

PESTICIDES

INTRODUCTION:

Man employs pesticides as purposeful environmental contaminants in order to improve environmental quality for himself and his domesticated animals and plants. In agriculture, pesticides are used to increase the cost/benefit ratio in favor of the farmer and of the ultimate consumer of food and fiber products, the citizen. It has been widely estimated that the U.S. farmer receives an average net return of about \$4 for every \$1 invested in pesticides (PSAC, 1965, Pimentel and Levitan, 1986). In our present era of managed ecology of monocultures, of farm mechanization, and of the complex system of food harvesting, processing, distribution and storage, the use of pesticides often represents the slender margin between crop production and crop failure, and between economic profit and economic loss. In the developing countries where food supplies are marginal, pesticide use may represent the margin between survival and starvation. In public health, pesticides often provide the only feasible means for the control of the invertebrate vectors of human and animal diseases. It is difficult to place monetary values on human health, but for malaria in India, the World Health Organization has estimated that an investment of \$200 million in malaria control by DDT residual house spraying during 1956-66 saved 179.5 million man days of labor or an estimated saving of \$490 million. The Cost/benefit ratio has thus been about \$2.7 return for every \$1 invested. In addition, during this period the annual number of cases of malaria has decreased from 75 million to 150,000 and deaths from about 750,000 to 1500 (World Health, 1968). In surveying the role of pesticides in environmental quality it must be remembered that pests themselves generally affect adversely the quality of the environment. The spectrum ranges from a mosquito in the bedroom or a cockroach in the pantry to a plague of locusts or the tsetse flies (*Glossina* spp.) which as vectors of trypanosomiasis have effectively prevented the development of 4.5 million square miles of Central Africa. The presence of vicious biting black flies (*Simulium* spp.) or wide-spread defoliation of

forest and shade trees by the gypsy moth (*Porthetria dispar*) or other defoliators are effective deterrents to the resort industry in many northland vacation sites. Who can place a realistic value on the loss to environmental quality from the chestnut blight or the Dutch elm disease which have destroyed millions of North America's finest shade trees? Therefore it must be recognized that the purposeful environmental contamination by pesticides generally provides environmental benefits substantially greater than the risk of environmental pollution. It is also necessary to distinguish carefully between *environmental contamination*, which may not pose any risk or hazard to the environment, and *environmental pollution* where the health or well being of man or other animals and plants may be severely threatened. Environmental contamination is often a matter of degree, as for example with selenium, which at very low levels is essential for the normal growth and development of vertebrates yet at higher levels is an extremely poisonous pollutant. What is wanted then in an exploration of "pesticides in the environment" is a scientific appraisal of all these elements, a judicious weighting of risk/benefit ratios, and where deleterious effects on environmental quality are detected, the prompt substitution of remedial measures and/or alternative pesticides which pose no environmental hazard (Brown, 1978, McEwen and Stevenson, 1979). Another measure of the economic value of pesticides is the total extent to which they are used. Pesticide production in the United States increase in total production from 1962 to 1976 was about 5% per year but since that time growth has averaged only about 1% per year. Over this period, there have been major changes in use patterns with herbicide use doubling from 1962 to 1968 and doubling again by 1980. The use of insecticides grew slowly from 1962 to 1974 and since that time has decreased about 5% per year. Agricultural use represents about 68% of the market, industrial use 17%, home and garden use 8%, and governmental use 7% (Storck, 1984, 1987). In global terms, the United States uses about 26% of total production, W. Europe 25%, the Far East 22%, E. Europe and USSR 10%, Latin America 9%, and the other regions about 8% (Chem. Week, 1985). The most recent major inventory of pesticide use in United States agriculture was made in 1976 when it

was estimated that 295 million kilograms of pesticide active ingredients were applied to 84 million hectares of cropland or about 61% of the total crop acreage. Herbicides were applied to 56%, insecticides to 18%, and fungicides to 2% of cropland. Corn was the most heavily treated crop with about 36% of total farm use, followed by soybean 13%, and cotton 12%. These three crops accounted for 61% of the total farm use of pesticides.

What are pesticides? Why are they used?

Pesticides are agents used to destroy pests. Under certain circumstances almost any living creature can be a pest. The purposes of pesticide use are to increase the production of food and fiber and to promote public health; in practice they are also used for aesthetic reasons. A pesticide that kills insects is an *insecticide*. One killing plants is a *herbicide*. Other pesticide types are seen in Table 16.1. Among the pests attacking agricultural crops are insects, weeds, rodents, birds, and disease-causing organisms including fungi and bacteria. Weeds are undesired plants of any kind that, if left uncontrolled, crowd out the desired crop plant. The amount of manual labor necessary to control weeds without help from herbicides or machines may be difficult to imagine. Well-to-do societies with their abundant food supply also don't ordinarily think of the total loss of a food crop. An example was the devastation of potato crops by a fungal infection in nineteenth-century Ireland. The resulting famine drove millions to immigrate to the United States, and resulted in the death of another million remaining behind. Similar fungal infections are still found in potatoes today, but are controlled using pesticides. Pest infestations have afflicted agriculture for as many thousands of years as humans have farmed. For longer periods yet, pests -- including fleas, lice, mosquitoes, flies, roundworms, rats, and mice -- have threatened human health. For thousands of years, people looked for means to rid their crops of the insects eating them, the weeds choking them, or the fungi making them uneatable.

Pesticide ^a	Pest killed
Insecticides	Insects
Larvicides	Insect larvae
Fungicides	Fungi growing on plants (or animals)
Herbicides	Plants (weeds)
Fumigants	All life forms
Disinfectants	Microorganisms outside the body

^aThere are also pesticides specific to: mites, algae, birds, snails, slugs, and other mollusks, nematodes, fish, and other organisms.

Chemical element *sulfur* as a pesticide thousands of years ago; some organic gardeners still use it. Extracts of chrysanthemum flowers containing *pyrethrum* have been used for nearly as long, and tobacco extracts containing *nicotine* have been used for hundreds of years. In the late 1800s, inorganic chemical pesticides containing arsenic, mercury, lead, and copper came into widespread use. An elderly man wrote a letter to a periodical in 1989 describing his grandmother's 1920s gardening chemicals. In addition to occasionally using the highly toxic gas hydrogen cyanide as a fumigant, she used Paris green (copper arsenate), lead arsenate, and nicotine sulfate to control garden pests. Given the widespread use of metal pesticides in the first half of this century, it was not surprising that the first round up of household hazardous waste that Massachusetts carried out in the 1980s, recovered 3 tons (2.7 tones) of arsenic chemicals that had lain around in sheds and barns for many years. These early pesticides were only partially effective. So, when the very effective synthetic insecticide *dichlorodiphenyltrichloroethane* (DDT) was introduced in 1942, farmers and the public-health community quickly embraced it. DDT was lethal to many insects, killing the insects infesting crops, the mosquitoes and flies spreading disease, and other insects, such as body lice. Swiss scientist Paul Hermann Müller discovered its insecticidal properties in 1942. Because DDT effectively killed disease-carrying organisms such as mosquitoes, this was considered a major medical coup, and Müller received the 1948 Nobel Prize for Physiology and Medicine. Many other synthetic chemical pesticides were quickly developed and saw widespread use.

