



Chapter 15

Optimizing Food Production

THE MAIN IDEA



Agriculture employs much chemistry.

[15.1 Humans Eat at All Trophic Levels](#)

[15.2 Plants Require Nutrients](#)

[15.3 Soil Fertility](#)

[15.4 Natural and Synthetic Fertilizers](#)

15.5 Pesticides Kill Pests

[15.6 Past Agricultural Practices](#)

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15.5 Pesticides Kill Pests

A high-yield crop needs more than adequate nutrition. It also needs defense against a host of natural enemies, such as shown in **Figure 15.13**. To control these pests, farmers can apply substances known as *pesticides*. There are several kinds of pesticides, including insect-killing *insecticides*, weed-killing herbicides, and fungus-killing *fungicides*.

Insecticides Kill Insects

Most species of insects are beneficial or even essential to agriculture. Honeybees, for example, are responsible for the pollination of \$10 billion worth of produce in the United States. Countless other species take part in nutrient recycling and help maintain soil quality. A small minority of insect species, however, have continually threatened our capacity to grow, harvest, and store crops, and it is against these species that insecticides are used. The most widely used insecticides are chlorinated hydrocarbons, organophosphorus compounds, and carbamates.

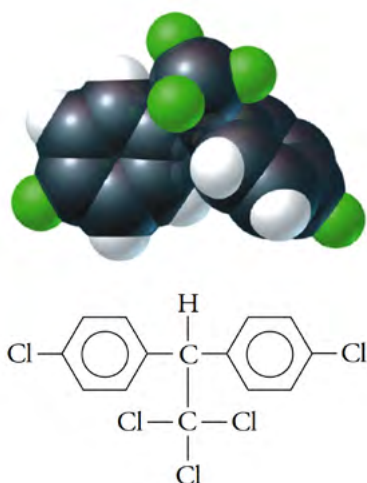


CHEMICAL CONNECTIONS

How is a steak dinner connected to the atmosphere?

< Figure 15.13

The larva of the *Helicoverpa armigera* moth, which is particularly resistant to chemical and biochemical pesticides (Source: David McClenaghan, CSIRO)



▲ **Figure 15.14**

The chemical name for DDT is dichlorodiphenyltrichloroethane.

The *chlorinated hydrocarbons* have a remarkable persistence, killing insects for months and years on treated surfaces. There are at least two reasons for this persistence. First, chlorinated hydrocarbons tend to be non-biodegradable, which means there are no natural pathways to break them down chemically. Second, they are nonpolar compounds, which means they are insoluble in water and thus are not washed away by rainwater.

In 1939, there was a breakthrough in the fight against insect pests with the chemical synthesis of the chlorinated hydrocarbon DDT, shown in **Figure 15.14**. During the 1940s and 1950s, DDT was applied liberally to crops, resulting in markedly greater yields. In addition to protecting plants, DDT protected people from disease. It was applied to rivers, streams, and villages to help control the proliferation of mosquitoes, lice, and tsetse flies, which spread malaria, typhus, and sleeping sickness, respectively. According to the World Health Organization, by protecting against these diseases, DDT has saved an estimated 25 million human lives.

Insect populations began to develop a resistance to DDT within a few years of its first application. Furthermore, DDT was found to be toxic to wildlife, including the natural predators of insects, such as birds. With fewer natural predators, DDT-resistant insects were able to thrive. The early increased crop yields resulting from DDT use were therefore not sustainable.

