposures and their special sensitivity to pesticides and other chemicals. This act requires an added safety factor when calculating risk to children.

Pesticide Use Statistics

Both the volume of pesticides used and the amount of money spent on pesticides demonstrate our dependency on these chemicals.

Amount of Pesticides Used in the US and Worldwide

The EPA reported that 4.9 billion pounds of pesticide products were used in the United States in 2001, which is equivalent to 4.5 pounds per person. Approximately 888 million pounds of active ingredients and 600 different chemical compounds were included in these pesticides. The agriculture industry used about 675 million pounds of pesticide active ingredient (76% of total active ingredients used) and 102 million pounds (11.5%) were used on lawns and gardens by homeowners and by government and general industry. Another 2.6 billion pounds were used in disinfectants, and 0.80 billion pounds were used for wood preservatives.
Worldwide, about 5.05 billion pounds of pesticide active ingredient were used in agriculture in 2001.

Pesticide Use in the United States (2001 estimates)

Type	Billions of Pounds	Percentage
Conventional pesticides (herbicides, insecticides, fungicides, etc.)	0.89	17.7
Other pesticide chemicals (sulfur, petroleum oil, etc.)*	0.32	6.4
Wood preservatives	0.8	16.1
Specialty biocides (antimicrobial pesticides)	0.35	7.2
Chlorine/hypochlorites (used in water disinfection)	2.61	52.5
TOTAL	4.97	100

*This category is defined by EPA as follows: "The pesticides in this group include sulfur and petroleum oil and other chemicals used as pesticides, such as sulfuric acid, insect repellants (e.g., DEET), moth control products (e.g., paradichlorobenzene), and others."
Source: EPA Pesticides Industry Sales and Usage 2000 and 2001 Market Estimates, Table 3.3 (2004)

US and Global Expenditures

In 2001, total expenditures for pesticides in the U.S. were $11.09 billion, of which $7.4 billion was spent by the agricultural industry. Worldwide, the cost of pesticides used for agriculture in 2001 was US$31.8 billion.

Home Use of Pesticides

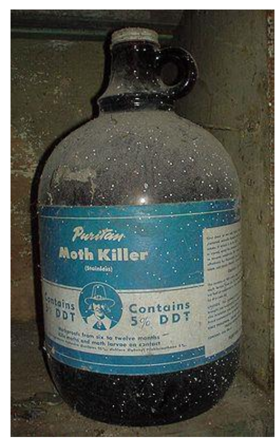
Home use of pesticides is widespread, and unfortunately there are many examples of home poisoning with pesticides. Consumers who use pesticides often apply them at much greater rates per acre than do farmers and professional pesticide applicators. Children are at particularly increased risk to pesticides that have been tracked in from outdoors as well as from pesticides that are used inside the home.

Efforts to Reduce Exposure and Use

Increased understanding of the possible health and environmental effects of pesticides is driving the demand for tighter regulation of pesticides use and is motivating efforts to reduce exposures, especially to children. Some communities are moving to ban the use of pesticides on lawns and landscaping, along roadsides to control weeds, and in and near schools, among other initiatives. People worldwide are recognizing the effects of pesticides on water quality and the health of wildlife, and there is increasing awareness of occupational hazards, especially to workers in developing nations. While pesticides may be needed to help protect crops and control indoor pests, they need to be used prudently and with knowledge of their potential harm. We need to continue to reduce unnecessary pesticide use, find safer and more selective pest management tools, and protect sensitive populations from exposure.

Biological Properties of Insecticides

Most chemical insecticides act by poisoning the nervous system. The central and peripheral nervous system of insects is fundamentally similar to that of mammals. A small amount of pesticide can be fatal to an insect, primarily because of the insect's small size and high rate of metabolism. While that same amount will not be fatal to a person, it may still cause harm.