Even as early as the 1940s, the ability of insects and other pests to demonstrate resistance to pesticides was observed. However, most pesticides remained effective and resistance caused little concern. DDT and similar organochlorine pesticides showed relatively low acute toxicity to humans, and were not absorbed through the skin. Possible chronic toxicity was little considered. The result was wide and often indiscriminate pesticide use. It was not until the early 1960s that Rachel Carson's famous book, *Silent Spring*, forced Americans to see the darker face of DDT and other pesticides.

Why are pesticides used?

As you read over the reasons that pesticides are used, distinguish between what pesticides *allow* us to do, and whether what they allow is always necessary. An example: many crops could not be grown in ecologically *inappropriate* regions without pesticides; as one instance, strawberries would not grow (as large commercial crops) without pesticides in the warm humid southeastern United States. Pesticides make it possible to *grow crops at times of year* when they could not otherwise grow because pests would make it impossible. Fruits and vegetables are found at the market year round not only because they can be transported long distances from warmer climates, but because pesticides make it possible to grow them over longer growing seasons. Without fungicides, for example, certain crops could not grow under conditions where fungi proliferate. Many believe that the health advantages of having fresh fruit and vegetables available year round and their lowered cost make up for any health risk that pesticides pose. Pesticide makes it possible to *grow crops in ecologically inappropriate regions* where they could not otherwise be reliably grown. In such locales, greater quantities of pesticides are often required for successful crops. Cotton, for example, grows well in some parts of Texas with little or no pesticide, whereas in humid southeastern US states the yield is higher, but the crop requires many pesticide applications. Unfortunately, growing a crop in a more appropriate region may not be easy or even possible for

established farmers, e.g., when a farmer already has a fruit orchard growing in a region requiring high pesticide use. If we grew crops only in ecologically appropriate locales, it would mean lower yields of some crops. It would also mean that some foods would only be seasonally available. Public-health uses of pesticides include killing *disease-carrying organisms*: mosquitoes, flies, ticks, and rats. Another health-related reason is *reducing the growth of fungi* on crops, fungi that sometimes produce very toxic chemicals; Pesticides also make it possible to *store food products* for long periods. After harvest, grain is fumigated to kill insects and other infesting organisms that could otherwise multiply during storage destroying grain or making it inedible. For similar reasons, crops are fumigated before being transported long distances to market. Pesticides are often used for *aesthetic reasons*. People growing up in an age of pesticides expect perfect fruits and vegetables. Many blemishes on fruit and vegetables caused by insects may not harm the produce, but people won't buy blemished fruit -- even fruits such as oranges, which are peeled anyway. Although caterpillars on broccoli can be washed away, people wouldn't buy broccoli with caterpillars on it; or, 50 years ago, a worm in an apple was something to pare from the apple, not a reason to throw it away. Golfing greens are kept looking perfect using pesticides, although historically golf was played on imperfect greens. Pesticides make *monocultures* possible. In a monoculture, large tracts of land are devoted to only one crop such as wheat, cotton, soybeans, or corn, season after season. Without pesticides, pests of that crop would build up to a point where the crop could no longer be grown at that location. In fact, monocultures were not possible before the 1940s when effective and inexpensive pesticides became available. Monoculture crops are farmed using heavy machinery leading to soil compaction. Soil quality is further worsened because neither pesticides nor synthetic fertilizers provide organic material to the soil as is the case with manure and compost. Lack of organic matter makes the soil inhospitable to the worms and microorganisms needed for good soil fertility. Fields planted in row-crop monocultures are prone to soil erosion and to runoff of fertilizer and pesticide applications. And monocultures -- by definition -- do not

support biodiversity, but rather the opposite. University of Maine entomologist Dr. Randall Alford spoke of entering cotton fields in the southern United States when he was a student and being struck by the stillness, the awareness that he and the cotton plants were probably the only living creatures. Intensive pesticide application had, for a time, destroyed essentially all other life. At one point, when he entered a field not posted as having been recently treated with organophosphate pesticide, he became very ill with sweating, trembling, and tunnel vision.

Who uses pesticides?

Perhaps a more accurate question would be who does not use pesticides? The surprise is how few people don't.

- Farmers use pesticides to control pests on their crops. They are the largest users of pesticides. They use especially large amounts of herbicides, which account for half of the total volume of pesticide use in the United States. Farmers use lower amounts of insecticides and fungicides and on significantly fewer acres (Figure 1).
- Public-health officials control rats, insects or other pests in the community that carry disease or present other dangers.
- Foresters kill invasions of insects or other pests.
- Utility owners keep rights-of-way clear using pesticides.
- Golf-course owners maintain weed-free greens.
- Businesses maintain their premises free of insects, mold, and other pests.
- Industry controls mold and algae that would otherwise grow in their processes.
- Homeowners might kill hornets in a nest too close to the home, unwanted dandelions, garden slugs or insects, house flies, cockroaches, ants, moths, rodents, mildew in a damp bathroom, or a pet's fleas.



Figure 1: Pesticide being applied by worker in protective suit.

PESTICIDES AS ENVIRONMENTAL CONTAMINANTS:

Pesticides are microchemical environmental contaminants, and their rates of utilization are such that they contaminate soil, water and food in terms of parts per trillion (0.000001 ppm) to parts per million (ppm). * Thus a pesticide applied at 1 lb/acre (1.12 kg/ha) contaminates the top 1 foot (30 cm) of soil (approximately 4 million lb. or 1800 metric tons) to 0.25 ppm. Where such contamination is deleterious to environmental quality the pesticide becomes a microchemical pollutant, exhibiting such objectionable properties as (1) high physiological and ecological specificity, (2) resistance to biochemical degradation, (3) sequential concentration in organisms of the trophic web, and (4) capacity for delayed onset of intoxication (Warner, 1967).

*Contamination of a substrate at 1 ppm represents 1 mg of contaminant per gram of substrate.

