4.3 Pest Management Practices

Insects, disease, and weeds cause significant yield and quality losses to U.S. crops. Pesticides, one option to combat pest damage, have been one of the fastest growing agricultural production inputs in the post-World War II era, and have contributed to the high productivity of U.S. agriculture. Herbicides and insecticides account for most pesticide use, but the recent increase in pounds of pesticide used is mostly for fungicides and other pesticide products applied to high-value crops. Pesticide expenses have increased from 4 to 5 percent of total production expenses during the 1990's. Many scientists recommend greater use of biological and cultural pest management methods. Major innovations have been the development of genetically engineered herbicide-tolerant varieties, which allow more effective use of herbicides, and plant pesticides, which reduce the need for chemical applications. Government programs to encourage the development and use of biological and cultural methods include areawide pest management, integrated pest management (IPM), national organic standards, and regulatory streamlining for biological pest control agents.

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Approximately 600 species of insects, 1,800 species of plants, and numerous species of fungi and nematodes are considered serious pests in agriculture (Klassen and Schwartz, 1985). If these pests were not managed, crop yields and quality would drop, likely increasing production costs and food and fiber prices. Producers with greater pest problems would become less competitive.

Synthetic pesticides are used on the majority of acreage of most major crops. Approximately $8.8 billion was spent in the United States on agricultural pesticides in 1997. Herbicides account for about two-thirds of the agricultural expenditures for pesticides, while insecticides account for about one-fifth (Aspelin, 1997). Many growers also use scouting, economic thresholds, pesticide-efficiency techniques, or cultural practices. Biological control methods, such as *Bacillus thuringiensis* applications and trap cropping, which use living organisms and strategic cropping to combat pest damage, are not as widely used (see box, "Glossary of Pest Management Practices").

Cultural and biological techniques were the primary methods used to manage pests in agriculture for thousands of years. Prior to the development of synthetic pesticides following World War II, farmers controlled weeds by tillage, mowing, site selection, crop rotation, use of seeds free of weed seeds, and hoeing or pulling by hand. Insect pests and diseases were controlled through crop variety selection, crop rotations, adjustment of planting dates, and other cultural practices, but the risk of severe infestations, yield losses, and even abandoned production was still ever-present. U.S. farmers began shifting to chemical methods upon the successful use of a

Glossary of Pest Management Practices

Chemical Methods

Pesticides **--** The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) defines a pesticide as "any substance or mixture of substances intended for preventing, destroying, repelling or mitigating any pest, and any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant."

> *Fungicides* **--** Control plant diseases and molds that either kill plants by invading plant tissues or cause rotting and other damage to the fruit before and after it can be harvested.
>
> *Herbicides* **--** Control weeds that compete for water, nutrients, and sunlight and reduce crop yields.
>
> *Insecticides* **--** Control insects that damage crops. Also include materials used to control mites and nematodes.
>
> *Other pesticides* **--** Include soil fumigants, growth regulators, desiccants, and other pesticide materials not otherwise classified.

Banded pesticide application **--** The spreading of pesticides over, or next to, each row of plants in a fields. Banding herbicides often requires row cultivation to control weeds in the center of rows.

Broadcast pesticide application **--** The spreading of pesticides over the entire surface area of the field.

Pre-emergence herbicides **--** Herbicides applied before weeds emerge. Pre-emergence herbicides have been the foundation of row-crop weed control for the past 30 years.

Post-emergence herbicides **--** Herbicides applied after weeds emerge. Post-emergence herbicides are considered more environmentally sound than pre-emergence herbicides because they have little or no soil residual activity.

Decision Criteria and Information

Economic thresholds **–** Levels of pest population that, if left untreated, would result in reductions in revenue that exceed treatment costs. Economic thresholds are used to decide if pesticide treatments or other pest management practices are economically justified. The decision generally requires information on pest infestation levels from scouting or monitoring.

Expert systems **--** Computer software packages that integrate information about pest density, economic thresholds, application methods, and other factors to help farmers decide when to treat, what pesticides or practices to use, and how much to use.

Scouting/Monitoring **--** Checking a field for the presence, population levels, activity, size, and/or density of weeds, insects, or diseases. A variety of methods can be used to scout a field. Insect pests, for example, can be scouted by using sweep nets, leaf counts, plant counts, soil samples, and general observation.

Cultural Methods

Crop rotation **--** Alternating the crops grown in a field on an annual basis, which interrupts the life cycle of insect or other pests by placing them in a nonhost habitat. Crop rotations can have other benefits such as enhanced fertility and reduced financial risk.

Planting and harvesting dates **--** Alterations of planting or harvesting date to avoid damaging pest infestations. Delayed planting of fall wheat seedlings may help avoid damage from the Hessian fly, for example.

Continued…

Glossary of Pest Management Practices (continued)

Sanitation procedures **--** Removing or destroying crops and plant material that are diseased, provide overwintering pest habitat, or encourage pest problems in other ways.

Tillage **–** Mechanical disturbance of the soil that destroy pests in a variety of ways, for example, by directly destroying weeds and volunteer crop plants in and around the field.

Water management **--** Water can be used as a pest management technique either directly, by suffocating insects, or indirectly, by changing the overall health of the plant.

Biological Methods

Beneficials -- *Pest predators, parasites, and weed-feeding invertebrates that are used to control crop pests and weeds.*

Biochemical agents **--** Materials such as semiochemicals, plant regulators, hormones, and enzymes. Many of these agents must be registered as pesticides under FIFRA.

