# The Context 2

The way pests are managed in the United States is changing. A growing emphasis is on reducing the reliance on conventional pesticides. Strong public opinion coupled with legislative and executive actions by state and federal governments is driving this change. Farmers, foresters, ranchers, homeowners, and others who seek to prevent excessive pest damage are increasingly aware of the shortcomings of many conventional approaches to pest control. Yet their need for effective methods is acute. Meeting this need with a diversity of pest control tools and techniques poses a significant challenge. It is in this context that Congress has asked the Office of Technology Assessment (OTA) to examine the current and potential future role of biologically based technologies (BBTs) in the nation's pest management practices.

The OTA assessment covers a group of technologies that are grounded in an understanding of pest biology and generally have the following characteristics that differentiate them from most conventional pesticides:[1]

- narrow spectrum of action, that is, affecting only one or a narrowly defined class of organisms;
- relatively low probability of harmful environmental impacts; and
- general lack of significant adverse impacts on human health.[2]

These BBTs for pest management are biological control, microbial pesticides, pest behavior-modifying chemicals, genetic manipulation of pest populations, and plant immunization (box 2-1). The tools raise a unified set of technical and policy issues. BBTs comprise a significant part of the "reduced-risk pesticides," "biopesticides," and "biorational pesticides" that are receiving a good deal of attention in federal and state policy initiatives.[3]

OTA's assessment takes a critical look at these BBTs. This chapter describes past, current,

[1] Conventional pesticides are chemical compounds in wide use that kill pests quickly (267).

[2] The technologies are not, however, risk free. See chapter 4 for a detailed analysis of the major risk issues.

[3] "Reduced-risk," "biopesticide," and "biorational pesticide" have all been used with differing meanings, depending on the source, to encompass various combinations of microbial pesticides, botanical pesticides, chemicals that modify pest behavior or growth, augmentative releases of natural enemies, and conventional pesticides having new chemistries. This report does not use these terms because of this ambiguity.

| CHAPTER 2 FINDINGS |
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| ■ The need for new pest control methods and systems will grow in the future. The number of available conventional pesticides is declining, especially for minor uses, because of regulatory constraints, economic forces, and continuing public concern. At the same time, the number of pests requiring new control methods is increasing as more pests become resistant to pesticides and new pest threats emerge.<br>■ Congress and the executive branch have sought to address the need for pest control in the future by pressing to diversify available pest control technologies and to expand the use of integrated pest management. Biologically based technologies underpin many of these efforts. An assessment of these technologies provides a "bottom-up" view of whether and how effectively the national infrastructure for research, development, and implementation can deliver on this agenda. |

and potential future trends in U.S. pest management. Chapter 3 examines the effectiveness of BBTs and their future potential. The remainder of the report identifies the many activities of the federal government that affect the availability and use of BBTs (table 2-1). The potential risks of BBTs and how these are addressed through federal regulation are covered in chapter 4. Chapter 5 focuses on the public-sector roles in the research, development, and implementation of BBTs. And chapter 6 looks at BBTs from the vantage of private-sector companies involved in the production of pest control products.

## AN INTRODUCTION TO PEST MANAGEMENT

Throughout history, humans have sought to eliminate or reduce the abundance of living organisms that cause problems. The "pests" include animals, plants, insects, and microbes[4] that reduce agricultural productivity, damage forests and gardens, infest human dwellings, spread disease, foul waterways, and have numerous other deleterious effects. Left unimpeded, their economic impacts in the United States would amount to billions of dollars annually. The Weed Science Society of America has estimated that annual U.S. losses to agriculture if weeds were uncontrolled would exceed $19.6 billion—almost five times the costs under current control regimes (32). The environmental impact of pests can be equally profound: European gypsy moth (*Lymantria dispar*) now infests some 255 million acres in the United States; if the pest was left untreated, its annual defoliation of trees could fundamentally change the composition of hardwood forests (385).

Although what constitutes a "pest" is highly subjective, needs for pest control identified by U.S. consumers, agribusiness, and industry now support a multibillion-dollar infrastructure of pesticide production, pest control companies, and consultants on pest control methods. U.S. expenditures for pesticides exceeded $8.4 billion in 1993, approximately one-third of the world market (table 2-2) (399)

Pest control is quite literally a science of the specific. In agriculture, each pest and crop combination represents a different problem that can further vary with the specific location and time of year. There are literally thousands of (crop × pest × site) combinations, each differing in its potential impact and in the way that it is most successfully and appropriately controlled. Pests in other environments, such as parks, suburban landscapes, and urban dwellings, pose a similarly complex array of management needs.

[4] Microbes include viruses, bacteria, and other organisms that are too small to be seen by the human eye. Many microbes that are pests cause animal or plant diseases.

**BOX 2-1: Scope of the OTA Assessment**

**Pest Control Technologies Within the Scope of the OTA Assessment**

- *Biological Control:* the use of living organisms to control pests (includes predators, parasites, competitors, pathogens,[1] and genetic engineering applied to this approach)
- *Microbial Pesticides:* formulations of live or killed bacteria, viruses, fungi, and other microbes that are repeatedly applied to suppress pest populations (includes Bt formulated from *Bacillus thuringiensis*, nuclear polyhedrosis viruses (NPVs), and genetic engineering applied to this approach)
- *Pest Behavior-Modifying Chemicals:* the use of chemicals to trap pests or to suppress pest mating (includes pheromones)
- *Genetic Manipulations of Pest Populations:* genetic modification of pests to suppress their reproduction or impacts (includes releases of sterile insects)
- *Plant Immunization:* non-genetic changes to crop or landscape plants that deter insect pests or reduce susceptibility to diseases (includes induced immunity and endophytes)

**Pest Control Technologies Outside the Scope of the OTA Assessment**

- *Chemical Pesticides:* chemicals that kill pests (inorganic substances like arsenic-containing salts; synthetic organic compounds like organophosphates, carbamates, and triazines; insect growth regulators that mimic insect hormones; and synthesized and naturally occurring botanical pesticides)
- *Physical, Mechanical, and Cultural Controls:* nonchemical pest control by methods such as crop rotation, tillage, mechanical removal of pests (e.g., by hand or vacuums), and heat treatment
- *Plant Breeding and Enhanced Resistance to Pests:* development of plant cultivars that are less susceptible to pest damage either through plant breeding or genetic engineering

[1] Pathogens can be used as biological control agents if they are released and then spread on their own. They can also be formulated into microbial pesticides that are applied repeatedly.

NOTE: Box 2-5 at the end of this chapter describes in detail certain subcategories of the technologies outside the scope of this assessment that are receiving increased attention for the same reasons as BBTs.

SOURCE: Office of Technology Assessment, 1995.

## The Role of Conventional Pesticides

Conventional pesticides greatly simplify control of these diverse problems. Most conventional pesticides are broad spectrum—providing control for numerous pests simultaneously. They are relatively easy to use, because most chemicals are applied with similar methods and allow a fair margin of error in application technique. Perhaps most important, conventional pesticides are effective at killing pests and are relatively inexpensive.