Pesticides in Air

The widespread application of pesticides in particulate sprays and dusts insures that appreciable contamination of the air is a consequence of pesticide use. Much of the total application of pesticides is from aircraft (about 80% of pesticide application in California in 1963 was by aircraft; Mrak, 1969) where the propeller wash and wing vortices characteristically throw small particles high into the air and wind currents may drift them for miles away from the target site. When released 10 ft above the ground into a 3 mph wind, 2 μ dia. Particles drifted 21 miles, 10 μ particles 1 mile, and 50 μ particles 200 ft (Akesson and Yates, 1964). It is evident that air applications produce increased air pollution, and Wasserman *et al.* (1960) found air concentrations in forests after air application of DDT at 18.9-170.9 mg/m³ as compared with 4.6-25.5 mg/m³ for ground application. Comparative values for BHC were: air 4.1-53.7 mg/m³ and ground 4.6-25.5 mg/m³. It has been estimated that 50% of the pesticide released in aerial spraying of forest drifts away from the target site. The use of more than 200 million individual aerosol spray dispensers annually in the United States discharges substantial amounts of such pesticides as pyrethrinspiperonyl butoxide, dichlorvos, malathion, methoxychlor, chlordane, diazinon, propoxur, and so on indoors in homes, stores, warehouses, and aircraft, in the 5-30 μ dia range. Organic insecticides have appreciable vapor pressures, ranging from 1.5×10^{-7} mm Hg for DDT, 1.2×10^{-2} for dichlorvos and 1420 mm for methyl bromide. Thus volatilization is a major factor in dispersal of pesticides into the air, and accounts for much of the dissipation of pesticides from treated plant surfaces and buildings and from soil (Harris and Lichtenstein, 1961). Wind erosion of dust from treated soil and so on is also a substantial factor in the dispersal of pesticides through the air.

Occupational Exposure: The degree of air pollution resulting from a variety of occupation uses of pesticides is shown in Table 1 (Jegier, 1969). These values illustrate the maximum air-borne concentrations to which humans are likely to be exposed and demonstrate the substantially higher exposures experienced indoors as

compared to outdoors. Spray operators during average spraying operations are exposed to minute fractions of the combined dermal and respiratory toxic dose: 0.29% for endrin, 0.43% for parathion, 0.72% for azinphos, and 1.43% for demeton; four highly toxic insecticides. The greatest hazards from air borne exposure to highly toxic materials are found during filling spray tanks with wettable powders.

Residential Exposure: Agricultural spraying operations, especially those from aircraft produce considerable air pollution and traces of pesticides have been identified for many miles downwind. Where highly toxic pesticides such as tetraethyl pyrophosphate have been dusted on orchards by air, typical cholinergic symptoms of poisoning have been observed in inhabitants of neighbouring rural communities (Quinby and Doornick, 1965). Spraying of apple orchards from ground air blast equipment has resulted in concentrations in nearby residential areas of azinphos, carbaryl, malathion, and parathion as high as 0.5 mg/m^3 (Jegier, 1969). Studies of the effect of DDT spraying operations upon air pollution of rural and urban communities have produced values ranging from $< 0.1 \text{ ng/m}^3$ (0.000001 mg/m^3) to $> 8500 \text{ ng/m}^3$. Ranges observed in specific localities included: Fresno, California 0.3-19; Sacramento, California 0-2; Florida City Florida 0.1-7.6; Fort Valley, Georgia 0.3-9.9; Leland, Mississippi 0.4-22; and Lake Apopka, Florida 0.3-8500 (Jegier, 1969). Pesticides are apparently present in the air everywhere as Risebrough *et al.* (1968) measured the concentrations in the air over Barbados as ranging from 13×10^{-6} to $380 \times 10^{-6} \text{ ng/m}^3$ as compared to that of La Jolla, California where the average was $7.0 \times 10^{-2} \text{ ng/m}^3$. A comprehensive study by Stanley (1968) to determine the atmospheric contamination by pesticides in urban and rural sites of 9 U.S. cities showed that only DDT was present in all localities. The maximum concentrations found were DDT 1560 ng/m^3 , toxaphene 2520 ng/m^3 , and parathion 465 ng/m^3 . The pesticides were mostly present in the atmosphere as particulates and the levels were generally correlated with spraying practices on particular crops. In another study of pesticides in the air near 10 urban

communities (Tabor, 1966), the maximum concentrations found near the center of town and at least a mile from agricultural operations were DDT 22 ng/m³, chlordane 6, aldrin 4, and toxaphene 15. Where communities were being fogged for control of pests DDT was found up to 8000 ng/m³ and malathion up to 140.

Pesticides in Dust: The windblown erosion of dust from agricultural lands treated by pesticides can become a substantial source of air pollution. Cohen and Pinkerton (1966) investigated the transport of pesticides to Cincinnati in a violent dust storm originating in the southern high plains of Texas in 1965. The major pesticide components of the dust and their concentrations in the dried dust particles after precipitation by rain in Cincinnati were: DT 0.6 ppm, chlordane 0.5 ppm, ronnel 0.2 ppm, DDE 0.2 ppm, heptachlor epoxide 0.04 ppm, 2, 4, 5-T 0.004 ppm, and dieldrin 0.003 ppm.

Pesticides in Rainwater: Many analyses of rainwater have shown substantial content of various pesticides indicating their general distribution in the atmosphere. As an example, the following mean concentrations of pesticides were found in three locations in Ohio in ppt DDT 0.07-0.34, DDE 0.005-0.03, and BHC 0.006-0.05. Chlordane, heptachlor, aldrin, dieldrin, and 2, 4, 5-T isooctyl ester were also found in rainwater samples (Cohen and Pinkerton, 1966). Recent investigations have shown that persistent residues of toxaphene, a chlorinated camphene with at least 177 separate components, have permeated the Great Lakes ecosystem. More than 2.5×10^8 kg of toxaphene was applied to cotton in the southern United States between 1947 and 1977. The characteristic gas chromatographic “fingerprints” of the multiple components indicate that lake trout, *Salvelinus namaychush* from Lake Michigan contain 6-10 ppm of these toxaphene components and trout from remote Lake Siskowit on Isle Royale in Lake Superior, contain 1.7-4.5 ppm (Rice and Evans 1984). This contamination of the Great Lakes and its biota could only have resulted by airborne transport and precipitation in rain. Study and the evaluation of pesticide pollution in air have been less intensive

than comparable investigations of water and food. However, it is clear that pesticide residues are constantly being transported and redistributed from their sites of application through the atmosphere and are present in some degree in the air everywhere. The degree of human exposure is related to occupation and to geographic location and is highest for workers in pesticide plants, spray operators, and users of household aerosol sprays. Inhabitants of rural regions or those dwelling in houses where spraying operations are conducted for agricultural or public health purposes are obviously exposed to substantially higher concentrations of airborne pesticides than are typical urban dwellers.