Semiochemicals -- *Pheromones, allomones, kairomones, and other naturally or synthetically produced substances that modify insect behavior and interfere with reproduction.*

Habitat provision for natural enemies -- *Growing crops and/or developing wild vegetative habitats to provide food (pollen, nectar, nonpest arthropods) and shelter for the natural enemies of crop pests.*

Hostplant resistance or tolerance -- *Genetic resistance or tolerance helps to reduce damage from insects, disease, or other pests without the use of a pesticide. Resistance can be developed through plant breeding or genetic engineering.*

Microbial pest control agents *-- Bacteria, such as* Bacillus thuringiensis*, viruses, fungi, protozoa and other microorganisms or their byproducts. Many of these must be registered as pesticides under FIFRA.*

Bacillus thuringiensis (Bt) **--** Bacteria that are used to control numerous larva, caterpillar, and insect pests in agriculture; Bt varieties kurstaki and aizawai are commonly used strains. In addition, some new varieties of corn contain natural genes and genes produced from the soil bacteria Bt to give them host-plant resistance to certain insect pests.

Sterile male technology **--** The male of the pest species is produced with inactive or no sperm, and is used to disrupt reproduction in the pest population.

Trap cropping **--** Planting a small plot of a crop earlier than the rest of the crop in order to attract a particular crop pest; the pests are then killed before they attack the rest of the crop.

Integrated Pest Management (IPM)

An approach or strategy to managing pests that combines a variety of practices, such as biological practices, cultural practices, pesticides, monitoring and thresholds. The approach often considers the population dynamics of pests and their natural enemies and the effects of controls on agroecosystems to manage pests more efficiently. Some variations of this approach seek to minimize or eliminate the use of pesticides and minimize risks to human health and the environment. For the USDA IPM Initiative, IPM is defined as "the judicious use and integration of various pest control tactics in the context of the associated environment of the pests in ways that complement and facilitate the biological and other controls of pests to meet economic, public health, and environmental goals."

natural arsenic compound to control Colorado potato beetles in 1867 (National Academy of Sciences, 1995) and the inception of USDA's chemical research program in 1881 (Klassen and Schwartz, 1985). Arsenicals, copper compounds, and sulfur were commonly used. Farmers adopted synthetic pesticides quickly after commercial introduction in the 1940's because they were inexpensive, effective, and easy to apply (MacIntyre, 1987). Aggregate pesticide use, as measured by pounds of active ingredient, grew through the early 1980's before stabilizing. Between 1950 and 1980, herbicide use climbed toward 100 percent of the acreage of corn, soybeans, cotton, and many other crops, and insecticides and other pesticides were also widely used. The increases in crop yields throughout this century have been partly credited to pesticide technology. The benefits of individual pesticides, the value of production that would be lost if alternatives were less effective, and the additional pest management costs if alternatives were more expensive have been shown in numerous studies (Osteen, 1987; Fernandez-Cornejo and others, 1998a).

However, pesticide use has raised concerns about health risks from pesticide residues on food and in drinking water and about the exposure of farmworkers when mixing and applying pesticides or working in treated fields. Pesticide use has also raised concerns about impacts on wildlife and sensitive ecosystems. Some pesticide applications are counterproductive because they kill beneficial species, including natural enemies of pests, and engender pest resistance to pesticides. The benefits of pesticide use and costs to human health and the environment have been difficult to quantify. An alternative method that is more expensive or less effective than pesticides might be economically justified when weighed against the indirect costs of pesticides (see box, "Why Reduce Reliance on Pesticides?")

The National Research Council concluded in 1995 that pest resistance and other problems created by pesticide use had created an "urgent need for an alternative approach to pest management that can complement and partially replace current chemically based pest-management practices" (National Academy of Sciences, 1995). Government programs and activities were initiated to encourage increased use of integrated pest management (IPM) and other strategies to reduce pesticide use and risks, and to promote research and implementation of biological and cultural controls (Jacobsen, 1996; Browner, 1993).

Pesticide Use on Major Crops

Pesticide use has conventionally been measured in pounds of active ingredients applied and acres treated in order to assess the adoption and intensity of pesticide use, compare use between commodities or production regions, and analyze the cost of pesticides as a production input. These measurements, however, do not capture pesticide attributes or application practices, which influence health or environmental risk. New products and the related changes in intensity of treatment, rather than treatment of additional acres, now account for most of the changes in pesticide use. Product formulations have been changed in order to lessen environmental and human health effects, to reduce development of pesticide-resistant pests, and to provide more cost-effective pest control.

Quantities of Pesticide Use

Synthetic pesticides were developed for commercial agriculture in the late 1940's and 1950's and were widely adopted by the mid-1970's. USDA's benchmark surveys of pesticide use by farmers show the quantities applied

Why Reduce Reliance on Pesticides?

Concern about the side effects of synthetic pesticides began emerging in scientific and agricultural communities in the late 1940's, after problems with insect resistance to DDT. The public became concerned about the unintentional effects of pesticide use after Rachel Carson's book on bioaccumulation and other potential hazards was published in the 1960's. Many unintentional effects of pesticide exposure on nontarget species have been reported since then, including acute pesticide poisonings of humans (especially during occupational exposure), damage to fish and wildlife, and damage to species that are beneficial in agricultural ecosystems. Since the 1960's, some pesticides have been banned, others restricted in use, and others' formulations changed to lessen undesirable effects.