Widespread use of conventional pesticides, however, is a recent development. Prior to the 1940s, U.S. farmers relied primarily on nonchemical methods such as crop rotation, tillage, and hand removal to minimize pest impacts (433). A number of inorganic salts (e.g., copper sulfate, lime sulfur, and lead arsenate) and botanically derived compounds (e.g., pyrethroids and rotenone) had come into use in the late 1800s and early 1900s. But chemical pest control did not truly burgeon until after World War II, with the increasing availability and use of DDT and other chlorinated hydrocarbon, organophosphate, and carbamate pesticides. From the 1950s to the 1980s, use of conventional pesticides in the United States grew dramatically, doubling between 1964 and 1978 (figure 2-1) (399). The increased use paralleled a growing mechanization of farming practices and a drop in the number of people engaged in farming. An example of how great the change has been can be seen in the

TABLE 2-1: Roles of Federal Agencies Related to Biologically Based Pest Control and Location of Discussion in This Report

| Agency | Regulates production or use of BBTs | Conducts research | Funds outside research | Implements technology in pest control programs | Educates end users | Transfers technology to the private sector |
|---|---|---|---|---|---|---|
| | (Chapter 4) | (Chapter 5) | (Chapter 5) | (Chapter 5) | (Chapter 5) | (Chapter 6) |
| USDA Agricultural Research Service (ARS) | | X | | | | X |
| USDA Cooperative State Research, Education, and Extension Service (CSREES)[a] | | X | X | | X | |
| USDA Forest Service | | X | | X | | |
| USDA Animal and Plant Health Inspection Service (APHIS) | X | X[b] | X | X[c] | X[c] | |
| U.S. Environmental Protection Agency (EPA) | X | X | X | | X | |
| Food and Drug Administration (FDA) | X | | | | | |
| Management agencies of the U.S. Department of the Interior (DoI)[d] | | X | X[e] | X | | |

[a] CSREES is a newly formed agency that incorporates prior functions of the Extension Service and the Cooperative State Research Service

[b] APHIS conducts "methods development" research, which translates the findings from more fundamental research into on-the-ground applications.

[c] The National Biological Control Institute produces a variety of public education materials and has provided about $1.5 million in grants for education and implementation of biological control over the past four years.

[d] The National Park Service, the Bureau of Land Management, the Bureau of Reclamation, and the U.S. Fish and Wildlife Service.

[e] Mostly via "pass-through" funds to the ARS for research on biological control of rangeland and other weeds.

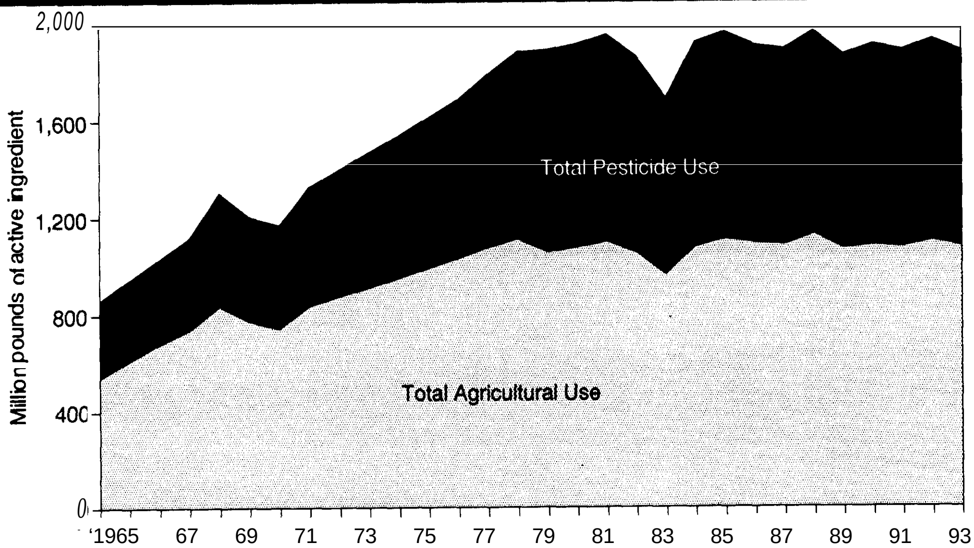
SOURCE: U.S. Congress, Office of Technology Assessment, 1995.

TABLE 2-2: User Expenditures for Pesticides in the U.S. by Sector, 1993

| Sector | Total in millions $ | Percentage |
|---|---|---|
| Agriculture | 6,130 | 72.2 |
| Individuals/Communities/Government | 1,136 | 13.4 |
| Home and Garden | 1,218 | 14.4 |
| Total | $8,484 | 100.0% |

SOURCE: U.S. Environmental Protection Agency, *Pesticide Industry Sales and Usage: 1992 and 1993 Market Estimates,* A.L. Aspelin, 733-K-94-001 (Washington, DC: June 1994).

FIGURE 2-1: Growth in U.S. Conventional Pesticide Use, 1964 to 1993




SOURCE: U.S. Environmental Protection Agency, *Pesticide Industry Sales and Usage: 1992 and 1993 Market Estimates*, A.L. Aspelin, 733-K-94-001 (Washington, DC: June 1994).

NOTE: Usage level is reported in millions of pounds of "active ingredient." The active ingredient is the component of a commercial product that has pesticidal properties. Newer pesticides tend to have active ingredients that are more potent and can be applied at a lower dosage level. Consequently, the leveling-off in the 1980s in the figure does not necessarily translate into a stabilization of pesticide use according to numbers of acres treated, numbers of products applied, frequency of pesticide application, or other relevant measures.

figures for cultivation of corn, cotton, and wheat: herbicides were applied to only 10 percent of acreage in 1952, but climbed to 90 to 95 percent of acreage by 1980 (378).

Conventional pesticides now pervade all aspects of pest management in the United States. More than 900,000 U.S. farms use pesticides (399). In 1993, pesticides were applied to more than 80 percent of the acreage planted in corn, cotton, soybeans, and potatoes (377). Between 35,000 and 40,000 commercial pest control companies and 351,600 certified commercial applicators apply pesticides to building, home, and landscape pests (399). Each year such commercial operations treat an estimated 20 percent of the 6.1 million U.S. households for indoor pests such as cockroaches (424). Most of these homes (85 percent) also contain pesticidal products, the majority of which (70 percent) had been used within the past year, according to the 1990 National Home and Garden Pesticide Use Survey commissioned by the Environmental Protection Agency (EPA) (424).[5]

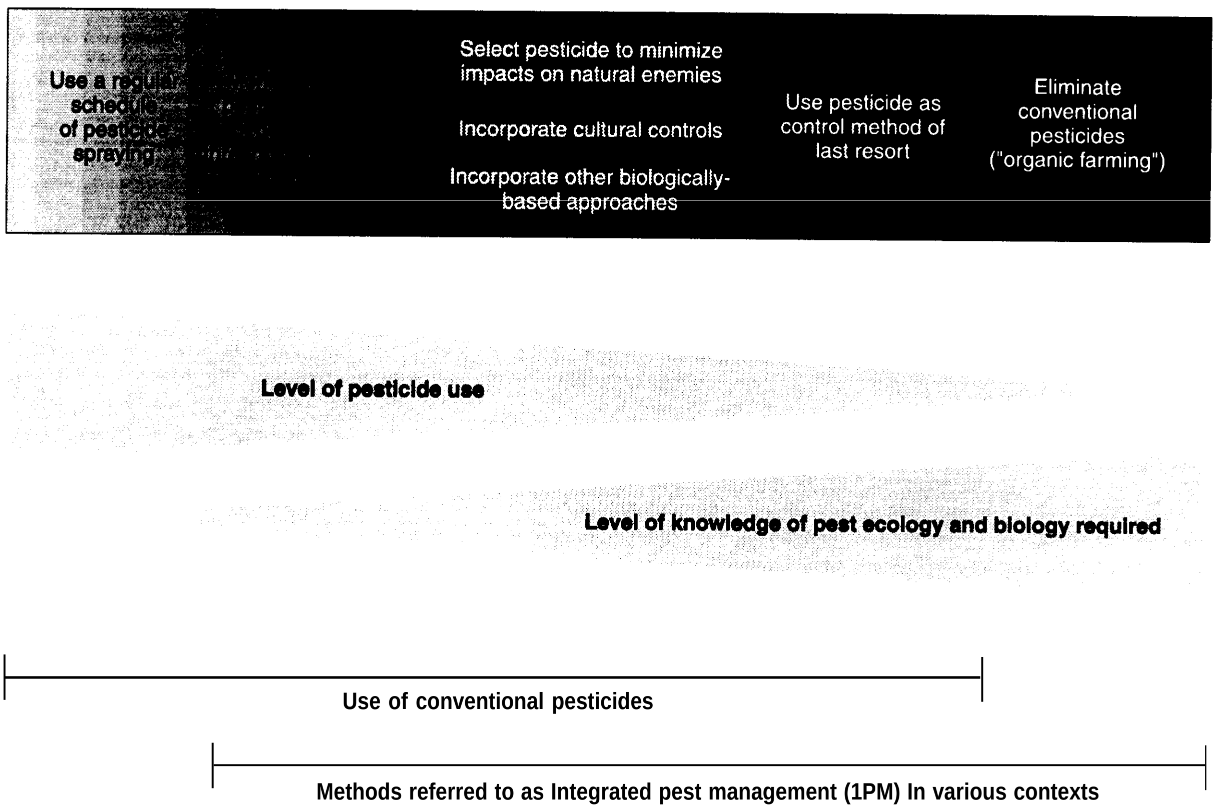
## The Spectrum of Approaches to Pest Control in Practice Today