The similarities of nervous system structure make it nearly impossible to design insecticides that affect only target insect pests; consequently, insecticides may affect non-pest insects, people, wildlife, and pets. Some insecticides harm water quality or affect organisms in other ways; for example, the insecticide carbaryl (a carbamate insecticide, further discussed below) is listed as a carcinogen by the state of California and as a possible hormone disruptor by the state of Illinois' EPA. The newer insecticides are designed to be more specific and less persistent in the environment.
The most prominent classes of insecticides are organochlorines, organophosphates, carbamates, andpyrethroids.

Organochlorines

The chemical structure of organochlorines is diverse, but they all contain chlorine, which places them in a larger class of compounds called chlorinated hydrocarbons. Organochlorines, which includeDDT, demonstrate many of the potential risks and benefits of insecticide use.

While organochlorines have the advantage of being cheap to manufacture and are effective against target species, they have serious unintended consequences. Organochlorines disrupt the movement of ions such as calcium, chloride, sodium, and potassium into and out of nerve cells. Depending on the specific structure of the organochlorine chemical, it may also affect the nervous system in other ways. At one time organochlorines were thought to be ideal because they are very stable, slow to degrade in the environment, dissolve in fats (and are therefore readily taken up by insects), and seemingly harmless to mammals. Unfortunately it eventually became clear that the attributes of persistence and fat solubility were actually very undesirable: the organochlorines passed up the food chain, where they bioaccumulated in the fat of large animals and humans and were passed on to nursing young. The global use and transport of organochlorines resulted in the contamination of wildlife around the globe, including in Arctic and Antarctic regions where these insecticides are rarely if ever used. A decline in the number of birds that prey on animals exposed to DDT was one of the first signs of the unintended consequences. Unexpectedly, DDT caused a thinning of the birds' eggshells and resulted in the death of their developing young.

Organochlorines like DDT are now largely banned in industrialized countries but they are still manufactured and used in developing countries. (Banned pesticides are still manufactured in some industrialized countries and exported.) Organochlorine insecticides provide many important lessons about the desirable and undesirable properties of pesticides.

Organophosphates and Carbamates

Organophosphates and carbamates have very different chemical structures, but share a similar mechanism of action and will be examined here as one class of insecticides.

Organophosphates were initially developed in the 1940s as highly toxic biological warfare agents (nerve gases). Modern derivatives, including sarin, soman, and VX, were stockpiled by various countries and now present some difficult disposal problems. Researchers created many different organophosphates in their search for insecticides that would target selected species and would be less toxic to mammals. When the organophosphate parathion was first used as a replacement for DDT, it was believed to be better as it was more specific. Unfortunately there were a number of human deaths because workers failed to appreciate the fact that parathion's short-term (acute) toxicity is greater than DDT's.

The problem with organophosphates and carbamates is that they affect an important neurotransmitter common to both insects and mammals. This neurotransmitter, acetylcholine, is essential for nerve cells to be able to communicate with each other. Acetylcholine released by one nerve cell initiates communication with another nerve cell, but that stimulation must eventually be stopped. To stop the communication, acetylcholine is removed from the area around the nerve cells, and an enzyme, acetylcholinesterase, breaks down the acetylcholine. Organophosphates and carbamates block the enzyme and disrupt the proper functioning of the nerve cells. Hence, these insecticides are called acetylcholinesterase inhibitors.

Structural differences between the various organophosphates and carbamates affect the efficiency and degree to which the acetylcholinesterase is blocked. Nerve gases are highly efficient and permanently block acetylcholinesterase, while the commonly used pesticides block acetylcholinesterase only temporarily. The toxicity of these pesticides presents significant health hazards, and researchers continue to work to develop new insecticides that have fewer unintended consequences.