Human Health Impacts. The American Association of Poison Control Centers estimates that approximately 67,000 nonfatal acute pesticide poisonings occur annually in the United States (Litovitz and others, 1990). However, the extent of chronic health illness resulting from pesticide exposure is much less documented. Epidemiological studies of cancer suggest that farmers in many countries, including the United States, have higher rates than the general population for Hodgkin's disease, leukemia, multiple myeloma, non-Hodgkin's lymphoma, and cancers of the lip, stomach, prostate, skin, brain, and connective tissue (Alavanja and others, 1996). Emerging case reports and experimental studies suggest that noncancer illnesses of the nervous, renal, respiratory, reproductive, and endocrine systems may be influenced by pesticide exposure. Case studies, for example, indicate that pesticide exposure is a risk factor for several neurodegenerative diseases, including Parkinson's disease and amyotrophic lateral sclerosis, also known as Lou Gehrig's disease (Alavanja and others, 1993). A comprehensive Federal research project on the impacts of occupational pesticide exposure on rates of cancer, neurodegenerative disease, and other illnesses was begun about 5 years ago in North Carolina and Iowa; about 49,000 farmers who apply pesticides and 20,000 of their spouses, along with 7,000 commercial pesticide applicators, are expected to participate in the study (Alavanja and others, 1996).

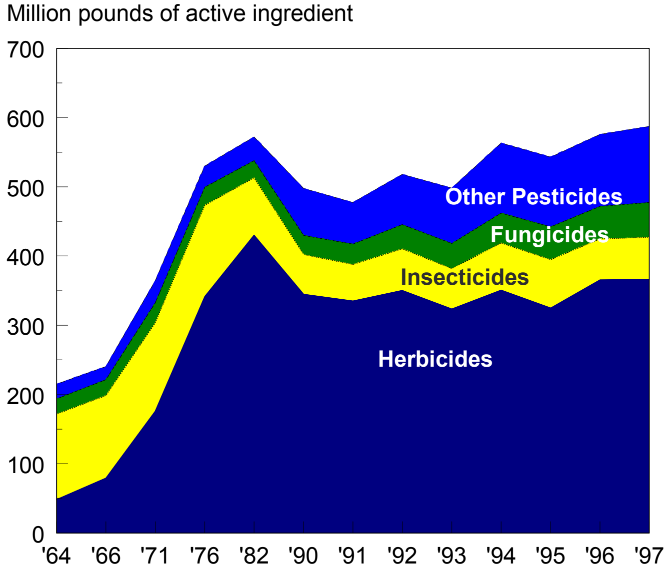
Direct exposure to pesticides by those who handle and work around these materials is believed to pose the greatest risk of human harm, but indirect exposure through trace residues in food and water is also a source of concern (EPA, 1987). The effects of these pesticide residues on infants and children and other vulnerable groups have recently been addressed with a new legislative mandate in the Food Quality Protection Act of 1996.

Environmental Quality. Documented environmental impacts of pesticides include poisonings of commercial honeybees and wild pollinators of fruits and vegetables; destruction of natural enemies of pests in natural and agricultural ecosystems; ground- and surface-water contamination by pesticide residues with destruction of fish and other aquatic organisms, birds, mammals, invertebrates, and microorganisms; and population shifts among plants and animals within ecosystems toward more tolerant species. Most insecticides used in agriculture are toxic to honeybees and wild bees, and costs related to pesticide damages include honeybee colony losses, honey and wax losses, loss of potential honey production, honeybee rental fees to substitute for pollination previously performed by wild pollinators, and crop failure because of lack of pollination. Approximately one-third of annual agricultural production in the United States is derived from insect-pollinated plants (Buchman and Nabhan, 1996), and flowering plants in natural ecosystems may not thrive because of fewer pollinators. The destruction of the natural enemies of crop pests has led to outbreak levels of primary and secondary crop pests for some commodities, and pest management costs have increased when additional pesticide applications have been needed for these larger or additional pest populations. Measurable costs related to pesticide residues in surface- and groundwater include residue monitoring and contamination cleanup costs and costs of damage to fish in commercial fisheries. Bird watching, fishing, hunting and other recreational activities have been affected by aquatic and terrestrial wildlife losses due to pesticide poisonings. The destruction of invertebrates and microorganisms that have an essential role to healthy ecosystems is an emerging issue.

Pesticide Resistance. After repeated exposure to pesticides, insect, disease, weed, and other pest populations may develop resistance to pesticides through a variety of mechanisms. The newer safety requirements for pesticide registration along with the increasing pace of pest resistance have raised doubts about the ability of chemical companies to keep up with the need for replacement pesticides. In the United States, over 183 insect and arachnid pests are resistant to 1 or more insecticides, and 18 weed species are resistant to herbicides (U.S. Congress, 1995). Cross-resistance to multiple families of pesticides, along with the need for higher doses and new pesticide formulations, is a growing concern among entomologists, weed ecologists, and other pest management specialists.