Today, the extent to which people seeking to control pests rely on conventional pesticides varies (figure 2-2). Some depend on a number of other pest control tools as well, including cultural practices, use of pest-resistant crop cultivars, and the BBTs that are the subject of this assessment.

At one end of the spectrum are those who use only conventional pesticides, often applying them as a prophylactic measure according to some regular, predetermined spray schedule. At the other end are those who control pests by a combination of numerous non-chemical tools, and use conventional pesticides either as the last method of choice or not at all.

5 A total of 2,078 households in 29 states were surveyed, with results statistically extrapolated to a target population of 84,573 households.

FIGURE 2-2: Approaches to Pest Control in Practice Today




SOURCE: Office of Technology Assessment, 1995,

The gradation from one end of the spectrum to the other entails increased targeting of pesticide application and incorporation of a greater number of pest control tools and techniques. Diversification of pest control approaches beyond the regularly scheduled use of conventional pesticides requires planning as well as a greater understanding of pest biology and ecology and the specific effects of each control technology. This thoughtful incorporation of various control methods into an overall pest suppression plan has generally been referred to as integrated pest management (IPM)[6] (box 2-2). Note that a diverse range of approaches have all been referred to as 1PM by various sources (figure 2-2).

Most users currently fall toward the left and center of figure 2-2. For example, according to a 1993 survey of pest control professionals commissioned by Sandoz Agro and conducted by the Gallup Organization? only 32 percent reported having ever used 1PM, with rates being highest among pest control operators (85 percent) and lowest among farmers (19 percent) (302).[7] A more precise survey by the Economic Research Service of the U.S. Department of Agriculture (USDA) showed that acreage under 1PM varied

6 The term IPM has been used with a good deal more precision in the scientific and technical literature on pest management, although various authors use it to mean different things, For a thoughtful analysis of how 1PM concepts and definitions have evolved since the 1950s, see ref. 44.

7 Survey was of 2,361 professional lawn care operators, golf course managers, pest control operators, mosquito district managers, roadside vegetation managers, small-animal veterinarians, and farmers, Note that the meaning of 1PM was not specified in the survey. Results thus indicate respondents' perceptions of whether they have ever used IPM, Some using varied techniques or monitoring pest levels may not refer to their management practices as 1PM.

## BOX 2-2: What Is Integrated Pest Management?

The concept of integrated pest management (IPM) originated in the late 1950s and 1960s, when entomologists at the University of California began to detect failures of pest control as a result of overuse of insecticides. Some pests became difficult to control because they developed resistance to formerly effective chemicals. And populations of certain other insects that had previously not been considered pests surged to outbreak levels. These "secondary pest outbreaks" were attributed to the harmful effects of pesticides on natural enemies—the insect predators and parasites that occurred naturally in fields and otherwise kept secondary pests in check through biological control.

IPM developed as a way to avoid the problems of insecticide resistance and secondary pest outbreaks by integrating biological and chemical control. Its cornerstones were:

- "Natural" control should be maximized, enhanced, and relied on whenever possible. Natural control results from factors both within (i.e., biological control) and outside (i.e., weather) human influence;
- Pesticides should be used only when the abundance of a pest reaches a threshold level that causes economically significant damage. Such restraint minimizes the harmful effects of pesticides on natural enemies.

Since the 1960s, ideas about IPM have expanded and changed. Additional pest management tools have come into wider use, and IPM concepts have been applied to other types of pests with a resulting proliferation of related terms like "integrated weed management" and "integrated disease management."

Practitioners now often use IPM to refer more generally to an approach that integrates all available tools for pest control—biological, chemical, cultural, and others. The idea that chemicals should be applied only when a pest is detected at an (economically or aesthetically) significant level of abundance has been retained. What is lost in many current applications, however, is the concept that biological control should form one of the foundations of IPM. One consequence, according to some critics, is that IPM as practiced today too often becomes integrated *pesticide* management instead.

Right now the difference between these interpretations of IPM may make very little difference in practice. Many users would be hard pressed to base a pest control system on natural control because they have access to little of the necessary information and relatively few alternatives to conventional pesticides.

The distinction does, however, make a great deal of difference in another regard. The two interpretations lead to very different conclusions regarding the types of research that must underpin IPM. A core reliance on natural control requires emphasizing research into the ecology of pest systems. It also requires giving greater weight to pest control methods that are compatible with biological control.

SOURCES: Office of Technology Assessment, 1995, and J.R. Cate and M.K. Hinckle, *Integrated Pest Management: The Path of a Paradigm,* National Audubon Society (Alexandria, VA: Weldon Printing Inc., July 1994).

TABLE 2-3: Use of Integrated Pest Management on U.S. Crops

| | Do not use IPM | Monitor levels of pests and use pesticides when levels exceed set thresholds, but use no additional pest control tactics | Use additional pest control tactics in an IPM program | Do not use pesticides |
|---|---|---|---|---|
| | | Percent of acres | | |
| Fruits and nuts | 42 | 6 | 44 | 8 |
| Vegetables | | | | |
| Insect control | 38 | 9 | 43 | 10 |
| Weed control | 60 | 2 | 33 | 6 |
| Disease control | 29 | 12 | 29 | 30 |
| Corn | | | | |
| Insect control | 15 | 52 | 22 | 11 |
| Weed control | 45 | 2 | 51 | 2 |
| Soybean | | | | |
| Weed control | 39 | 2 | 57 | 2 |
| Fall Potatoes | | | | |
| Insect control | 25 | 3 | 69 | 3 |
| Weed control | 30 | 1 | 65 | 5 |
| Disease control | 14 | 5 | 58 | 22 |

SOURCE: Adapted from U.S. Department of Agriculture, Economic Research Service, *Adoption of Integrated Pest Management in U.S. Agriculture,* prepared by A. Vandeman et al., AIB-707 (Washington, DC: September 1994).

NOTE: Survey was conducted during 1991 and 1992 and covered from 70 to 100 percent of total acreage per crop in the United States.

with type of crop and pest, but that an absence of pesticide use is rare (table 2-3) (377).

## FORCES SHAPING THE FUTURE OF U.S. PEST MANAGEMENT

Because conventional pesticides are easy to use and effective, they are the sole or primary tool used by most practitioners today to control the number and impact of pests. But constraints are being imposed on the nation's pest management practices. Some—such as the increased rigor of pesticide screening prior to registration, economic forces within the industry, and continuing widespread public concern—will tend to limit growth in the number of available pesticides (especially insecticides and fungicides) and their use. At the same time, increasing resistance to pesticides and newly emerging pest threats will cause the need for pest control to rise. The resulting gap between pests requiring control and available pesticides will generate the need for more and a greater variety of pest control tools and techniques—essentially a centerward shift of those toward the left end of the spectrum in figure 2-2.