TABLE 1
Occupation exposure to insecticides in air ^a

Insecticide	Use	Mean concentration $\mu\text{mg}/\text{m}^3$
Azinphos	Orchard spraying	670
Carbaryl	Orchard spraying	600
Malathion	Orchard spraying	590
Parathion	Orchard spraying	150-360
Endrin	Vegetable spraying	50
Demeton	Greenhouse spraying	9150
Chlordane	Household spraying	440
Diazinon	Household spraying	2680
Methoxychlor	Barn and cattle spraying	7680
Lindane	Household vaporizer	100
Azinphos	Tank filling	2270
Parathion	Tank filling	530

^a Data from Jegier (1969).

Pesticides in Water

The water environment provides the ultimate sink for pesticide residues which enter it by direct contamination from rain precipitating pesticide aerosols or

atmospheric codistillates, by direct application to surface waters, by runoff from treated plants and soils, by industrial and household sewage effluents, and by residues in human and animal excreta. An intrinsic property of most pesticidal molecules is high lipid solubility and low water solubility and this property strongly favors concentration from water to the lipids of living animals through partitioning through the animal cuticle and the gills. Such absorption and subsequent storage and concentration may result in aquatic animals accumulating pesticide residues hundreds and even thousands of times greater than that in the surrounding aquatic medium. This concentration process is dependent upon the initial pesticide residue in water, the length of animal exposure, i.e. lifetime, and the rate of metabolism or breakdown of the pesticide in the organism, i.e. biological half life. Thus this subject has assumed great ecological importance.

Ground Waters: Pesticide residues in ppt to ppb quantities eventually percolate into ground waters. This problem has become a major environmental concern because of greatly increased soil applications of pesticides (more than 100 million ha are treated annually), improper waste disposal, and the enhanced analytical capability provided by gas chromatography/mass spectrometry. The Safe Drinking Water Act of 1974 (Public Law 95-523) requires EPA to promulgate and enforce nonpolluting drinking water standards by establishing maximum contamination levels at which no adverse health effects are observable. The Act requires EPA to publish such non-polluting drinking water standards for some 83 water contaminants by Jan. 1991. An EPA survey of 1988 has disclosed the presence of 74 different pesticides in the ground waters of 38 states. Aldicarb insecticide has been detected as the sulfoxide and sulfone derivatives in ground waters of 15 states and 29% of the wells in the potato growing area of Suffolk Co. New York had aldicarb residues of 7 ppb with maximum concentrations reaching 600 ppb. In Massachusetts 220 drinking water wells were closed because of aldicarb contamination from 1-50 ppb (Pesticide & Toxic Chemical News 1985). Ethylene dibromide soil fumigant has been detected in the ground waters of 8 states and in

11% of more than 1000 wells in Florida, with exposure of more than 50,000 people (Pesticide & Toxic Chemicals News 1985). Iowa ground water has been found to be contaminated with the herbicides atrazine, cyanazine, metalochlor, alachlor and the insecticides terbufos and sulprofos; all applied as preplanting applications to corn and soybeans. In California, more than 50 different pesticides were detected in water sampled from over 8,000 wells in 24 counties. In Ontario, Canada the herbicides alachlor, butylate, dalapon, dicamba, MCPA and simazine were detected in the waters of 159 of 237 wells analyzed (Frank *et al.*, 1979). This widespread pollution of drinking water sources is one of the most important environmental problems of the 1990s. Many of the soil applied pesticides migrate very slowly through the soil and even if annual applications were discontinued, water pollution levels are expected to increase for another 5 to 10 years. Pesticides have long residence times in ground water because of the absence of light, air, and microorganisms that are primarily involved in degradation. The number of persons exposed for long periods of time is very large. The mandatory provisions of the Safe Drinking Water Act may change forever how pesticides are applied.

Surface Waters: The Mrak Commission (Mrak, 1969) observed that the current U.S. annual production of pesticides, ca. 1×10^9 lb, applied to the annual U.S. runoff, ca. 1×10^6 gal/day, could result in a maximum concentration of 0.3 mg/l (0.3 ppm). Fortunately, most of the environmental contamination with pesticides is directly or indirectly to the soil where the various compounds are often tightly bound to soil colloids and/or degraded by soil microorganisms. The average runoff concentrations of 9 organochlorine insecticides, obtained from analysis of 6000 samples at 100 locations in all major U.S. river basins from 1958-65, is summarized in Table 4 (Breidenback *et al.*, 1967). The maximum amounts determined, dieldrin 0.122 ppb, endrin 0.214 ppb, DDT 0.144 ppb, aldrin 0.006 ppb, heptachlor 0.002 ppb heptachlor epoxide 0.008 ppb, and BHC 0.022 ppb were well below the suggested Federal Drinking Water Standards (USPHS, 1968) of dieldrin 17 ppb, endrin 1 ppb, DDT 42 ppb, heptachlor 19 ppb, heptachlor epoxide

18 ppb and lindane 56 ppb, except for endrin. The yearly analyses showed dieldrin to be the dominant contaminant but declining, DDT and congeners virtually constant, endrin reaching a peak in 1964 and declining. In another study of 12 organochlorine pesticides in 11 streams in Western United States (Brown and Nishioka, 1967) the contaminants, positive samples, and range detected were: DDT-82, 0.01–0.12 ppb; DDE-49, 0.0–0.06; DDD-35, 0.0–0.04; 2,4-D-41, 0.01–0.35; 2,4,5-T-28, 0.01–0.07; heptachlor-27, 0.01–0.04; dieldrin-24, 0.01–0.07; silvex-14, 0.01–0.21; Lindane-11, 0.01–0.04; aldrin-11, 0.01–0.07; endrin-4, 0.01–0.07; and heptachlor epoxide-2, 0.02–0.04. A major source of pesticide pollution of ground water is from soil particles contaminating attached pesticide residues through erosion runoff, or flooding. Application of aldrin to rice fields at 415 g/ha by seeding with treated rice seeds resulted in 1.6 ppb aldrin plus dieldrin in the water after 2 days and 0.07 ppb 14 weeks after seeding. Draining of the fields after 14 weeks produced 0.027 ppb in the ditches, 0.44 ppb in the stream receiving the ditches, and concentrations as high as 0.023 ppb in the river into which the stream flowed (Sparr *et al.*, 1955). In a companion study runoff from a cotton field treated 7 days before with 450 g/ha of endrin, contained 0.66 ppb endrin after a 1.15 in. rain. Used irrigation water contained 0.11 ppb endrin 3 days after spraying.