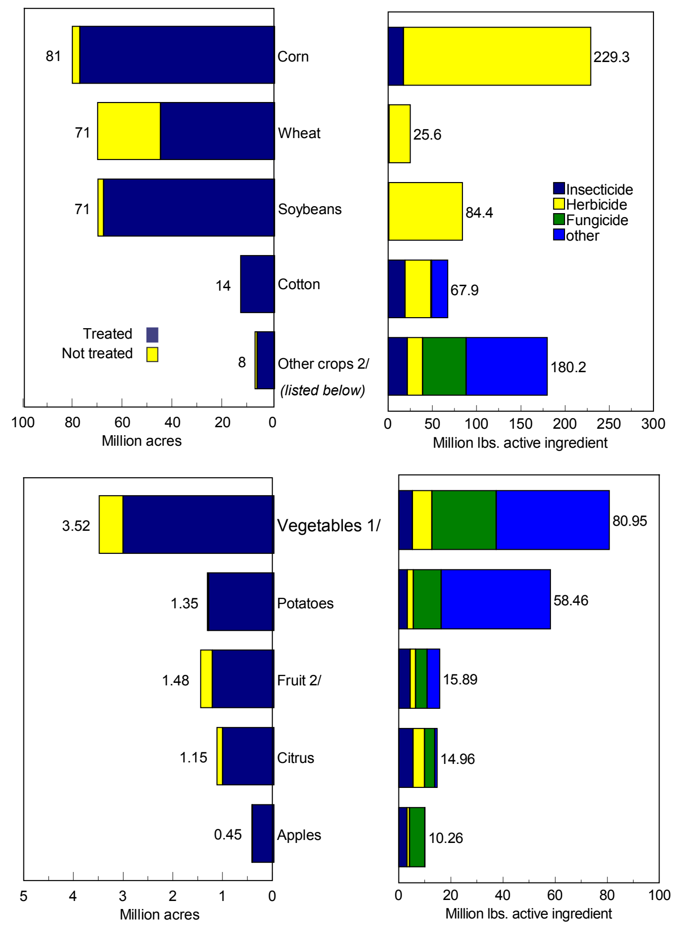
Emerging Issues. Important new issues are the impact of endocrine-system disrupting pesticides on human health and wildlife -- including potential reproductive effects and effects on child growth and development (EPA, 1997), and the potential for synergistic impacts from exposure to pesticides (Arnold and others, 1996).

Figure 1--Conventional pesticide use on major crops, 1964-97



Estimates includes use on total U.S. acreage of corn, cotton, soybean soybeans, wheat, potatoes, other vegetables citrus, apples, and other fruit (about 70 percent of U.S. cropland, see table 1).
Source: USDA, ERS estimates

Figure 2--Amount of pesticide applied and acres treated, 1997



1/ Represents 1996 fresh and processed vegetables and strawberries.
2/ Excludes citrus and apples, but includes other deciduous fruits and berries
Source: USDA, ERS estimates

to major field crops, fruits, and vegetables from 1964 to 1997 (fig. 1 and table 4.3.1). The crops included in the surveys -- corn, cotton, soybeans, wheat, fall potatoes, other vegetables, citrus, apples, and other fruit -- account for about 70 percent of current cropland used for crops. Pesticide use on these crops grew from 215 million pounds in 1964 to 588 million pounds in 1997. (These estimates do not include use on such crops as rice, sorghum, peanuts, sugarbeets, sugarcane, tobacco, barley, oats, rye, other grains, nuts, hay, pasture, and range because they were not surveyed in enough years to construct a time series. The estimates also exclude sulfur, oils, and other nonconventional pesticides.)

Pesticide use first peaked in 1982 when cropland used for crops was at a record high. This increase in pesticide use can be attributed to three factors: increased planted acreage, greater proportion of acres treated with pesticides, and higher application rates per treated acre. The widespread adoption of herbicides on field crops accounted for most of the increase. Total quantity of pesticides declined between 1982 and 1990 as commodity prices fell and land was idled by Federal programs. In 1996, total quantity of pesticides edged above the 1982 peak (table 4.3.1), due mainly to expanded use of soil fumigants, defoliants, and fungicides on potatoes, fruits, and vegetables. The total quantities of herbicides and insecticides dropped even with expanded crop acreage. Also contributing to the increase were more intensive insecticide treatments on cotton and potatoes and an increased share of wheat acres treated with herbicides (table 4.3.2, appendix table 4.3.1 hyperlinks to .xls files).

Table 4.3.1—Estimated use of conventional pesticides on selected U.S. crops by pesticide type, 1964-97 1/

Item	1964	1966	1971	1976	1982	1990	1991	1992	1993	1994	1995	1996	1997
	Million pounds of active ingredients												
Herbicides	48.2	79.4	175.7	341.4	430.3	344.6	335.2	350.5	323.5	350.6	324.9	365.7	366.4
Insecticides	123.3	119.2	127.7	131.7	82.7	57.4	52.8	60	58.1	68.2	69.9	59.2	60.5
Fungicides	22.2	23.2	29.3	26.6	25.2	27.8	29.4	34.9	36.6	43.6	47.5	46.8	50.5
Other pesticides	21.4	18.7	31.7	30.7	34.2	67.9	60.1	72.7	80	101.1	101	104	110.2
Total	215	240.6	364.4	530.5	572.4	497.7	477.5	518.2	498.2	563.4	543.3	575.8	587.6
	Million cropland acres												
Area represented	174.6	175	190.6	233.2	255.9	228.5	226	231.5	226.6	232.8	228	242.1	243.8
Total cropland used for crops	335	332	340	340.8	383	341	337	337	330	339	332	346	349
Percent of cropland represented 2/	52	53	56	68	67	67	67	69	69	69	69	70	70
	Pounds of active ingredient per planted acre												
Herbicides	0.276	0.454	0.921	1.464	1.682	1.508	1.483	1.514	1.428	1.505	1.425	1.511	1.502
Insecticides	0.706	0.681	0.67	0.565	0.323	0.251	0.234	0.259	0.256	0.293	0.306	0.245	0.248
Fungicides	0.127	0.133	0.154	0.114	0.099	0.121	0.13	0.151	0.161	0.187	0.208	0.193	0.207
Other pesticides	0.122	0.107	0.166	0.132	0.134	0.297	0.266	0.314	0.353	0.434	0.443	0.43	0.452
Total	1.232	1.375	1.911	2.275	2.237	2.178	2.113	2.238	2.199	2.419	2.383	2.379	2.41

1/ Estimated use on total U.S. acreage of corn, soybeans, wheat, cotton, potatoes, other vegetables, citrus fruit, apples, and other fruits and berries. Exclude are rice, sorghum, peanuts, nuts, sugarcane, sugarbeets, tobacco, barley, oats, rye, other grains, dry peas and beans, hay, pasture, range, and other crops. The estimates exclude sulfur, oils, and other nonconventional pesticides. The estimates assume that pesticide use on acreage in non-surveyed States occurred at the same average rate as in the surveyed States For fruits and vegetables, use rates were interpolated between surveyed years.