That such needs already exist is evident from EPA data on exemptions under section 18 of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the authorizing statute under which EPA regulates registration and use of pesticides.[8] These exemptions are granted under emergency circumstances to allow use of a pesticide without the normal registration requirements that ensure safety to human health and the environment. According to EPA, at least 200 exemptions are being approved each year (164,19). Resistance to pesticides, cancellation of a pesticide previously in use, and emergence of new pests are the most

[8] Such exemptions are authorized under section 18 of FIFRA (1947) as amended (7 U.S.C.A. 136, *et seq.*) (105).

common reasons for exemptions. The level of use of these exempted chemicals is uncertain. Nevertheless, one consequence of the growing backlog of pest control needs is circumvention of the standard criteria that ensure safe pesticide use.

## Regulation of Conventional Pesticides

More rigorous federal regulation of conventional pesticides is directly and indirectly causing certain pesticides to be withdrawn from U.S. markets. These losses are unlikely to be completely offset by the new chemicals coming on line.

Over the past few decades, the Congress has set a clear national policy, through amendments in 1972 and 1988 to FIFRA, to phase out conventional pesticides that are harmful to human health or the environment. These amendments required reevaluation and reregistration of pesticides already on the market to bring them into line with current testing requirements.

A significant number of pesticides are expected to disappear from U.S. markets as a result of the reregistration requirements. In the early 1990s, companies elected not to reregister an estimated 25,000 of the 45,000 products on the market (401). The total number that will ultimately disappear is unknown, as are the specific reasons why companies decide not to reregister each product. According to EPA, 19,000 of the dropped registrations were for older products that had not been produced in the three previous years (401). With respect to the remaining 6,000 products, companies may not have sought the reregistration of some that would not meet the more scrupulous registration criteria. But a more common reason may be that manufacturers have determined that the potential market size for certain products does not justify the costs of reregistration.

Experts expect that many pesticides falling into the last category are those that serve relatively small markets, the "minor use" pesticides, for use in crops like fruits, vegetables, and nuts where the potential market size per registration is quite small, especially when compared with markets for major crops like corn, wheat, soy, and cotton. Corn, for example, was grown on about 79 million U.S. acres in 1992; in contrast, the acres devoted to all vegetables combined amounted to only 4.6 million (379). Industry experts now anticipate that manufacturers will drop the registrations on 4,000 pesticides currently labeled for only minor uses; about 1,000 of these have significant uses (335).

Congress has sought to redress these economic disincentives for registration of minor use pesticides in a number of ways. The IR-4 program,[9] administered by USDA through the Cooperative State Research, Education, and Extension Service (CSREES) and funded at $5.7 million in fiscal year 1995, supports the development of data for minor use registrations. IR-4 works in conjunction with the Agricultural Research Service (ARS) minor use program, funded at $2.1 million for 1995. A number of bills have been introduced with strong bipartisan support in the 103d and 104th Congresses[10] to reduce the costs of minor use registrations—most recently in H.R. 1627 introduced May 12, 1995.

Removal of the economic constraints will not completely counter the effects of reregistration on the number of available pesticide products. The active ingredients and products that have been reregistered first are those that require the least new data on environmental and health risks. Older chemicals long on the market generally require more data to support reregistration and will be the last to be reregistered. Far less is known about the potential risks of these chemicals. As the chemicals come under review, additional products may have uses restricted or be removed from the market due to risk considerations, not economic forces.

Costs of pesticide research and development have risen steadily in the recent past. These

[9] The Interregional Research Project, No. 4 was begun in 1963 by directors of the State Agricultural Experiment Stations.
[10] Related bills include H.R. 967 and S. 985 in the 103d Congress and H.R. 1352, H.R. 1627, and S. 794 in the 104th Congress.

costs, coupled with the more careful scrutiny of potential impacts, have slowed the rate at which new pesticide products have been marketed (150) (see chapter 6). Moreover, companies are increasingly seeking to position new products in major, not minor markets. The effects of this trend on the number of pesticides available in the United States are uncertain, but the development of new pesticides is unlikely to compensate for the losses of current pesticides through the reregistration process, especially of those for minor use markets.

Development of pesticide replacements may also be impeded by the rate of the pesticide reregistration process. EPA has been widely criticized for its slow action on reregistration, prompting repeated prodding by Congress through oversight hearings (336). The delays allow continued marketing of older pesticides, potentially creating a deterrent to the development of new, lower-risk alternatives (190).

## Public Concern

Assessment of the benefits and risks of conventional pesticides is beyond the scope of this report. The use of pesticides in the United States over the past several decades has obviously had considerable benefits to agriculture and public health, but has also caused harm. The body of information addressing pesticide impacts on human health and the environment is complex and large (202). Certainly, humans and wildlife exposed to certain pesticides under specific conditions have shown short- and long-term adverse impacts ranging from poisoning to sterility and cancer (55,202). The thousands of chemical formulations in use today vary greatly in their modes of action, toxicological profiles, and other significant features. Effects of any given pesticide depend not only on such specific characteristics, but also on the ways in which it is used, the environment into which it is released, and the duration and level of exposure of humans and other living organisms.

Despite this complexity, it is clear that the public now has substantial concern about exposure to pesticides. This concern is driven as much by perceptions about how much we don't know about pesticide impacts as by what we do. It is compounded by the frequent reports of unanticipated exposure from groundwater contamination, food residues, and improper pesticide use and storage. The resulting public sentiment can be powerful, especially if the level of uncertainty is great, even in the absence of technical evidence that an unambiguous risk to public health or the environment exists (e.g., box 2-3).

The level of media coverage suggests that public interest is constant and intense. OTA's search of six major newspapers across the country showed that they run, on average, more than three related articles a week, providing a constant chronicle of public exposure, health impacts, and unintended contamination of food and the environment.[11] Not surprisingly, the media focus on events of greatest public interest, such as recently reported widespread contamination of tap water by agricultural herbicides in the Midwest (199) and the potential effects of pesticides on reproduction in humans and wildlife (323).

Recent surveys consistently show that the public is genuinely concerned about pesticide residues in food (421). For example, a 1990 survey of 1,900 U.S. households by researchers from the USDA Economic Research Service showed that the majority were concerned about pesticide safety and food residues (206). More than half of the respondents expressed the belief that foods were unsafe when grown using pesticides at approved levels. The majority also did not believe that the health risks of pesticide use are well understood and agreed that pesticides should not be used on food crops because the risks exceed the benefits (206).

[11] OTA's search covered the years 1992, 1993, and 1994 for the following newspapers: *New York Times, St. Louis Post-Dispatch, Washington Post, Chicago Tribune, Houston Post,* and *Los Angeles Times*. Search criteria covered various types of pesticides and health or environmental impacts.

### BOX 2-3: Alar: A Case Study on the Influence of Public Opinion

In early 1989, the television show *60 Minutes* and other media sources focused public attention on a report from the Natural Resources Defense Council (NRDC) charging that children were particularly at risk from exposure to residues of cancer-causing agents in their food. The NRDC report identified as an example Alar, a chemical widely used in apple production to enhance fruit color and to keep fruit from falling off trees. Demand for fresh apples plummeted and concern about the presence of other chemical residues on produce increased. Losses to apple growers caused by diminished sales exceeded $100 million that spring.

The NRDC report stated that Alar is a potent carcinogen and that children face particular risk. The scientific information underlying this assertion was inconclusive, however. In 1973, scientists in Omaha, Nebraska, had found evidence that unsymmetrical dimethyl hydrazine (UDMH), a chemical comprising 1 percent of Alar, was carcinogenic to mice at very high doses. EPA declared these results "unscientific" because the mice received excessively high doses of the chemical. Subsequent tests found effects on mice only at extremely high doses and no effects on rats at any level of exposure. Neither U.S. nor British regulators found sufficient justification in the research to ban the use of Alar.