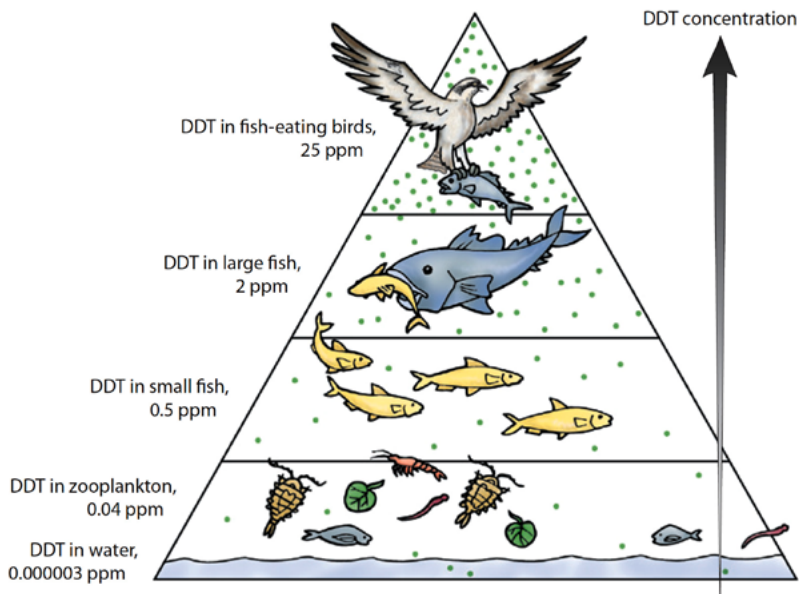
In the 1950s and 1960s, these and other negative aspects of DDT and other pesticides were brought to the public's attention by a number of publications, including the biologist Rachel Carson's book *Silent Spring*. Carson, shown in **Figure 15.15**, described the importance of understanding the dynamics of ecosystems, most of which are highly sensitive to human activities.

Carson also described a phenomenon known as **bioaccumulation**, whereby a toxic chemical that enters a food chain at a low trophic level becomes more concentrated in organisms higher up the chain, as illustrated in **Figure 15.16**. In bodies of water sprayed with DDT, for example, small



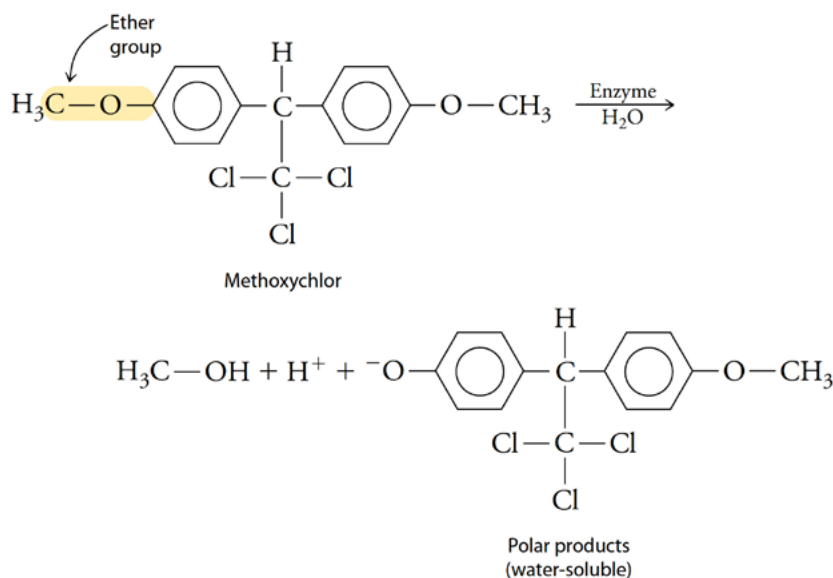
▲ **Figure 15.15**

Rachel Carson was a pioneer in the fight against the excessive use of pesticides.



▲ **Figure 15.16**

The DDT concentration in a food chain can be magnified from 0.000003 parts per million (ppm) as a pollutant in the water to 25 ppm in a bird at the top of the chain.



< **Figure 15.17**

Methoxychlor is one of many alternatives to DDT. Enzymes in the liver can cleave the ether groups to produce polar products. Look back at Figure 15.14, and you will see that DDT lacks ether groups.

amounts of the pesticide were ingested and stored in the nonpolar lipids of aquatic microorganisms. Because these microorganisms serve as food for animals at higher trophic levels, DDT became more concentrated in the body fat of these larger creatures. Predatory birds at the top of the chain accumulated the greatest amounts of DDT. Eventually, the elevated DDT levels affected avian population numbers, because the egg shells of affected birds were too thin and fragile to support the growing chick embryos. DDT contributed to the decline of many bird populations and the near extinction of some species of ospreys, hawks, eagles, and falcons. In the early 1970s, the United States and many other countries banned the use of DDT. Within a matter of years, many wildlife species in these countries were able to recover.