2/ Share of total for the selected crops to total cropland used for crops.

Source: USDA, ERS, based on Lin and others (1995a) (prior to 1991): USDA survey data (following 1990).

In 1997, corn received almost 40 percent of total pesticides applied to the major crops (fig. 2). Corn accounted for almost 60 percent of all herbicide use and 29 percent of insecticides. Cotton accounted for over 60 percent of insecticide use. Potatoes and other vegetables used the most fungicides, soil fumigants, desiccants, growth regulators, and vine killers.

Herbicides. Herbicides are the largest pesticide class, accounting for 62 percent of total quantity of pesticide active ingredients in 1997 (table 4.3.1). Weeds compete with crops for water, nutrients, and sunlight, and cause reduced yields. Producers, in managing weeds, must consider infestation levels; weed species resistant to specific ingredients; the effect of treatment on following crops; control of weed seed populations; and the labor requirements, cost, and risk of using cultivation or other mechanical methods of weed control. With an increase in corn and soybean acreage, herbicide quantities were up slightly in 1996 and 1997, but were still 15 percent less than in 1982.

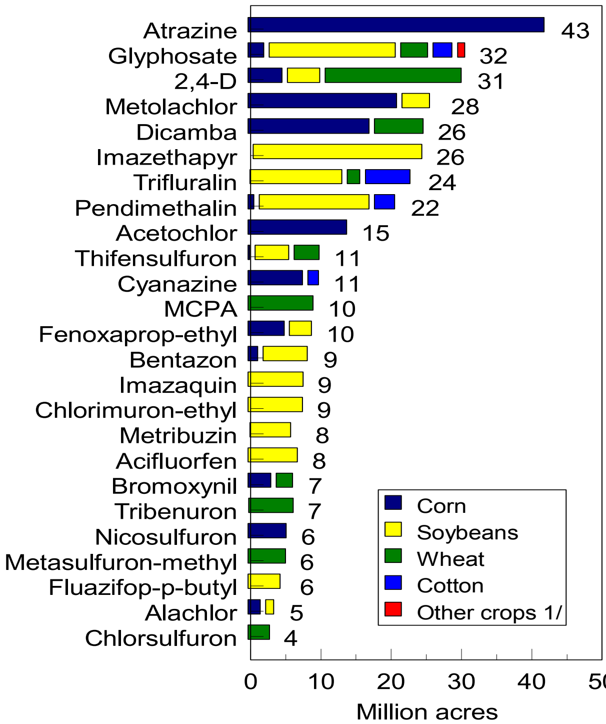
Although many herbicide active ingredients are used in agriculture, relatively few account for most of the use. Atrazine, 2,4-D, dicamba, and trifluralin, all widely used for more than 30 years, are still four of the seven leading herbicides in use by acreage (appendix table 4.3.2, hyperlink to .xls file, fig. 3). Atrazine, which remains active in the soil throughout most of the growing season, is used to control many types of weeds in corn and sorghum. Glyphosate, is used on a wide variety of crops, and its use has increased as the acreage of genetically-engineered glyphosate-resistant crops has increased. The herbicide, 2,4-D, has been widely used on wheat and corn, and more recently on soybeans as a preplant application with no-till. Metolachlor is widely used as a pre-emergence treatment on corn and often mixed with other herbicides to provide a broader spectrum of weed control. Since 1992, imazethapyr has replaced trifluralin as the leading herbicide on soybeans. Trifluralin remains the leading herbicide used on cotton and continues to be widely used on soybeans and vegetable crops.

Insecticides. Insecticides accounted for 10 percent of the total quantity of pesticides applied in 1997 to the surveyed crops (fig. 1). Damaging insect populations can vary annually depending on weather, pest cycles, cultural practices such as crop rotation and destruction of host crop residues, and other factors. Insecticide use includes both preventive treatments, which are applied before infestation levels are known, and intervention treatments, which are based on monitored infestation levels and expected crop damages. While the quantity of insecticides applied has been stable in recent years, it is down half from the 1960’s and early 1970’s (table 4.3.1). The drop from earlier years is primarily due to the replacement of organochlorine insecticides, used prior to the 1970's, with other insecticides that can be applied at much lower rates. Corn and cotton account for the largest shares of insecticide use.

Chlorpyrifos and methyl parathion are the two most widely used insecticides on the surveyed crops (fig. 4, appendix table 4.3.3, hyperlink to .xls file). Both ingredients are organophosphates, which have been identified by the U.S. Environmental Protection Agency (EPA) as the first family of pesticides to undergo the review of tolerances required by the Food Quality Protection Act of 1996 (discussed in more detail under “Pesticide Regulatory Issues”). Chlorpyrifos was applied to 18 percent of fruits and vegetables, 7 percent of corn, 4 percent of cotton, and 2 percent of winter wheat acres in 1997. Methyl parathion is used to control boll weevils and many biting or sucking insect pests on cotton and other agricultural crops.