Pyrethroids

One of the newer classes of insecticide, synthetic pyrethroids are loosely based upon the naturally occurring pyrethrum found in chrysanthemum flowers. Synthetic pyrethroids were first developed in the 1980s, but the naturally occurring pyrethrum was first commercially used in the 1800s. Their use has increased significantly over the last 20 years. The chemical structure of pyrethroids is quite different from that of organochlorines, organophosphates, and carbamates but the primary site of action is also the nervous system. Pyrethroids affect the movement of sodium ions (Na+) into and out of nerve cells, causing the nerve cells to become hypersensitive to neurotransmitters. Structural differences between various pyrethroids can change their toxic effects on specific insects and even mammals.

Synthetic pyrethroids are more persistent in the environment than natural pyrethrum, which is unstable in light and breaks down very quickly in sunlight.

Biological Properties of Herbicides

Herbicides are used to kill or damage plants and are the most rapidly growing type of pesticide. Prior to the 1930s, herbicides were nonspecific and often very toxic to humans as well as other animals. In the 1930s, researchers discovered several chemicals that selectively killed plants while developing new insecticides. These chemicals are now widely used to increase food production by killing weeds that choke out or compete with food crops.

The most well-known herbicides are the chlorophenoxy compounds that include 2,4-D and 2,4,5-T. This herbicide mixture, sometimes called Agent Orange in the 1960s, was widely used to kill broadleaf plants in agricultural fields, along roadsides, and on rights of way for power lines. It was also extensively used as a chemical warfare agent to kill unwanted vegetation, for example in jungles. The mechanism of action of this class of chemicals is poorly understood, but the herbicides appear to interact with plant growth hormones. (See Pesticides - History for discussion of the contamination of 2,4,5-T with dioxin.)

Paraquat and the related chemical diquat are nonselective herbicides that are also toxic to mammals. Occupational or accidental exposure to paraquat can occur by ingestion, skin exposure, or inhalation, all of which can cause serious illness or death. While seldom used in the United States at this time, paraquat is still widely used in developing countries. At one time it was used in marijuana plant eradication programs, but it was discontinued when a number of fatalities were observed in smokers of paraquat-contaminated marijuana.

There are many other herbicides in widespread use, such as alachlor, glyphosate, and atrazine, and they have a range of actions on plants and animals.

Herbicides have become an essential part of the agriculture business and are thought by some to be necessary for high crop yields. However, a serious limitation of many herbicides is their lack of specificity; in other words, herbicides can damage the crops of interest. The manufacturers of herbicides

are working to address this problem and are increasingly turning to biotechnology to create genetically modified crops that are herbicide resistant. For example, Monsanto produces the glyphosate-based herbicide RoundUp. The company also manufactures a genetically modified soybean that is resistant to RoundUp. This allows farmers to use RoundUp herbicide with the RoundUp Ready soybean plants and not have to worry about killing the soybean plants. The genetically modified RoundUp Ready soybean is now widely planted, though the practice has generated considerable controversy internationally.
(Photo: weeds sprayed with herbicide)

Biological Properties of Fungicides

Fungicides were developed to control the fungi and mold that may grow on crops, stored foods and seeds, and in our bodies. Control of plant fungus in agriculture is important not only because fungi can damage crops, but also because some fungi produce toxic chemicals (mycotoxins). One fungus, *Aspergillus flavus*, often contaminates nuts (e.g. peanuts) and grains (e.g. corn). This fungus produces aflatoxin, a compound that can cause liver disease and in some situations, liver cancer. Another naturally occurring grain fungus produces an ergot alkaloid that can cause hallucinations.
Early fungicides were sulfur, copper sulfate, and mercury-based compounds. In the 1940s and 50s, hexachlorobenzene, a synthetic fungicide, was widely used to protect seed grain from fungal rot. Mercurial compounds were also applied to seed grains to protect them from soil fungus. Both of these chemicals caused severe illness when people ate treated grains intended for planting as crops. These two fungicides are now rarely used and have been replaced by less-toxic ones, but careful harvest and storage procedures for seeds are necessary to prevent potential contamination of food supplies. The overall need for fungicides in seed and crop storage can be reduced by controlling environmental conditions that encourage the growth of fungi, and Integrated Pest Management reduces the need to use dangerous fungicides on growing plants.