Lakes and Reservoirs: These bodies of water often represent the sites of the most serious environmental pollution problems resulting from the applications of pesticides to both land and water. The direct application of pesticides to water for the control of mosquito or black fly larvae, snails, or water weeds is an obvious source of contamination. Rates of application commonly range from 0.1–1 kg/ha of water surface for insecticides to as much as 100 kg/ha for 2, 4-D herbicide. In water 0.3 m deep these rates would range from 2 ppm to 2000 ppm. One of the first examples of serious water pollution by pesticides resulted from the application of the larvicide DDD to Clear Lake, California for the control of Clear Lake gnat *Chaborus astictopus* which was a severe nuisance. In 1949, 14,000 gal of emulsive concentrate of DDD was applied to the lake at a rate of 14 ppb. The gnats were

nearly exterminated and it appeared that no damage to fish occurred. Reinfestation from nearby lakes resulted in retreatment with DDD at 20 ppb in 1954 and 1957. Dying Western Grebes (*Aechmophorus occidentalis*) in areas around the lake were observed in 1954, 1955, and 1957 and they had tremors characteristic of DDD poisoning. Their body tissues showed as much as 1600 ppm DDD. Subsequent study showed DDD residues of up to 10 ppm in plankton, and as much as 2375 ppm in the body fat of the white catfish, *Ictalurus catus* (Hunt and Bischoff, 1960). Thus this episode provided the first well studied example of ecological magnification of a pesticide from water through a food chain of plankton→fish→birds, which died from chronic DDD poisoning. Large fresh water lakes may have astonishingly long water retention times, which magnify pesticide contamination problems. In the Great Lakes system Lake Superior with an area of 82,366 km² and a volume of 12,221 km³ has an average water retention time of 189 years, and Lake Michigan with an area of 58,016 km² has an average water retention time of 30.8 years. Rainey (1967) has pointed out that in such bodies of water contamination is a major disaster for which there is no apparent solution. Thus the times for 90% waste removal are >500 years for Lake Superior and 100 years for Lake Michigan, as compared to 20 years for Lake Ontario and 6 years for Lake Erie. Lake Michigan is exposed to pesticide contamination from intensive agriculture and from effluents from the densely populated urban areas within its 117,845 km² watershed. Analyses of Lake Michigan surface waters in 1968-1969 showed DDT $2.0-2.8 \times 10^{-6}$ ppm, DDE $0.8-1.4 \times 10^{-6}$ ppm, and DDD $0.3-0.5 \times 10^{-6}$ ppm; while grab samples at the Chicago filtration plant had DDT $0.034-0.058 \times 10^{-3}$ ppm, lindane $0.01-0.02 \times 10^{-3}$ ppm, aldrin 0.019×10^{-3} ppm, and heptachlor epoxide $0.019-0.049 \times 10^{-3}$ (Mrak, 1969). The ecological significance of these trace amounts is shown by studies reporting concentrations of DDT in the Lake Michigan ecosystem of 0.014 ppm in bottom muds, 0.410 ppm in amphipods, 3.22 ppm in yellow perch, 6.9 ppm in lake trout, 6.71 ppm in lake herring, and 99 ppm in herring gulls (Reinert, 1970; Harrison *et al.*, 1970). The overall concentration of DDT from water to fish-eating bird is $\times 10^7$.

Dieldrin was present in lake trout and lake herring to 0.20 ppm (Reinert, 1970), for an overall concentration of about 2×10^5 .

TABLE 4
Organochlorine pesticides in major river basins of the United States ^a

Pesticide	Positive samples of 537	Range ppb	Area of highest concentration
Dieldrin	495	0.008-0.122	lower Miss. 1964
Endrin	217	0.008-0.214	Lower Miss. 1963
DDT	145	0.008-0.144	W. Gulf Basin 1963
DDE	176	0.002-0.011	lower Miss. 1965
DDD	231	0.004-0.080	N. Atlantic basin 1963
Aldrin	31	<0.001-0.006	S.W. basin 1964
Heptachlor	6	0-0.002	lower Miss. 1965
Heptachlor eposice	26	<0.001-0.008	N. Atlantic basin 1963
BHC	44	0.003-0.022	S.E. basin 1960

^a From Breidenback *et al.* (1967).

Estuaries: The importance of estuarine waters to commercial and sports fishing makes these locations especially vulnerable targets to the runoff of pesticides in streams and rivers from agricultural practices and industrial operations. It has been estimated (PSAC, 1965) that more than 50% of the total harvest of sea foods from waters of the United States is composed of species whose existence of spawning grounds are in the estuarine zone, and this harvest includes some of the most valued sea foods—shrimp, lobster, crabs, oysters, salmon, menhaden, and game fish. Agricultural pesticides are more toxic to the marine life than any other group of chemicals, and lethal concentrations for the organochlorine insecticides aldrin, dieldrin, heptachlor, endrin, DDT, lindane, and toxaphene range from 0.0006-0.06 ppm. Mollusks in particular can concentrate extraordinary quantities of stable pesticides, and oysters have been found to accumulate DDT to 70,000 times the amount in the surrounding water. Thus these organisms are especially useful as

biological indicators of pesticide pollution. Woodwell *et al.* (1967) estimated that the Carmans River estuary of Long Island contained about 0.00005 ppm DDT in the water, with concentrations of 0.04 ppm in plankton, 2-3 ppm in small fish, and up to 75.5 ppm in the ring-billed gull (*Larus delawarensis*).

Oceans: Little information exists about pesticide residues in the oceans. As these compounds are leached from the land or precipitated by rains, they circulate initially in the mixed layer above the thermocline and may eventually be transferred slowly into the abyss which provides a reservoir of virtually infinite capacity (Woodwell *et al.*, 1971). The organochlorine compounds such as DDT with their high lipid solubility and very low water solubility must be largely absorbed into organic matter. Woodwell *et al.* (1971) estimate concentrations of DDT in algae of the oceans ranging from 0.1-1.0 ppm and a maximum accumulation in the mixed layer of the ocean of about 15 ppt. Scattered observations suggest that DDT is present in most marine animals, with levels in whales of 0.4-6 ppm, tuna up to 2 ppm, oysters 0-5.4 ppm, and sea birds up to 10 ppm (Butler, 1966; Wolman and Wilson, 1971). Virtually nothing is known of the presence of other pesticides in marine organisms. Trapping of pesticides in petroleum slicks, which may contain up to 10,000 ppm DDT, provides another facet to marine pollution.

Pesticides in Soils:

Pesticides are most frequently applied directly to soil or to plant surfaces above it and concern for the persistence of pesticide residues in soils has existed since the first widespread use of lead and calcium arsenate. A study by Jones and Hatch (1937) reported that 3500 lb of lead arsenate was applied to a commercial apple orchard over a 25 year period. Most of the lead and arsenic was confined to the upper 6-8 in of soil and did not harm the roots of the fruit trees. However, the residual levels were highly toxic to cover crops or to young newly planted trees. Pesticides are applied to crops and soils in most of the agricultural areas of the United States. Estimates in 1982 suggest that of the 113 million ha of cropland,

herbicides were applied to 59%, insecticides to 18%, and fungicides to 13% (Pimentel and Levitan, 1986).