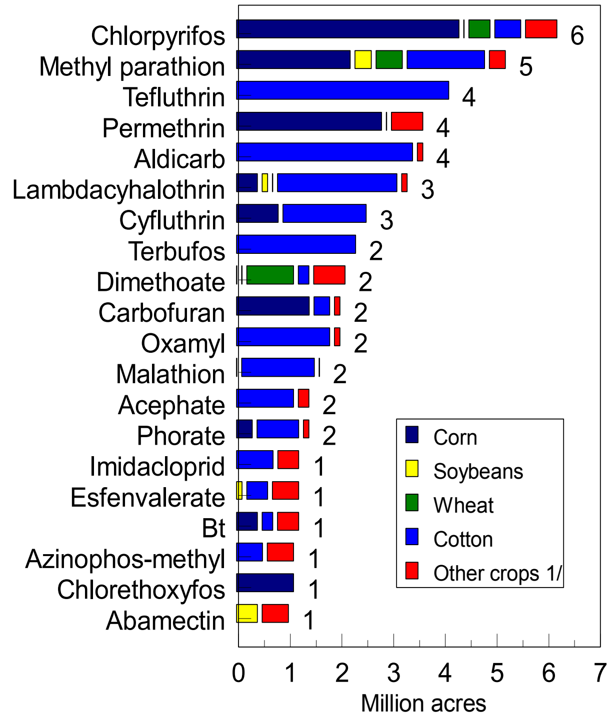
Fungicides. Fungicides, excluding seed treatments, are applied to fewer acres than are herbicides and insecticides and account for the smallest share of total pesticide use (table 4.3.1). Fungicides are mostly used on fruits and vegetables to control diseases that affect the health of the plant or quality and appearance of the fruit.

Figure 3--Acres treated with commonly used herbicides, major producing States, circa 1997



1/Icludes potato (1997), fruit (1995), and vegetable (1996) crops.
Source: USDA surveys: ARMS, 1997, vegetables, 1996, and fruit, 1995

Figure 4--Acres treated with commonly used insecticides, major producing States, circa 1997

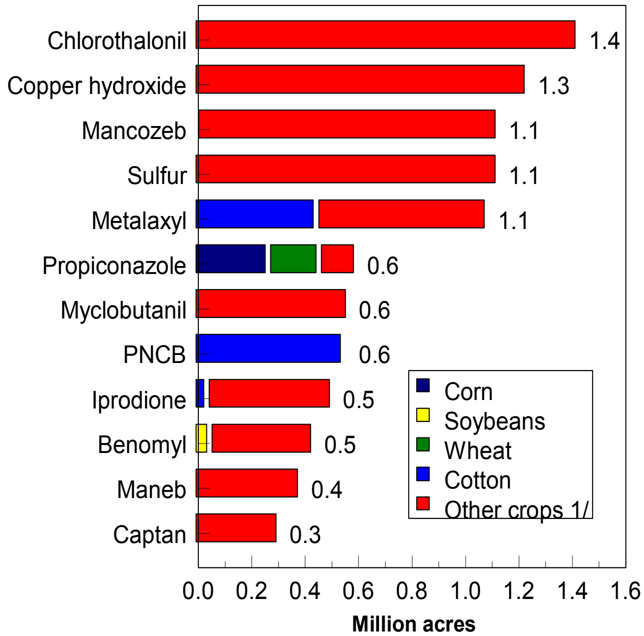


1/Icludes potato (1997), fruit (1995), and vegetable (1996) crops.
Source: USDA surveys: ARMS, 1997, vegetables, 1996, and fruit, 1995.

The 50 million pounds estimated in 1997 is up 7 percent from 1996 and 82 percent from 1990. A large share of this increase is attributed to diseases on potatoes and other vegetables. The use of several common fungicides used to treat potatoes for early and late blight (chlorothalonil, mancozeb, metalaxyl, and copper hydroxide) has tripled since the early 1990's (fig. 5). Some cotton and wheat acres are treated for diseases, but these treatments account for only a small share of total fungicide use.

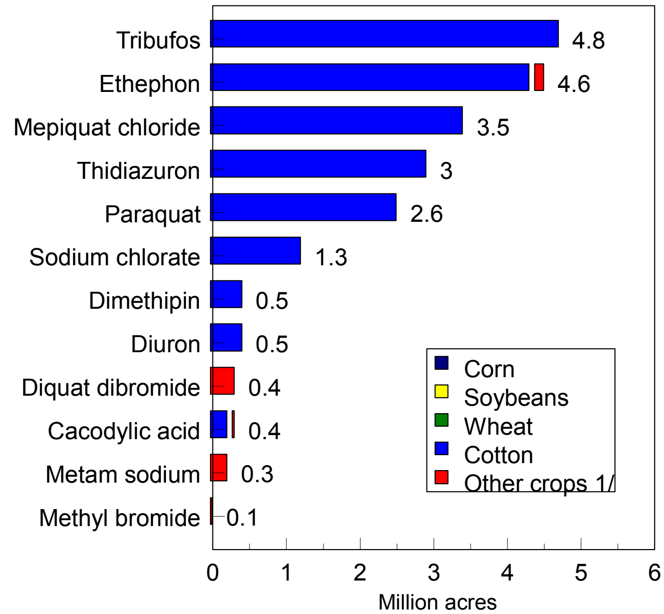
Other pesticides. Pesticides designated as "other," including soil fumigants, growth regulators, desiccants, and harvest aids, had the largest increase in use of any of the pesticide classes (table 4.3.1, fig. 1). The use of these pesticides increased about 8 percent each year since 1990 and accounts for about one-fifth of the total pounds of all active ingredients applied to the surveyed crops (110 million pounds in 1997). Growth regulators, desiccants, and harvest aids, normally applied at low rates, are used to affect the branching structure of plants, to control the time of maturity or ripening, to alter other plant functions to improve quality or yield and to aid mechanical harvest. These materials are used extensively on cotton, which accounts for most of the acreage of "other pesticides" (fig.6). Fumigants, including methyl bromide, metam sodium, chloropicrin, and dichloropropene (1,3-D), are normally applied at very high application rates and are used mostly on potatoes, fresh-market tomatoes, strawberries, and vegetable root crops susceptible to damage from soil nematodes and other soil organisms. Sulfuric acid is often applied at several hundred pounds per acre to kill potato vines in order to aid harvest. Fumigants and sulfuric acid account for over 85 percent of the quantity of "other pesticides" used but less than 5 percent of the acres treated with those materials. Small changes in the use of these ingredients, when averaged with other products applied at only a few pounds or less per acre, can grossly affect the total quantity of pesticide use in this class.