Many chlorinated hydrocarbon alternatives to DDT have been developed. One of the earliest substitutes was methoxychlor, shown in **Figure 15.17**. This compound has much lower toxicity in most animals and, unlike DDT, is not readily stored in animal fat. Look carefully at the structures of methoxychlor and DDT and you'll see that they are identical except that methoxychlor has two ether groups whereas DDT has two chlorine atoms. Because the structures are nearly identical, they have nearly the same level of toxicity in insects. In higher animals, however, the oxygen atoms facilitate detoxification. Specifically, enzymes in the liver cleave the ether groups to synthesize polar products that are readily excreted through the kidneys.

Organophosphorus compounds and carbamates, in contrast to chlorinated hydrocarbons, readily decompose to water-soluble components and so do not act over extended periods of time. Their immediate toxicity to both insects and animals is much greater than that of chlorinated hydrocarbons, however. Added safety precautions are required during the application of organophosphates and carbamates, especially because of their toxicity to honeybees (**Figure 15.18**).

There are hundreds of organophosphorus and carbamate insecticides in agricultural and household use. Two important examples are malathion, an organophosphorus compound, and carbaryl, a carbamate, both shown in **Figure 15.19**. Malathion kills a variety of insects, such as aphids, leafhoppers, beetles, and spider mites. Carbaryl, like many other carbamates, is relatively selective in the types of insects that it kills.



FOR YOUR INFORMATION

Many nations still rely on DDT as an economical method of controlling insects that carry human diseases. DDT can be most effective in this manner, but not without consequences. In Malaysia, for example, thatched roofs were once sprayed with DDT to kill malaria-carrying mosquitos. Wasps that kill straw-eating moths were also killed. The moths prospered, leading to the destruction of the thatched roofs. Furthermore, cats that ate geckos that ate DDT-laden cockroaches died. With no cats, rats multiplied, as did the bubonic-plague-carrying fleas that lived on the rats. Cats were therefore dropped by parachute to remote villages to help prevent outbreaks of the plague. When it comes to ecosystems, you can never change only one thing.



Figure 15.18

Honeybees do not forage at night. Quick-acting pesticides, such as organo-phosphorus compounds and carbamates, are therefore best applied in the evening. By the time the bees return the next day, these pesticides have lost much of their toxicity.

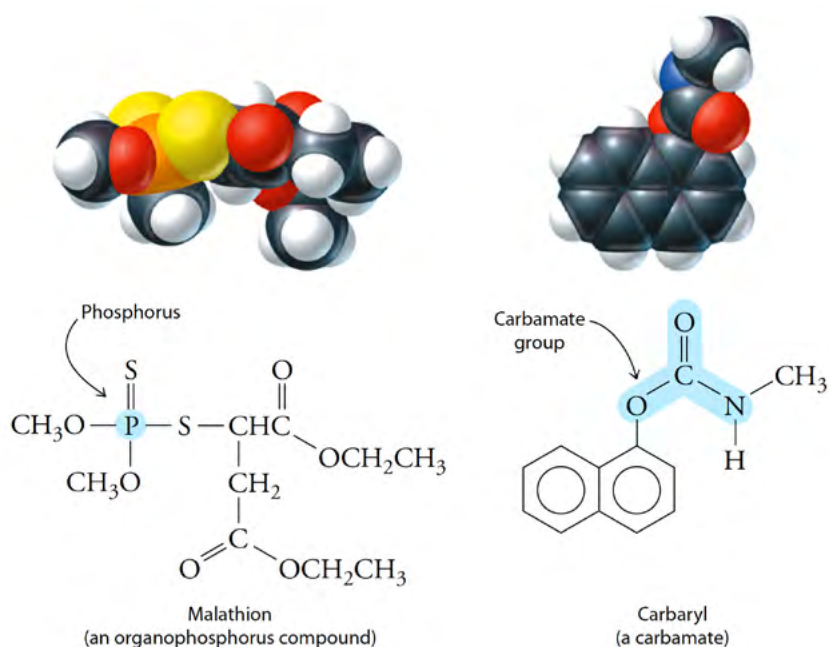


Figure 15.19

The widely used pesticides malathion and carbaryl.