Soil Residues of Pesticides: Monitoring studies made of pesticide residues in soils of the heavily treated cotton growing areas of the Mississippi Delta (Gentry, 1966) have given a general picture of the extent to which agricultural soils may be contaminated. In an area where a cumulative total of 30 kg of DDT/ha had been applied over a 9 year period 1955-63, the level in the top soil in 1964 was 1.3 ppm or about 1.3 kg/ha. In another area where 13 applications of endrin at 0.2 kg/ha were applied since 1956, the average level in the soil in 1964 was 0.05 ppm. Aldrin and dieldrin, although not used since about 1955, were found in the study area in 1964 at levels of up to 0.06 ppm dieldrin and 0.13 ppm aldrin, and benzene hexachloride was found at about 0.02 ppm. Toxaphene was present in the soils at 0.8-3.7 ppm, and calcium arsenate, although not used for many years, had left an arsenic level of 2.18-12.8 ppm. The occurrence of residues of chlorinated hydrocarbon insecticides in soils from 31 farms in Southern Ontario has been explored by Harris *et al.* (1966). Orchard soils contained the highest levels of DDT 19.9-118.9 ppm, DDE 3.4-15.7 ppm, DDD 0.2-3.5 ppm, and dicofol 2.4-6.9 ppm. A vegetable farm where radishes were grown on muck soil had the highest concentrations of dieldrin 1.6 ppm, aldrin 2.1 ppm, endrin 3.8 ppm, together with DDT 13.8 ppm, DDE 0.8 ppm, and DDD 0.4 ppm. The highest levels of other pesticides found were: heptachlor 0.2 ppm, chlordane 0.6 ppm, and endosulfan 1.4 ppm. The average levels found in soils from 16 farms in this area in 1966 were aldrin 0.47 ppm, dieldrin 0.78 ppm, endrin 0.12 ppm, and DDT 23.9 ppm (Harris, 1971). The rate of degradation of any pesticide in the soil is a function of its chemical structure and the formulation applied whether emulsion, granular, or seed treatment. Most pesticide degradation in soil is accomplished by the wide range of soil microorganisms which can use the compound as an energy source, although hydrolysis and photochemical oxidations may also play a role. Soil factors which determine the actual rate of persistence are (1) soil type, (2) soil moisture, (3)

temperature, (4) uptake by plants, (5) leaching by water, (6) wind erosion. Thus it is difficult to generalize about soil persistence of pesticides, which is, however, greater in muck soils heavy in organic matter than in light sandy soils. Some idea of the relative persistence of various pesticides in soils is given in Table 5, from data by Edwards (1964), Lichtenstein (1969), and Harris (1971).

TABLE 5
Persistence of Pesticides in Soils

Pesticide	Approximate time for 70–95% loss ^a
DDT	4-10 years
Toxaphene	2-10 years
Dieldrin	3-8 years
Lindane	3-6 years
Chlordane, Heptachlor	3-5 years
Aldrin	2-3 years
Picloram	1-2 years
Simazine, atrazine	10-12 months
Monuron, fenuron, diuron	8-10 months
Trifluralin	6 months
Carbaryl, Carbofuran	4-6 months
2,4,5-T	3-5 months
Parathion, Chlorpyrifos, Diazinon	3-6 months
Amiben, Dicamba, MCPA	2-3 months
Dalapon, Protham, CDAA, CDEC, EPTC	1-2 months
Phorate, Disulfoton	2-6 weeks
2,4-D	4-6 weeks
Captan	3-6 weeks
Malathion	1-2 weeks

^aData from Edwards (1961), Kearney, Nash and Isensee (1969).

Uptake of Pesticides by Plants: Plants obviously absorb pesticides from the soil and translocate them throughout the leaves and fruits or pre-emergent herbicides would have little activity in killing weeds and systemic insecticides would fail to protect plants against insect attack. The actual amounts absorbed by plant roots are dependent upon the solubility of the pesticide in the lipids of the root cuticle, and the amounts translocated are a function of the water solubility of the pesticide in the translocation stream. The organochlorine insecticides are absorbed in trace amounts by root crops such as carrots, radishes, and potatoes and these crops grown in soil treated with 1 kg /ha of aldrin contained as much as 0.03-0.05 ppm of the pesticide (Lichtenstein, 1969). Residues of these pesticides also enter above ground portions of crops and Lichtenstein (1969) has calculated that alfalfa grown on soil treated with aldrin and heptachlor at 1 kg/ha would contain approximately 0.005 ppm aldrin and dieldrin and 0.015 ppm of heptachlor and heptachlor epoxide. In contrast, residue studies made of the results of soil and seed treatments with phorate and disulfoton showed residues in the leaves after 39 days ranging from 5-12 ppm in alfalfa, 32-137 ppm in cotton, and 7-46 ppm in sugar beets (Reynolds *et al.*, 1957). These residues dissipated rapidly as the plants grew older and in practical use conform to the residue tolerance levels in hay and cottonseed.

Pesticides in Foods

The most direct avenue for pesticide contamination of the human body is through ingestion of pesticide residues on food products. Perhaps 75% of all pesticides production is used for the production or protection of agricultural commodities and wide-spread contamination of food products is the inevitable result. However, much of the initial pesticide load is lost by “weathering”, through action of rain and dew and by photochemical oxidations, by enzymatic destruction in the tissues of plants or animals and through losses in harvesting and food processing. The processes of degradation and persistence of pesticide residues usually follow first order chemical kinetics and can be plotted semilogarithmically as straight lines of log. residue in ppm vs. time elapsed since treatment. Such

residue persistence curves give values for residue half-lives or RL 50 (Gunther and Blinn, 1965) which are independent of initial concentration and thus represent a characteristic of each pesticide on or in a particular substrate such as leaf surface, fruit peel, plant wax or juice, and so on. This concept then supports the empirically derived practice of observing a “safe period” after pesticide application and before harvest to permit the pesticide residue to attenuate to levels which long term animal feeding studies have shown to be innocuous to animal health. Based on these animal feeding studies and incorporating a safety factor, ideally 100-fold to allow for peculiar human metabolic idiosyncrasies and sensitivities, together with the potential daily intake in foods, the U.S. Food and Drug Administration has established pesticide residue tolerances for each registered pesticide used on a food commodity. The range of tolerances for commonly used pesticides is shown in Table 6. The actual occurrence of pesticide residues in human foods has been studied by the FDA from 1964-1966, through the examination of 26,326 samples including raw agricultural products, milk and dairy products, processed animal feeds, shell eggs, fish and shell fish, meat, canned and frozen foods, vegetable oils, and special dietary products (Duggan, 1969). Residues of 81 different pesticide chemicals were detected, with 11 chemicals accounting for 95% of the residues found. Those most commonly detected in domestic foods were, in order of importance: DDT 25%, DDE 24%, dieldrin 17%, DDD 9%, heptachlor epoxide 7%, lindane 4.5%, BHC 2.6%, endrin 2.3%, aldrin 1.8%, toxaphene 1.4% and dicofol 0.7%. Animal tissues contained, in addition, methoxychlor and chlordane. Approximately 95% of the residues were below 0.5 ppm, 78% below 0.1 ppm and 58% below 0.03 ppm. Excessive residues, above tolerances, were found in 3.6% of the samples. It is apparent that the chlorinated organics provided the great majority of readily detectable residues in food products, because of their high stability and fat solubility. The exposure of humans to pesticide residues in a well balanced diet has been studied by FDA since 1962. For 1964-1966 this was calculated to contain an average of 0.025 ppm chlorinated organics, 0.003 ppm organophosphates, 0.003 ppm chlorophenoxy acids, and 0.05 ppm carbamates. The average daily intake of