Figure 5--Acres treated with commonly used fungicides, major producing States, circa 1997



1/Icludes potato (1997), fruit (1995), and vegetable (1996) crops.
Source: USDA surveys: ARMS, 1997, vegetables, 1996, and fruit, 1995

Figure 6--Acres treated with commonly used "other" pesticides major producing States, circa,1997



1/Icludes potato (1997), fruit (1995), and vegetable (1996) crops.
Source: USDA surveys: ARMS, 1997, vegetables, 1996, and fruit, 1995.

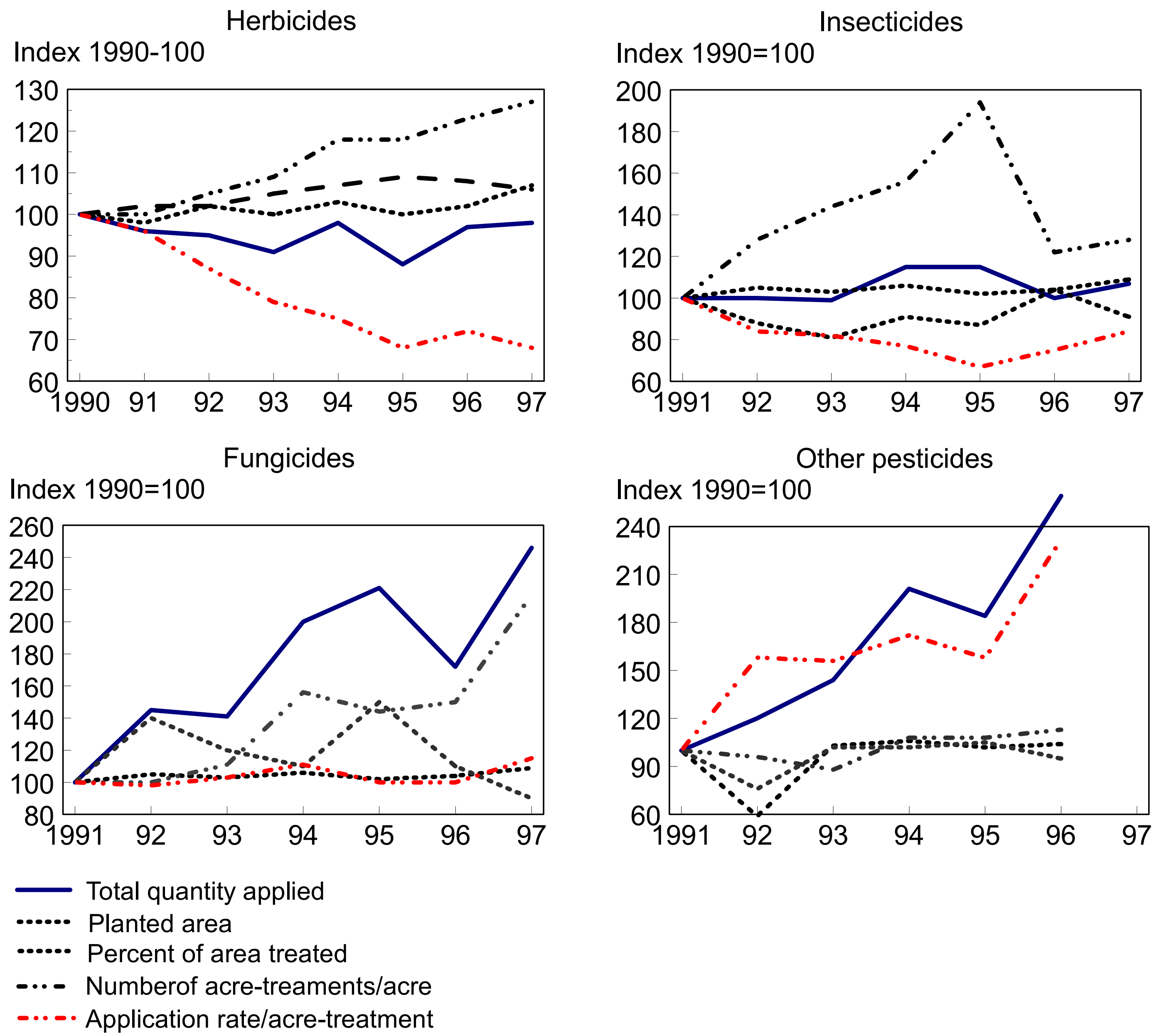
Pesticide Treatment Trends

Although the total number of acres treated with pesticides fluctuates from year to year, most changes in pesticide use are in the pesticide ingredients applied and their time of application. USDA's Cropping Practices (1950-95) and Agricultural Resource Management Study (1996-1997) surveys show that for most crops, the total number of different pesticide ingredients applied to each acre has been increasing and that more of the treatments are being applied after planting (table 4.3.2, hyperlink to .xls file). Also, herbicide and insecticide application rates per acre-treatment decreased from 1990-97, while the number of acre-treatments per acre increased (fig. 7).