The most widely used insecticides, however, are the neonicotinoids, such as the compound imidacloprid, shown in **Figure 15.20**. These compounds are derivatives of the compound nicotine, which is a naturally occurring neurotoxin, both to insects and mammals. The neonicotinoids, however, are selectively more toxic to insects than they are to mammals, making them safer for us to handle. These compounds tend to be water-soluble and can be added to irrigation water or even sprayed on the seeds, which grow into plants that then retain enough neonicotinoids to fight off insects. The neonicotinoids are biodegradable, especially when exposed to sunlight. There is strong evidence, however, that these compounds are having a negative impact on bee populations. Notably, they may be responsible, in part, for a phenomenon called *colony collapse disorder*.

Herbicides Kill Plants

Weeds compete with crop plants for valuable nutrients. The traditional method for controlling weeds is to plow them under the soil, where in decomposing, they release the nutrients they absorbed while they were alive. **Plowing also aerates the soil, but it is either labor-intensive or energy-intensive and can lead to topsoil erosion.** In the early 1900s, farmers noted that certain fertilizers, such as calcium cyanamide, CaNCN, selectively kill weeds while causing little harm to crops. This prompted a broad search for chemicals that act as herbicides. Today, a farmer can choose from hundreds

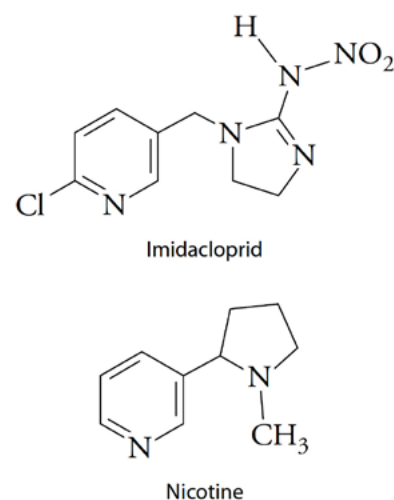


Figure 15.20

Imidacloprid is an example of a neonicotinoid, which is a compound that mimics the insecticidal properties of naturally occurring nicotine.

CONCEPT CHECK

Why are fish-eating birds more susceptible to DDT contamination compared to plankton-eating fish?

CHECK YOUR ANSWER A plankton-eating fish gets DDT from all the plankton it eats. This same DDT then enters the bird that eats this fish. But because the bird eats many fish, its exposure to DDT is amplified.

of herbicides, many tailored for a specific weed. Farmers in the United States apply millions of pounds of herbicides annually.

Two selective herbicides are the carboxylic acids 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), shown in **Figure 15.21**. Both mimic the action of plant growth hormones and are selective in killing broad-leafed plants but not grass-like crops such as corn and wheat. A herbicide known as Agent Orange is a blend of 2,4-D and 2,4,5-T. During the Vietnam War, U.S. military forces applied more than 15 million gallons of *Agent Orange* and related herbicides in an effort to defoliate jungle areas that could harbor enemy troops. Health problems in Vietnamese troops and civilians, U.S. troops, and others exposed to Agent Orange have since been linked to a minor contaminant of the herbicide—the highly toxic compound 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD). This contaminant was generated as a side product in the manufacture of 2,4,5-T. In 1985, because of this contamination, the use of 2,4,5-T was prohibited by the U.S. Environmental Protection Agency. TCDD-free methods of 2,4,5-T production, however, have since been developed, which raises the possibility that 2,4,5-T may once again be introduced as an effective herbicide.

Three other commonly used herbicides are atrazine, paraquat, and glyphosate, all shown in **Figure 15.22**. Atrazine is toxic to common weeds but not to many grass-like crops, which can rapidly detoxify this herbicide through metabolism.