Alar, like other plant growth regulators, is regulated as a pesticide by EPA. The strong public outcry against Alar following the media coverage forced EPA to reassess its findings. The agency subsequently determined that the risks of Alar were too high and pulled the chemical from the market.

Uncertainty was the real issue underlying the debate about Alar. Because there was no proven risk, government regulators and industry assumed that the chemical was safe. In contrast, the possibility that Alar might cause cancer led NRDC and parent groups to call for the chemical's prohibition—especially in light of the high consumption of apples and apple products by infants and children and the uncertainties regarding long-term effects of exposure to carcinogens early in life.

SOURCES: E. Marshall, "A is for Apple, Alar, and . . . Alarmist?" *Science* 254(5028):20–4, Oct. 4, 1991; J.D. Rosen, "Much Ado About Alar," *Issues in Science and Technology* 6:85, Fall 1990; D. Warner, "The Food Industry Takes the Offensive," *Nation's Business* 79(7):42–45, July 1991; and F.E. Young, "Weighing Food Safety Risks," *FDA Consumer* 23(7):8–14, September 1989.

Concern about pesticide food safety issues gained new impetus in 1993 with the release of the National Research Council's highly publicized report on "Pesticides in the Diets of Infants and Children." The study concluded that children and infants may be uniquely susceptible to the toxic effects of pesticides and are at greater risk than adults from some chemicals. Past risk assessments may not always have adequately protected infants and children because they did not explicitly account for these differing impacts, as well as for differences between adults and children in diet and other factors—and hence in pesticide exposure levels (241).

Consumer worries about food safety have fueled a 20 percent annual growth in the market for organically grown products since 1989. Sales by U.S. companies amounted to $2.3 billion in 1994 (226). Pest control professionals also report growing public concern. In the 1993 Sandoz survey of pest control professionals, 76 percent reported greater public concern about the environmental impacts of pest control than five years previously (302). One response to this growing concern has been a reduction in pesticide use. In a 15-state survey of 9,754 farmers conducted in 1994, 82 percent reported using less or the same amount of pesticides than five years ago, compared with only 6 percent reporting an increase in pesticide use (131).

## Pesticide Resistance

An increasing number of pests—insects, weeds, and plant diseases—have become resistant to pesticides that formerly were effective in controlling them. Alternative control technologies may provide the solutions to management of some resistant pests. They also will become integral components of strategies to slow the rate at which resistance develops (77,111). Abundant evidence exists that the use of multiple tactics to control a pest slows the rate at which the pest develops resistance to any single tactic in the arsenal (125).

A pest becomes resistant to a formerly effective pesticide when the chemical ceases to provide adequate control. Resistance develops because repeated exposure to the pesticide causes the selective survival of pest strains that can tolerate the chemical. Farmers and other users often find themselves applying the pesticide at an ever-increasing rate to achieve the same level of pest control. Eventually, the pesticide may cease to have any effect on the pest whatsoever.

Evidence of pesticide resistance was observed as early as the 1950s. As of 1992, the numbers of resistant species worldwide were estimated at 504 arthropods (including insects and arachnids, such as mites), 87 weeds, and 100 plant pathogens (68).

As of 1988, at least 18 herbicide-resistant weed species had been reported from 31 states (198). Twelve of these species have shown resistance to triazines, the most widely used category of herbicides. More than three million acres in the United States are now infested with resistant weeds (198). They include such well known weeds as cheatgrass (*Bromus tectorum*), a common seed contaminant and cause of fire hazards on western rangelands, and black nightshade (*Solanum nigrum*), a common crop weed whose toxic berries can contaminate harvests of peas and beans (425).

Today in the United States at least 183 insect and arachnid pests are resistant to one or more insecticides; 62 of these have developed resistance to synthetic insecticides within at least two of the three major categories of these products now in use (organophosphates, carbamates, pyrethroids) (112). California scientists believe that almost every arthropod pest in the state is resistant to at least one insecticide, and some populations of such important pests as the tobacco budworm (*Heliothis virescens*) in cotton and leafminers in certain vegetable crops (*Liriomyza sativae*) cannot be effectively controlled by any chemical now available (410). Table 2-4 shows the most critical cases today of multiple resistance among arthropod pests in the United States. George Georghiou, a renowned world expert on insecticide resistance, predicts that new instances of pest resistance to specific insecticides will pose a continuing impediment to effective control through conventional pesticides (112).

**TABLE 2-4: Critical Cases of Multiple Insecticide Resistance in the U.S. Today**

| Pest | Major impacts | Resistant to | | | |
|---|---|---|---|---|---|
| | | OP* | C | P | Oth |
| Two-spotted spider mite (*Tetranychus urticae*) | Attacks most greenhouse-grown plants; also damages grapes, vegetables, and field and orchard crops | X | X | X | X |
| Colorado potato beetle (*Leptinotarsa decemlineata*) | Attacks potato, tomato, eggplant, tobacco, and other crops; found throughout most of the United States | X | X | X | |
| Southern house mosquito (*Culex quinquefasciatus*) | Bites humans and can transfer encephalitis | X | X | X | X |
| House fly (*Musca domestica*) | Most abundant fly in human dwellings; causes annoyance, spreads filth, and is the suspected vector of numerous human diseases; distributed worldwide | X | X | X | X |
| Little house fly (*Fannia canicularis*) | Occasional parasite of the human urinary tract and intestines | X | | X | X |

(*continued*)

TABLE 2-4: Critical Cases of Multiple Insecticide Resistance in the U.S. Today (Cont'd.)

| Pest | Major impacts | Resistant to | | | |
|---|---|---|---|---|---|
| | | OP* | C | P | Oth |
| Sweetpotato whitefly (*Bemisia tabaci*) | Destructive pest of irrigated cotton and vegetables; has caused annual losses in excess of $100 million to California agriculture during severe outbreaks; damages greenhouse crops | X | X | X | |
| Silverleaf whitefly (*Bemisia argentifolii*) | Attacks over 600 plants including melons, squash, tomatoes, lettuce, cotton, and poinsettias; has caused over $500 million in damage in California, Arizona, Florida, and Texas | X | | | X |
| Greenhouse whitefly (*Trialeurodes vaporariorum*) | Attacks cucumber, tomato, lettuce, geranium, and many other plants | X | X | X | |
| Cotton aphid (*Aphis gossypii*) | Important aphid pest of agriculture, affecting cotton, melons, citrus, and other crops; distributed throughout the United States; most destructive in the South and Southwest | X | X | X | |
| Pear psylla (*Cacopsylla pyricola*) | One of the most important pear pests where established; transmits pear disease; distributed throughout eastern states and pear-growing regions of Pacific Coast | X | X | X | |
| Tobacco budworm (*Heliothis virescens*) | Attacks tobacco, cotton, and other plants; key secondary pest of cotton; occurs from Missouri, Ohio, and Connecticut southward; most injurious in Gulf states | X | X | X | |
| Soybean looper (*Pseudoplusia includens*) | Major defoliator of soybean; also attacks peanut, cotton, tobacco, and other crops; occurs in southern Atlantic and Delta regions of the United States | X | X | X | |
| Beet armyworm (*Spodoptera exigua*) | Attacks beet, alfalfa, cotton, asparagus, and other root and vegetable crops; distributed from the Gulf states north to Kansas and Nebraska and west to the Pacific Coast | X | X | X | |
| Fall armyworm (*Spodoptera frugiperda*) | Attacks corn, sorghums, and other grass-type plants; occurs throughout Gulf states; sometimes migrates north as far as Montana or New Hampshire, but cannot survive winter | X | X | X | |
| Diamondback moth (*Plutella xylostella*) | Attacks cabbage, and ornamental and greenhouse plants; occurs wherever its host plants are grown | X | X | X | X |
| German cockroach (*Blattella germanica*) | Most common household roach; spreads filth; damages household items; is suspected vector of human diseases; distributed worldwide | X | X | X | X |
| Cat flea (*Ctenocephalides felis*) | Worldwide pest of cats; common indoors in eastern United States; can carry the bacteria that causes bubonic plague | X | X | X | X |
| Citrus thrips (*Scirtothrips citri*) | One of the most important citrus pests in California and Arizona | X | X | X | |

* OP = organophosphates; C = carbamates; P = pyrethroids; Oth = other smaller categories of pesticides, including microbial pesticides.