Biological Properties of Rodenticides

Rodenticides are a broad class of pesticides designed to kill small mammals such as rats and mice. Some rodenticides are anticoagulants and work by inhibiting blood-clotting; these are often used to control rat populations. One of the first anticoagulant rodenticides was warfarin, which is related to plant-derived coumadin (from spoiled sweet clover). In the 1950s rats developed resistance to warfarin, which prompted scientists to develop more potent anticoagulants, which are termed second-generation anticoagulants. Other rodenticides include fluoroacetic acid and zinc phosphide (which are both very toxic), and thiourea-based compounds.

One of the problems of rodenticides is that they may also harm wildlife that mistake pesticide-containing baits or pellets for food. Wildlife, such as wolves or birds of prey, may also be harmed by eating rodents or other animals that have been poisoned. The primary alternative to using chemical rodenticides is trapping.

Biological Properties of Molluscicides

Molluscicides are used to control slugs and snails. Molluscs are a group of invertebrate animals that include shellfish, cephalopods (such as squid and octopus), slugs, and snails.
The most commonly used active ingredient in molluscicides is metaldehyde, which disrupts the gastric organs of slugs and snails, causing death. This product is often manufactured as brightly colored pellets, which has the unfortunate unintended consequence of being attractive to children, wildlife, and pets. Some manufacturers have added a bitter agent to make the products unpalatable.
Alternatives to chemical molluscicides include using traps or barriers, or designing gardens that are less attractive to slugs. Slug and snail baits containing iron phosphate as the active ingredient are also available and are less toxic than metaldehyde. (Photo: *Arion ater* slug)

Effects of Pesticides on Human Health

Introduction

Pesticides are designed to kill and because their mode of action is not specific to one species, they often kill or harm organisms other than pests, including humans. The World Health Organization estimates that there are 3 million cases of pesticide poisoning each year and up to 220,000 deaths, primarily in developing countries. The application of pesticides is often not very precise, and unintended exposures occur to other organisms in the general area where pesticides are applied. Children, and indeed any young and developing organisms, are particularly vulnerable to the harmful effects of pesticides. Even very low levels of exposure during development may have adverse health effects.

Pesticide exposure can cause a range of neurological health effects such as memory loss, loss of coordination, reduced speed of response to stimuli, reduced visual ability, altered or uncontrollable mood and general behavior, and reduced motor skills. These symptoms are often very subtle and may not be recognized by the medical community as a clinical effect. Other possible health effects include asthma, allergies, and hypersensitivity, and pesticide exposure is also linked with cancer, hormone disruption, and problems with reproduction and fetal development.

Pesticide formulations contain both "active" and "inert" ingredients. Active ingredients are what kill the pest, and inert ingredients help the active ingredients to work more effectively. These "inert" ingredients may not be tested as thoroughly as active ingredients and are seldom disclosed on product labels. Solvents, which are inert ingredients in many pesticide formulations, may be toxic if inhaled or absorbed by the skin.

Children are at greater risk from exposure to pesticides because of their small size: relative to their size, children eat, drink, and breathe more than adults. Their bodies and organs are growing rapidly, which also makes them more susceptible; in fact, children may be exposed to pesticides even while in the womb.

Insecticides

Organochlorines

Acute ingestion of organochlorine insecticides can cause a loss of sensation around the mouth, hypersensitivity to light, sound, and touch, dizziness, tremors, nausea, vomiting, nervousness, and confusion.

In 1975, over 70 workers manufacturing Kepone, an organochlorine insecticide, in Hopewell, Virginia, developed a variety of neurological symptoms, the most prominent of which became known as the "Kepone shakes." The workers' symptoms started about 30 days after their first exposure to Kepone. Subsequent testing also revealed decreases in sperm count and motility. In 1976, Kepone was discontinued and substituted with organophosphates.