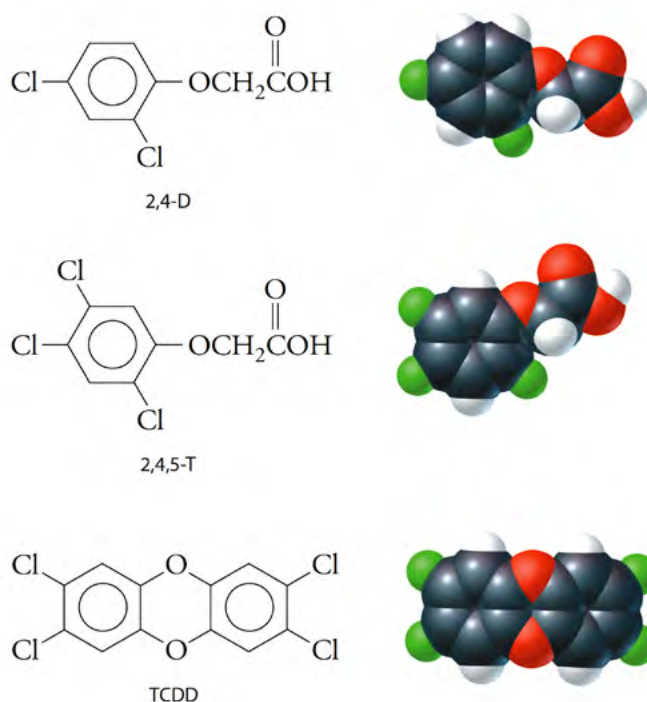
Paraquat kills weeds in their sprouting phase. During the 1970s and 1980s, this herbicide was sprayed aerially to destroy drug-producing poppy and marijuana fields in the United States, Mexico, and much of Central America and South America. Paraquat residues made their way into the illicit drug products, however, causing lung damage in users. So, for ethical reasons, the spraying of paraquat on drug-producing plants is no longer common practice.

Glyphosate is a nonselective herbicide that affects a biochemical process common to all plants—the biosynthesis of the amino acids tyrosine and phenylalanine. Glyphosate has low toxicity in animals because most



READING CHECK

What disadvantage is there to plowing weeds under the soil?



< **Figure 15.21**

The herbicides 2,4-D and 2,4,5-T and the dioxin contaminant TCDD.

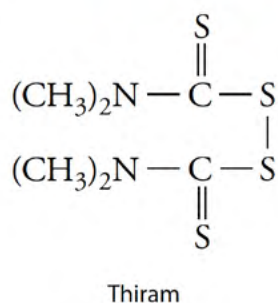
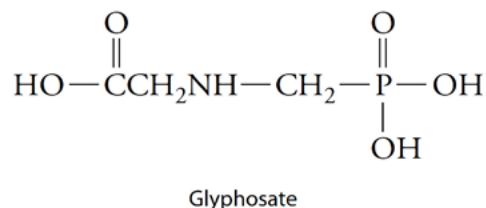
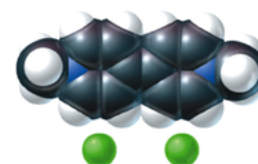
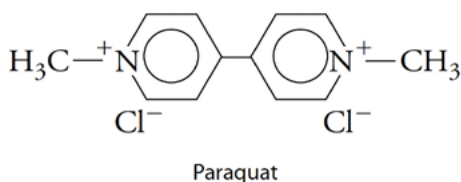
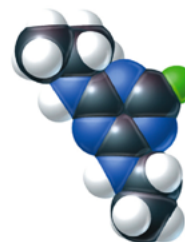
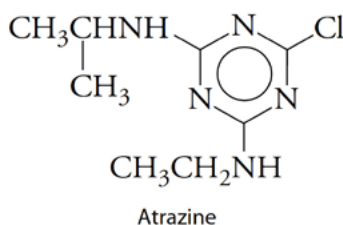


Figure 15.22 >

The herbicides atrazine, paraquat, and glyphosate.

animals do not synthesize these amino acids, obtaining them from food instead. Glyphosate is the active ingredient of the herbicide Roundup®. Long term exposure, however, is associated within an increased risk for certain types of blood cancers.

Fungicides Kill Fungi

As decomposers, fungi play an important role in soil formation, but they can also harm crops. Most of the harm they cause occurs during a plant's early growth stages. Fungi can also spoil stored food and are particularly devastating to the world's fruit harvest. In the United States, fungicides rank third after herbicides and insecticides in the amounts used. An example of a fungicide is thiram, widely used on fruits and vegetables (see **Figure 15.23**).

During the last 60 years, pesticides have benefited our society by preventing disease and increasing food production. Our need for pesticides will continue, but greater specificity will certainly be demanded. Furthermore, it is becoming increasingly apparent that the benefits of using pesticides must be considered in the context of potential risks.

Figure 15.23

The fungicide thiram.