SOURCES: Resistance data from G.P. Georghiou, University of California, Riverside, CA, "Insecticide Resistance in the United States," unpublished contractor report prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, April 1995; and data on pest impact from R.L. Metcalf and R.A. Metcalf, *Destructive and Useful Insects: Their Habits and Control,* 5th Ed. (New York, NY: McGraw Hill, 1993).

NOTE: Data in table indicate where resistance has been documented in one or more locations in the United States.

## Newly Emerging Pest Threats

The number of pests in the United States is constantly growing. The 1993 OTA assessment of *Harmful Non-Indigenous Species in the United States* showed that new species continuously flow into the country, but few previous immigrant (or nonindigenous) pests, such as the bollworm *(Helicoverpa zea)* or the European gypsy moth, are ever eradicated (338). Newly arrived pests just since 1980 include:

- the Russian wheat aphid *(Diuraphis noxia)*, which has caused more than $850 million in crop losses;
- the zebra mussel *(Dreissena* spp.), which spread to more than 17 states in less than a decade, imperiling native mussels, fouling water intake systems, and causing losses to the power industry that are expected to exceed several billion dollars; and
- the Asian tiger mosquito *(Aedes albopictus)*, which is now found in more than 22 states and is an effective vector of several serious human diseases such as dengue fever (338).

OTA estimated that more than 205 species were newly detected or introduced into the United States from 1980 through 1993, with at least 59 having the potential to become pests. Moreover, this rate of pest entry is expected to rise with the increasing globalization of trade and advent of more rapid methods of transportation (338). Global warming is similarly expected to increase rates of pest entry to the United States, as species usually restricted to lower latitudes migrate northward (338).

In addition, public authorities are now attacking some old pests with new vigor. Specifically, changing public values have caused increased emphasis on the conservation of indigenous biodiversity —the nation's biological heritage. In numerous parks and nature reserves, this biodiversity is now imperiled by nonindigenous weeds, insect pests, and plant diseases that parasitize, kill, consume, compete with, or destroy the habitats of native plants and animals.

*In the late 1980s, the silverleaf whitefly (Bemisia argentifolii) emerged as a new pest in the southwestern United States, causing hundreds of millions of dollars in crop damage.*

*Agricultural Research Service, USDA*

National Park Service managers, for example, now rank nonindigenous species as one of the top threats to park natural resources (338). Stewards of Nature Conservancy lands in 46 states report problems with pest plants, and 59 percent of all stewards rank pest plants as one of their top 10 conservation concerns (284).

Managers of natural areas are increasingly seeking methods to suppress these pests while leaving the native flora and fauna unharmed. Scientists are similarly directing increased attention toward dealing with introduced pests in aquatic systems—rivers, lakes, streams, and oceans (191). The need is for effective, but highly specific, pest control methods that can be used in environmentally sensitive habitats-criteria met by few conventional pesticides.

Nonindigenous weeds also degrade western rangelands. A number provide only low-value forage for cattle, and some, like leafy spurge

*Some pests can have profound environmental impacts. These leafless trees in midsummer result from the European gypsy moth's* (Lymantria dispar) *voracious appetite.*

*Agricultural Research Service, USDA*

(*Euphorbia esula*), are toxic (425). These harmful plants are spreading rapidly across federal lands and now infest around 17 million acres. Indeed, the threats from certain nonindigenous weeds—called noxious weeds[12]—were deemed significant enough to merit special mention in the 1990 Farm Bill,[13] which amended the Federal Noxious Weed Act to require the development of weed management plans on all federal lands. The Secretary of the U.S. Department of the Interior (DoI) recently set up an agency-wide task force to aid in addressing this requirement (290). In addition, a number of DoI and USDA agencies have signed onto a Memorandum of Understanding to coordinate the prevention and control of noxious weeds (see also chapter 5).

## RESPONSES BY CONGRESS AND THE EXECUTIVE BRANCH

The significance of pesticide losses, pest resistance, and emerging pest threats has not been lost on national policymakers. Congress responded directly to a number of these in the 1990 Farm Bill in provisions related to use and registration of pesticides, identification of pest control tools, and control of exotic pests (box 2-4). Pesticide issues have generally remained high on the congressional agenda: between 45 and 152 bills directly or indirectly addressing pesticide issues have been introduced into each Congress since the 98th Congress convened in 1985.[14] In the 103d Congress alone (January 1993 to January 1995), 33 bills dealt directly with pesticide-related issues. Of these, 19 addressed the health and environmental impacts of pesticides, and at least three dealt with future need for effective pest control methods and approaches. This interest continues in the 104th Congress, where eight pesticide-related bills had been introduced as of May 24, 1995. Two dealt with pesticide impacts on health and the environment, and five with meeting future pest control needs.

The most notable related action in the executive branch of government is the Clinton Administration's June 1993 announcement of its intent to reduce the use and risks of pesticides (see also box 5-1 in chapter 5). A major mechanism for achieving this goal is the Administration's stated commitment to develop and implement IPM practices on 75 percent of U.S. crop acreage by the year 2000 through the actions of three federal agencies—USDA, EPA, and the Food and Drug Administration (FDA).[15] The Administration has

[12] A "noxious weed" under the Federal Noxious Weed Act, as amended (7 U.S.C.A. 2814), is "of foreign origin, is new to or not widely prevalent in the United States, and can directly or indirectly injure crops, other useful plants, livestock, or poultry, or other interests of agriculture, including irrigation, or navigation or the fish or wildlife resources of the United States or the public health." A total of 93 species have been designated federal noxious weeds by the U.S. Department of Agriculture's Animal and Plant Health Inspection Service. Weed experts believe that hundreds of other species also deserve this designation (338).

[13] The Food, Agriculture, Conservation, and Trade Act of 1990.

[14] Data derived from OTA's search of the Legislate and Scorpio databases.

[15] Note that this is the third administration to develop an IPM initiative (44). Under President Nixon, the Council on Environmental Quality issued an IPM policy document in 1972 and $12.5 million were allocated to the "Huffaker Project"—a research, training, and demonstration program for IPM. President Carter also tasked the Council on Environmental Quality to make recommendations to facilitate expansion of IPM.

*Some pests can have profound environmental impacts. These leafless trees in midsummer result from the European gypsy moth's* (Lymantria dispar) voracious *appetite.*

*Agricultural Research Service, USDA*

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12 A "noxious weed" under the Federal Noxious Weed Act, as amended (7 U. S.C.A, 2814), is "Of foreign Origin, is new to or not widely prevalent in the United States, and can directly or indirectly injure crops, other useful plants, livestock, or poultry, or other interests of agriculture, including irrigation, or navigation or the fish or wildlife resources of the United States or the public health." A total of 93 species have been designated federal noxious weeds by the U.S. Department of Agriculture's Animal and Plant Health Inspection Service, Weed experts believe that hundreds of other species also deserve this designation (338).

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**BOX 2-4: Congress Anticipates Future Pest Control Needs in the 1990 Farm Bill**

**Registering pesticides for minor use crops**

*Title XIV—Conservation; Subtitle H—Pesticides:* Amends the Federal Insecticide, Fungicide, and Rodenticide Act to allow the EPA Administrator to reduce or waive the fee for registration of a minor use pesticide if that fee "would significantly reduce the availability of the pesticide for the use."