TABLE 6
Typical pesticide residue tolerances in the United States ^a

Pesticide	Crops, commodities	Tolerance ppm
Alachlor	Forage	0.2-0.75
Atrazine	Forage	0.1-0.25
Azinphos methyl	Fruits, vegetables, forage	0.3-5
Butylate	Fruits, vegetables	0.1
Captan	Fruits, vegetables	100
Carbaryl	Fruits, vegetables, forage	5-100
Carbofuran	Forage	0.1-1.0
Coumaphos	Milk, eggs, meat	0-1
Cryolite	Fruits, vegetables	7
2,4-D	Fruits	5
Diazinon	Fruits, vegetables, forage	0.75-40
Disulfoton	Vegetables, forage	0.75-12
Diuron	Fruits, vegetables, forage	0.2-7
Dormant oils	Fruits	exempt
Endosulfan	Fruits, vegetables	2
Endrin	Fruits, vegetables	0
Ferbam	Fruits, vegetables	0.1-7
Lindane	Fruits, vegetables	10
Linuron	Vegetables, forage	0.25-0.5
Malathion	Fruits, vegetables, forage	8-135
Maneb	Fruits, vegetables	0.1-10
Methomyl	Fruits, vegetables	0.1-5
Methoxychlor	Fruits, vegetables, forage	1-100
Methyl bromide	Fruits, vegetables, nuts	2-240
Nicotine	Fruits vegetables	2
Paraquat		0.5
Parathion, methyl parathion	Fruits, vegetables, forage	1
<i>o</i> -phenyphenol	Fruits, vegetables	10-20
Pyrethrins	Fruits, vegetables	exempt
Ronnel	Meat	0
Rotenone	Fruits, vegetables	exempt
Simazine	Alfalfa, grass	15
Tetradifon	Fruits	1-5
Thiram	Fruits	1-7
Trifluralin	Fruits, vegetables	0.05
Zineb	Fruits, vegetables	7-60

^a Environmental Protection Agency (1971).

TABLE 7

Average daily intake and incidence of pesticides in U.S. human diet composites ^a

Pesticide	Daily intake from total diet mg/kg	% positive samples	FAO-WHO acceptable intake mg/kg
DDT	0.0005	37.4	0.01
Dieldrin	0.00009	20.2	0.0001
Lindane	0.00006	13.6	0.0125
Heptachlor epoxide	0.00004	12.6	0.0006
Carbaryl	0.0012	4.7	0.02
Malathion	0.001	4.5	0.02
Aldrin	0.00003	4.5	-
2,4-D	0.00005	3.5	0.017
Diazinon	0.000014	3.0	-
Dicofol	0.00011	2.5	-
Pentachlorophenol	0.00006	2.5	-
Endrin	trace	2.3	-

^a Data from Duggan (1969).

15 pesticides in 516 diet composites sampled by FDA are shown in Table 7 (Duggan, 1969). Increasingly sophisticated evolution procedures have shown that a number of pesticides traditionally considered safe are in fact carcinogens when fed to laboratory animals over their lifetimes. There is much public concern about the long term hazards of eating processed foods containing trace residues of such pesticides. In the United States pesticide residues in food are regulated under the 1954 Food Drug and Cosmetic Act (FDCA) and the 1947 Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) as modified in 1978. Under these laws, the Environmental Protection Agency grants approval for the presence of certain levels of a particular pesticide on a specific agricultural commodity, that is, a “tolerance”. Typical pesticide residue tolerances are given in Table 6. However, the Delaney Clause of the FDCA states that no tolerance may be set for any

pesticide found to be oncogenic. Based on risk studies determined from carcinogenic effects in laboratory animals together with human dietary contamination levels, a National Academy of Sciences study (1987) concluded that nearly 80% of the estimated oncogenic risk to humans is from residues to 10 pesticides. The study concluded that 98% of the oncogenic dietary risk could be eliminated by revoking the registrations of 28 carcinogenic pesticides.

PESTICIDES AND HUMANS

Humans, in an ecological sense, are consumers at the top of the food pyramid and are exposed to pesticide residues contained nearly everywhere in cereals, fruits and vegetables, and in meat, fish and poultry. Additionally humans are exposed directly to pesticides from occupational use of aerosol products in the home, from home and garden sprays, and from effluents from agricultural operations. Therefore it is not surprising that traces of the stable organochlorine insecticides are found in the body fats of humans everywhere.

DDT in Humans

Elaborate monitoring studies of pesticide residues in humans have been reported by Hayes (1966), Durham (1969) and Mrak (1969). DDT was first found in human fat in 1948 and at least 9 general surveys of the DDT content of human fat have been made in various areas of the United States. These show that DDT is stored in the body fat of everyone in the United States, with a mean storage level in the 1960's of about 8 ppm combined DDT and its principal metabolite DDE. With the revoking of the registrations of DDT in 1973 and aldrin and dieldrin in 1974, the levels of these insecticide residues in human body fat have declined slowly over the next decade as shown in Table 10. However, detectable tissue levels of oxychlordan, the principal persistent metabolite of chlordane, very widely used for household pest control have persisted unchanged (Table 10). The storage levels of DDT and DDE in people in other countries have also been investigated (Durham, 1969). The levels were lowest in countries where little DDT is used, for

example Denmark with DDT 0.6 and DDE 2.7 ppm; and highest in countries such as India, DDT 16 and DDE 10 ppm, where large amounts of DDT are used in malaria eradication. The storage of DDT in human fat is a direct function of level

TABLE 10
Insecticide residues in human body fat—United States ^a

Year	DDT-T	ppm in fat	
		dieldrin	oxychlorane
1972	6.97	0.18	0.10
1974	5.15	0.14	0.12
1976	4.35	0.09	0.11
1978	3.52	0.09	0.11
1980	2.82	0.10	0.12
1983	1.67	0.06	0.10

^a Council on Environmental Quality, 17th Report, 1987.