Organophosphates and Carbamates

Acute organophosphate and carbamate exposure causes signs and symptoms of excess acetylcholine, such as increased salivation and perspiration, narrowing of the pupils, nausea, diarrhea, decrease in blood pressure, muscle weakness, and fatigue. These symptoms usually decline within days after exposure ends as acetylcholine levels return to normal.

Some organophosphates also have a delayed neurological reaction characterized by muscle weakness in the legs and arms. During Prohibition, people consumed a homemade alcoholic drink made out of Jamaican ginger that was contaminated with the organophosphate triorthocresyl phosphate (TOCP). More than 20,000 people were affected by a condition called "Ginger Jake paralysis." Later research found that these effects could be reproduced in animals, and the US government required that organophosphates be tested for delayed effects during the registration process. The human toxicity of organophosphates caused a decline in their use and spurred the search for new alternatives.

Pyrethroids

Among the most promising alternatives to organophosphates were synthetic pyrethroids. However, pyrethroids can cause hyper-excitation, aggressiveness, uncoordination, whole-body tremors, and seizures. Acute exposure in humans, usually resulting from skin exposure due to poor handling procedures, usually resolve within 24 hours. Pyrethroids can cause an allergic skin response, and some pyrethroids may cause cancer, reproductive or developmental effects, or endocrine system effects.

Herbicides

Herbicides are generally less toxic to mammals than insecticides. Most herbicides interfere with plant hormones or enzymes that do not have any direct counterpart in animals. The most serious human health concerns have been related to chemical contaminants in the active ingredient. Military personnel and others exposed toAgent Orange, a mixture of the herbicides 2,4-Dand 2,4,5-T that was contaminated with dioxin(TCDD), reported birth defects, cancers, liver disease, and other illness. These concerns lead to improvement in the manufacturing process of 2,4,5-T to reduce TCDD contamination and ultimately lead to cancellation of 2,4,5-T and reduction in use of 2,4-D. However, some herbicides may cause cancer, reproductive or developmental effects, or endocrine system effects.

There is also concern that some herbicides may affect wildlife, especially aquatic organisms. For example, atrazine, a persistent herbicide, may adversely affect frogs. Concerns about the effect of atrazine on amphibians resulted in its ban in the European Union, but atrazine remains one of the most widely used herbicides in the US (over 70 million pounds used per year). Persistent herbicides may also contaminate surface water and groundwater.

Integrated Pest Management (IPM)

Integrated pest management (IPM) is an approach to pest management that can significantly reduce pesticide use. Widely used in agriculture, landscape maintenance, and structural pest control, it emphasizes prevention and monitoring of pest problems and considers pesticide applications only when non-chemical controls are ineffective or impractical.

IPM can be practiced by individuals in and around their homes. A home IPM approach stresses proper food-waste management, appropriate plant selection and landscape design, biological and cultural controls, and physical controls such as traps, barriers, and mechanical removal.

Summary and Recommendations

Pesticides are widely used to help ensure an adequate food supply as well as to protect our health and safety from unwanted pests. But despite their benefits, these chemicals are not without their problems: they pose known and potential risks to human and environmental health. Individually and collectively we need to examine our use of all forms of pesticides and consider alternatives to the use of pesticides. More research is needed to find and test less-toxic alternatives as well as to develop pesticides that do a better job targeting particular species.

Businesses, schools, institutions, and home gardeners that use pesticides should explore integrated pest management (IPM) methods to reduce pesticide use. Storage and proper disposal of pesticides also deserves special attention.

An ongoing problem is the lack of data on the use of pesticides in various sectors. States and nations should consider adopting pesticide use registries to determine the actual volume of pesticides used, and to assist in the study of pesticide-related health and environmental effects. Finally, farmworkers and other workers who apply pesticides should receive adequate training on proper handling, storage, and protective equipment.