**Reducing pesticide use**

*Title XIII—Fruits, Vegetables, and Marketing; Subtitle C—Cosmetic Appearance:* Directs the Secretary of Agriculture to conduct research to determine impacts of federal grade standards and other regulations on pesticide use on perishable commodities, and to determine the impacts of reducing emphasis on cosmetic appearance in grade standards and other regulations on "the adoption of agricultural practices that result in reduced pesticide use."

**Identifying and developing pest control tools to fill future needs**

*Title XIV—Conservation; Subtitle D—Other Conservation Measures:* Directs federal agencies to develop programs for control of undesirable plants (including noxious weeds) on federal lands and for related "integrated management systems" based on education, prevention, and control by physical, chemical, and biological methods.

*Title XIV—Conservation; Subtitle H—Pesticides:* Directs the EPA Administrator in cooperation with the Secretary of Agriculture to identify available methods of pest control by crop or animal; minor pest control programs (either problems in minor crops or small problems in major crops); and factors limiting the availability of pest control methods (such as resistance and regulatory actions). Requires the Secretary of Agriculture to identify crucial pest control needs where a shortage of control methods occurs and to describe in detail research and extension designed to address these needs.

Directs the Environmental Protection Agency Administrator and the Secretary of Agriculture to develop approaches to pest control, based on integrated pest management and emphasizing minor pests, that respond to the needs of producers.

Requires the National Academy of Sciences to conduct a study of the biological control programs and registration procedures used by the Food and Drug Administration, the USDA Animal and Plant Health Inspection Service, and the EPA. Directs these federal agencies to develop and implement a common process for reviewing and approving biological control applications.

*Title XVI—Research; Subtitle F—Plant and Animal Pest and Disease Control Program:* Directs the Secretary of Agriculture to set priorities designed to overcome shortages in its pest and disease control research and extension programs where data indicate a shortage of available pest or disease control materials or methods to protect a particular crop or animal.

Directs the Secretary of Agriculture to expand research and grant programs related to exotic (nonindigenous) pests to improve existing methods (i.e., sterile release), develop safer pesticides (e.g., pheromones), and develop new methods of pest control.

SOURCE: Compiled by the Office of Technology Assessment, 1995, from the Food, Agriculture, Conservation, and Trade Act of 1990, P.L. 101–624.

not specified its interpretation of IPM, but the goal of expanding IPM is to reduce the use of pesticides by making a broader array of pest management tools and techniques available to farmers (84).

The executive branch's national IPM initiative encompasses a number of different actions (401). EPA and USDA signed a memorandum of understanding in August 1994 to provide the agricultural community with pest management practices that reduce pesticide risks. According to this agreement, USDA will increase its research on alternative pest control tools and means of transferring these tools to farmers. In addition, USDA and EPA will work together 1) to identify crop/pest situations in which pest control tools will become unavailable because of regulatory action, a lack of alternatives, or pest resistance and 2) to expedite research, development, education, and registration to attack these problems.

Specific programs are now being developed to meet the general goals just identified. USDA has assembled an IPM Coordinating Council with membership from all eight USDA agencies that have related responsibilities, and has requested approximately $22 million in fiscal year 1996 funding for related programs. A major part of the USDA effort will be a program to assemble teams composed of farmers, researchers, extension staff, crop advisors, and others to develop crop-specific IPM systems. This will be funded through the Cooperative State Research, Education, and Extension Service (CSREES). EPA has launched a pilot Biopesticides and Pollution Prevention Division to facilitate registration of biological pesticides, administer EPA's IPM program, and develop activities to prevent pesticide pollution.

## DEFINING THE TERMS OF OTA'S ASSESSMENT

The five kinds of biologically based technologies (BBTs) covered in this assessment represent an important segment of the alternatives to conventional pesticides (presented earlier in box 2-1) and a significant part of USDA's emphasis in pest control. The majority of the "safer" pesticides that EPA is promoting to reduce the risks of pesticide use are microbial pesticides and pheromone-based products; these two categories made up 45 percent of all new active pesticidal ingredients registered by EPA in 1994 (401).

OTA's assessment of BBTs thus provides a "bottom-up" view of whether the national infrastructure supporting research, development, and implementation can support diversification of pest control technologies and expansion of IPM. Box 2-5 describes in greater detail several additional technologies not within OTA's scope that are receiving increased attention for the same reasons as BBTs.

Most activity related to BBTs has occurred within the agricultural sector. Pests plague all areas of human activity, and the forces affecting the availability of pest control in the future will affect nonagricultural areas as well. The OTA assessment thus examines application of BBTs to the full array of pest problems, ranging from agriculture, rangelands, and forestry, to parks and wilderness preserves, urban and suburban environments, and even aquatic habitats.

### A Caution on Terminology

A multitude of terms characterize the field of biologically based pest control. Moreover, the same terms are used with somewhat different meanings among varying subdisciplines (e.g., insect pest management versus plant disease management) (15). Although some of these differences seem esoteric to nonspecialists, unfamiliar uses of terms can arouse strong feelings among scientists, in part because research funding is often tied to specific definitional interpretations (15). Moreover, some definitional niceties reflect underlying philosophical beliefs about the most appropriate approach to pest management.

The best known example of such controversy occurred in response to the report from a National Academy of Sciences working group (243). That report broadened the definition of *biological control* beyond the use of living organisms to include the use of *genes or gene products* to reduce pest impacts. All of the technologies within OTA's scope would fall within this definition, as might naturally derived botanical pesticides and insect growth regulators (box 2-1). Adherents to the historical, narrower interpretation of biological control worried that other, newer approaches might garner a disproportionate share of research dollars at the expense of

## BOX 2-5: Technologies Not Covered in This Assessment Also Receiving Increased Attention

**Botanical pesticides**

"Botanicals" are chemicals derived from plants that are used in the same way as conventional pesticides. They can be either naturally occurring or synthesized. Examples include pyrethroids originally from chrysanthemum flowers and nicotine from tobacco. Naturally occurring botanicals enjoy popularity among organic farmers and gardeners because they are derived from "natural" sources. However, scientists believe that botanicals are no safer as a group than synthetic chemicals and pose the same questions of mammalian toxicity, carcinogenicity, and environmental impact.

**Insect growth regulators (IGRs)**

IGRs are naturally occurring hormones or similar synthesized compounds that influence insect growth. Insects repeatedly shed and then form a new outer layer as they grow in a process called molting. IGRs kill insects by interfering with the molting process. These insecticides have low toxicity to mammals, but some IGRs affect crabs, shrimp, and other animals that molt. Concerns about nontarget impacts on these other species, some of which are economically important, have led to stringent restrictions on allowed uses of IGRs. IGRs are now being examined with renewed interest for use in environments where such nontarget impacts are highly unlikely, such as in homes or grain storage elevators. More specific IGRs might be developed for high-dollar pests; however, no species-specific IGRs are presently on the market.

**Plant breeding and enhanced resistance to pest damage**

For centuries, humans have selected the most hardy strains of crop plants to propagate and grow. Significant reductions of pest damage to plants in agriculture and landscapes can be attributed to the efforts over the past few decades of plant breeders who have developed pest-resistant plant cultivars. Recent advances in genetic engineering have greatly enhanced the possibilities in this area by enabling the transfer of genes that confer resistance to pests between widely unrelated organisms. The new genetic engineering techniques bring great promise, but also certain risks. A number of important issues remain unresolved in the policy arena, such as food safety effects, potential transfer of genes to weedy species, the appropriate venue and standards for regulation, and the ability of pests to evolve tolerance to the plant changes. Of particular significance is that many crop plants are being genetically engineered to produce toxins found in Bt. Scientists worry this will speed the rate at which pests become resistant to Bt—rendering microbial pesticides composed of the bacteria ineffective (see also chapter 4 of this report).