of intake and is lowest in meat abstainers, DDT 2.3 and DDE 3.6 ppm; and Eskimos, DDT 0.8 and DDE 2.2 ppm, whose diets contained the lowest amounts of DDT. Volunteers given 35 mg per day orally stored DDT 281 and DDE 40 ppm, and a formulator in a DDT factory had DDT 648 and DDE 483 ppm; yet these men remained in good health (Hayes, 1966). DDT and its metabolites DDE and DDD are also found in other human tissues: blood DDT 0.0068 and DDE 0.0114 ppm, milk 0.08-0.13 ppm, adrenal glands 0.7 ppm (Durham, 1969). DDT ingested by humans is excreted slowly as 4, 4-dichlorodiphenyl acetic acid (DDA) which is present in the urine of the general U.S. population at < 0.02-0.18 ppm (Hayes, 1966). The levels of DDA in human blood and urine roughly parallel the rate of intake and can be used to monitor the exposure (Mrak, 1969). The significance of levels of DDT and its metabolites DDE and DDD in the general population is complex. Food is generally believed to contribute as much as 89% of the total intake of DDT but recent studies showing substantial fat storage of DDT in

Eskimos and in institutional patients where DDT intake is very low suggest that nondietary sources such as house dust may contribute up to 50% of the total body burden (Mrak, 1969). The non-white population of the U.S. has significantly higher fat storage of DDT than the white population suggesting the influence of dietary factors and socioeconomic factors resulting in greater use of house-hold insecticides. Fat storage of DDE increases with the age of the population, especially in non-whites where the level increased from 4.06 ppm in the 0-5 year's category to 8.61 ppm in 41-50 years, and 15.50 ppm at 90+ years. Accumulation in states with cooler climates averaged 4.85 ppm as compared with 9.21 ppm in warmer States. There is no clear cut evidence of a sex difference in fat storage of DDT or in positive association with specific disease conditions (Mrak, 1969).

Other Pesticides in Humans

Other stable organochlorine insecticides or their stable metabolites are also found in human tissues. Surveys of the U.S. population have shown levels of these materials in fat and blood: BHC isomers—fat 0.20-0.60 ppm, blood 0.0031-0.0019 ppm; heptachlor epoxide—fat 0.10-0.24 ppm, blood 0.0008–0.0011 ppm (Hayes, 1966; Durham, 1969). In addition to these pesticides demonstrated in the blood of the general U.S. population, trace levels of chlordane, toxaphene, endrin, aldrin, pentachlorophenol, and 2,4-D have been found in tissues of humans with unusual occupational or accidental exposure. Most of the other types of pesticides widely used, the organophosphorus esters, carbamates, phenoxy- and benzoic-acids, triazines, ureas are less persistent in the environment than the organochlorine compounds and are rapidly metabolized by enzymes in the human liver and converted to predominantly water-soluble products eliminated in the urine. Therefore there is little evidence of fat storage of these compounds. Monitoring of the urinary content of water-soluble metabolites is a very sensitive measure of intake of such pesticides and has been studied for parathion, malathion and related organophorus esters, the carbamates carbaryl and propoxur, dinitro-*o*-cresol, lead, arsenic, and mercury (Hayes, 1966).

Acute Toxicity in Humans

The substitution of the more hazardous organophosphate and carbamate insecticides for the organochlorines has greatly increased the incidence of acute human poisoning. WHO has estimated that worldwide there are as many as 500,000 accidental poisonings annually with 20,000 deaths (Copplestone, 1977). In the United States, EPA estimates suggest that there are 45,000 accidental poisonings with 3000 hospitalizations and 200 deaths annually (Pimentel and Levitan, 1986).

Searching for alternative pesticides:

Sometimes less-toxic pesticides are available to farmers, but they may not have the knowledge to use them or they may cost more. In recent years, chemical companies have emphasized the development of pesticides that are less toxic to non-target species and to the environment, and that work at much lower concentrations. Some new herbicides are effective when applied at 0.02 lb/acre (22 g/ha). Compare this with the more typical 2 lb/acre (2.2 kg/ha) for older herbicides. See Table 16.2 for traits that are desirable in a pesticide.

Table 16.2

Desirable characteristics in a pesticide

-
- Only a small amount is needed to kill targeted pests
 - Low toxicity to non-target species
 - Specific to one or a few pests
 - A lifetime just long enough to kill target pests (i.e., does not persist)
 - Degrades into benign products
 - Does not bioaccumulate
 - Does not runoff with water from application site
 - Pests are slow to develop resistance to it
-

Controlling a pest with the pest's own chemicals

One example is *pheromones*, chemicals produced by female insects to attract males. The pheromone is used to attract males into a trap. Another example is insect *growth regulators*, chemicals that control stages of their life cycle. The growth regulator is sprayed on a crop infested with that insect's larvae and interferes with larval development into adults. Notice that the chemist's handiwork is necessary for pheromones or growth regulators to work. A pheromone or growth regulator must first be purified from the insect and its structure elucidated. Then, because such tiny amounts of these chemicals are produced by the insects themselves, the chemicals must be synthesized to provide quantities large enough to be useful. In other words, they are synthetic chemicals, but the information used to make them is taken from living organisms.

Green chemistry

Two major goal of "green chemistry" is to develop chemicals that are less toxic or to make them in less toxic ways, preferably both. The development of pheromones and growth regulators are examples of green chemistry. These are toxic only to the insect whose lives they disrupt. Other examples can fulfill the green chemistry criteria too: A herbicide (applied at only teaspoons per acre) affects only a plant enzyme, and has very low toxicity to humans and animals. An insecticide (also only applied in tiny quantities) affects an insect enzyme, and shows low toxicity to non-target species. One herbicide approved by the EPA for use on corn and soybeans has an LD50 in rats of greater than 500 mg/kg body weight; that is, it is only slightly toxic (Table 3.4). Moreover, the herbicide is not a teratogen or carcinogen, breaks down quickly in the environment, and does not threaten groundwater.

Table 3.4

Comparing the toxicity of chemicals

Toxicity	LD₅₀^a	Examples
Slightly toxic	500-5000	Aspirin, vanillin, salt
Moderately toxic	50-500	Phenobarbital, caffeine, nicotine, warfarin
Highly toxic	1-50	Sodium cyanide, vitamin D, parathion
Supertoxic	Less than 0.01	Atropine, nerve poisons 2,3,7,8-TCDD (dioxin)
Biotoxins	Much less than 0.01	Botulinum toxin, ricin (in castor oil beans)

^a LD₅₀ is the dose killing 50% of the animals exposed to it, expressed in milligrams per kilogram (mg/kg) body weight.

Adapted from: Crone, H. D. Chemicals and Society. Cambridge: Cambridge University Press, 1986, 35.