**Physical, cultural, and mechanical control**

These approaches either manipulate the environment to make it less conducive to pest damage, or directly remove a pest through mechanical means. Examples include crop rotation, sanitation, choice of planting and harvest dates to avoid pest infestations, water management practices, and solarization (heating soil to kill pests). Most cultural/mechanical approaches are environmentally benign, although tillage can contribute to soil erosion. Use of these approaches is widespread but patchy. They require a knowledgeable farmer, and because most cultural/mechanical approaches do not involve a marketable product, sources of adequate information often are lacking. For this reason, research and development of cultural/mechanical approaches depends primarily on the public sector.

SOURCE: Office of Technology Assessment, 1995; M.L. Flint, University of California, Davis, CA, "Biological Pest Control: Technology and Research Needs," unpublished contractor report prepared for Office of Technology Assessment, U.S. Congress, Washington DC, November 1993.

NOTE: Technologies presented here are a subset of those outside of OTA's scope shown in box 2-1 earlier in this chapter.

their discipline (15). They also felt that some approaches gained unwarranted legitimacy by their association with more "environmentally friendly" biological control: microbial pesticides based on Bt, for example, kill pests by a toxin, and, according to these critics, perpetuate the mind-set of a pesticide-based approach (see also box 2-2). This debate, which continues today, was the focus of considerable discussion during an ongoing study by the National Research Council.[16]

## OTA's Definitions of Technologies Covered in This Assessment

OTA's selection of the definitions here balances a straightforward conceptual presentation with policy relevance and commonly accepted usage among scientists and other professionals. The goal is to clarify the presentation of this report while retaining scrupulous technical accuracy. The definitions are not necessarily intended for direct incorporation into statutes, regulations, or policy statements.

### *Biological Control*

Populations of all living organisms are, to some degree, reduced by the natural actions of their predators, parasites, competitors, and diseases. Scientists refer to this process as *biological control* and to the agents that exert the control (i.e., predators, parasites, competitors, and pathogens[17]) as *natural enemies.*[18] Humans can exploit biological control in various ways to suppress pest populations. These approaches differ in how much effort is required, who is involved, and how suitable the approach is for commercial development.

Some organisms become significant pests only when they move to a new locale where their natural enemies are absent and therefore the organism's population expands greatly. One approach to managing these nonindigenous pests is to reestablish control by importing and releasing natural enemies from the pest's region of origin. Termed *classical biological control*[19] by specialists, the goal is permanent establishment of the natural enemies in the new locale. Through reproduction and natural spread, the control agents can then effectively "track" the pest throughout all or part of its new range and provide enduring pest suppression with little or no additional effort. Classical biological control is generally regarded as a public-sector activity having little potential for commercial involvement. Researchers from universities and federal and state government are the primary people involved in the discovery, importation, and release of classical biological control agents. Many farmers, homeowners, and other users of pest control products are unaware of the extent to which imported natural enemies now keep certain potential pests in check, obviating or reducing the need to use additional control measures. Examples of such pests are the woolly apple aphid (*Eriosoma lanigerum*) of the Pacific Northwest, the sugarcane delphacid (*Perkinsiella saccharicida*) in Hawaii, and the weed St. John's wort (*Hypericum perforatum*) in the western United States, all of which are currently under a significant level of biological control.

Some natural enemies, both imported and indigenous, can be repeatedly propagated and released in large numbers. These *augmentative*[20] releases temporarily increase the natural enemy's abundance in a specific target area and therefore

[16] The NRC's Board on Agriculture has an ongoing study of "Pest and Pathogen Control Through Management of Biological Control Agents and Enhanced Natural Cycles and Processes." The report, scheduled for publication in late 1995, discusses issues related to necessary types of research, and complements but does not duplicate the OTA assessment.

[17] Pathogens are disease-causing agents, including certain bacteria, viruses, fungi, protozoa, and nematodes (microscopic worm-like animals).

[18] Natural enemies are also sometimes referred to as *beneficial organisms.* Use of this term can be confusing because some organisms, like honeybees, are beneficial organisms but are not natural enemies.

[19] The term *innoculative biological control* is also used by some specialists (418).

[20] The term *innundative biological control* is also used by some specialists (418).

its impact on the pest species. The temporarily boosted abundance may far exceed that which the environment would normally support. Augmentation can also create a transient population of a natural enemy that could not otherwise persist in the environment (e.g., because it cannot tolerate cold winters). One potential advantage of augmentation is that the release can be timed to coincide with the period of the pest's maximum vulnerability, such as a particular larval stage. In most agricultural applications, augmentative releases occur once or several times throughout a growing season. Live microbial pesticides (discussed in the next subsection) are another form of augmentative biological control. A small U.S. industry now commercially distributes and sells insects that are natural enemies of insect and weed pests, primarily to farmers and ranchers. Approximately 110 different species are now commercially available from more than 130 North American companies (60). Some federal and state government agencies also make augmentative releases.

The action of all natural enemies—indigenous, imported, and augmented—can be enhanced by simply encouraging their survival and multiplication. This *conservation of natural enemies* usually involves specific crop, forest, or landscape management practices that provide the natural enemies with a hospitable environment and limit practices that kill natural enemies—for example, by reducing pesticide use or selecting specific pesticides. The practitioners of this approach are farmers and others who seek to control pests. Usually, no commercial products are directly involved but crop, forest, or landscape management advisors may provide advice to farmers, homeowners, and others about conservation of natural enemies or other related services for a fee. Federal and state governments also provide public education on such management practices through extension and outreach activities.

### Microbial Pesticides

A wide variety of microorganisms (organisms too small to be seen by the naked eye) suppress pests by producing poisons, causing disease, preventing establishment of other microorganisms, or various other mechanisms. Such microorganisms include certain bacteria, viruses, fungi, protozoa, and nematodes. A *microbial pesticide* is a relatively stable formulation of one or several microbes designed for large-scale application. The most widely used microbial pesticide today is Bt, formulated from the bacteria *Bacillus thuringiensis*. Its pesticidal properties result from toxins the bacteria produce that can kill certain insect pests. Most microbial pesticides are produced commercially and sold to farmers, foresters, homeowners, government agencies, and other users of pest control products.

### Behavior-Modifying Chemicals

Many organisms emit chemical cues that evoke specific behaviors from other individuals of the same or a different species. Pheromones are one category of these chemicals that currently has application in pest management. Pheromones serve to communicate information among members of a single species. Mate-attraction pheromones are now used in pest lures or in traps laced with insecticides or microbial pesticides. Some are sold commercially for pest control, although the primary function of most is monitoring of pest distribution. The pheromone-based method in greatest use is widespread application of pheromones to disrupt a pest's normal mate-finding behavior (and thereby reduce successful reproduction). Farmers, foresters, homeowners, and government agencies rely on commercially produced pheromone products.

### Genetic Manipulation of Pests

In this approach individuals of the pest species are genetically altered and then released into the pest population. The individuals carry genes that interfere with reproduction or impact of the pest. The specific method in significant use today is the release of sterile males for insect control. Males of the pest insect are made sterile by irradiation. Following release, they compete with fertile males for female mates, thereby reducing the number of matings that successfully produce offspring. The result is a drop in the size of the pest population.

### *Plant Immunization*

The ability of crop and landscape plants to resist diseases and insect pests can be enhanced through a number of methods that do not involve plant breeding or genetic engineering. One approach of growing importance in the turfgrass industry is the use of grass containing endophytes—certain fungi that live within plant tissues. Plants containing these fungi are less susceptible to damage by insects and diseases. Researchers are working on developing methods of transferring endophytes to plants in which they do not normally occur. Scientists have also found they can enhance resistance to disease in certain plants by exposing them to specific microbes or chemicals or by inoculating them with a less-damaging strain of a disease-causing microbe. The various methods of inducing disease and pest resistance are experimental and not yet in practical use.