Corn. The largest crop in the United States in terms of acreage, corn exceeds any other crop in the number of acres treated with pesticides (table 4.3.2, hyperlink to .xls file). At least some herbicide was applied to 97 percent of the corn area in the 10 surveyed States in 1997. While amount of herbicide per acre fell slightly, the average number of herbicide treatments and number of different ingredients grew, reflecting an increase in the number of treatments later in the growing season and the grower's need for more broad-spectrum weed control. The average number of herbicide acre-treatments (number of ingredients times the number of repeat treatments) increased from 2.2 in 1990 to 2.8 in 1997. Most of this increase results from the increased use of herbicides after planting. During this time, the share of acres receiving herbicide treatments after planting increased from 60 percent in 1990 to 78 percent in 1997 (table 4.3.2, hyperlink to .xls file). The amount of herbicide applied per acre has fallen with the increased use of low-rate sulfonylurea herbicides and with reduced-rate application of atrazine and other older herbicides.

About 30 percent of the corn acreage in the 10 States surveyed received insecticides in 1997, and corn rootworm was the most frequently treated insect. Insecticide applied to soil before or during planting kills hatching

Figure 7--Pesticide use trends by pesticide type, 1990-97



1/Includes corn, cotton, soybeans, wheat and potatos in major prducing States

Source: USDA, ERS, based on USDA Survey data.

rootworm larvae and is a common control method, especially when corn is planted every year. Corn acreage treated with insecticides fluctuated between 26 and 32 percent between 1990 and 1997.

Soybeans. Herbicides account for virtually all the pesticides used on soybeans (table 4.3.2, hyperlink to .xls file). In the late 1980's, sulfonylurea and imidazolinone herbicides, which could be applied at less than an ounce per acre, began to replace the older products commonly applied at 1 to 2 pounds per acre. They are now among the most commonly used soybean herbicides and have reduced total herbicide quantities for soybeans. However, the number of acres treated and number of treatments per acre have increased, partly due to the growth in no-till soybean systems, which often replace tillage prior to planting with a preplant "burndown" herbicide to kill existing vegetation. The soybean acreage treated both before and after planting increased from 32 percent in 1990 to 48 percent in 1997.

Wheat. Wheat, one of the largest U.S. field crops, in terms of acreage, is the least pesticide-intensive. Wheat accounted for 27 percent of the surveyed crop acreage in 1997, but received only 4 percent of total pesticides. Herbicides were applied on 47 percent of the winter wheat and 82 percent of the spring and durum wheats (table 4.3.2, hyperlink to .xls file). Winter wheat grows through the fall and winter, and many weeds germinating in the spring cannot compete with the established wheat. In contrast, spring wheat seedlings compete directly with weed seedlings in the spring, and often require treatment. Like corn and soybeans, the average number of acre-treatments on all wheat has increased: from 1.5 in 1990 to 2.1 in 1997 for winter wheat, and from 1.9 to 3.1 for spring and durum wheat.

Insecticide use on wheat fluctuates with cycles of pest infestation, but it is generally well under 10 percent of the wheat area. Large populations of Russian wheat aphid and other insect pests in 1994 and 1996 caused winter wheat farmers to treat a larger than normal share of their acreage. Because disease-resistant varieties are used to combat many wheat diseases, fungicides are normally applied to less than 5 percent of the wheat acres.

Cotton. Cotton is one of the most pesticide-intensive field crops grown in the United States. In 1997, 96 percent of cotton acreage received herbicides, 74 percent received insecticides, and 68 percent received other types of pesticides (table 4.3.2, hyperlink to .xls file). Herbicides and insecticides account for about 71 percent of the pesticides applied to cotton, while plant growth regulators, defoliants, and other pesticides used to aid harvesting account for most of the remainder. Fungicides account for only 1 percent of all pesticides used on cotton.

Insect infestation on cotton is much greater than on corn, soybeans, or wheat, partly due to its longer growing season and the winter survival rates of insect eggs and larvae in warmer climates where it is grown. Although boll weevil eradication programs have been successful in several Southern States, tobacco budworms, cotton boll worms, thrips, and the boll weevil prevail in other States and require frequent treatments. About two-thirds of the cotton acres are treated for these insect pests, often with repetitive treatments. Insecticide use was high in 1994 and 1995 when an average of nearly 8 insecticide acre-treatments were applied to each treated acre. While approximately 75 percent of the acreage continued to get insecticide treatments in 1996 and 1997, the average number of acre-treatments dropped to 5.4.

The average number of herbicide ingredients and treatments per acre increased between 1990 and 1997 and more applications were made after planting. The number of acres treated after planting increased from 37 percent in 1990 to 62 percent in 1997 (table 4.3.2, hyperlink to .xls file). The area receiving herbicide treatments both before and after planting nearly doubled in this time period.

Potatoes. Potatoes are among the most pesticide-intensive crops for all types of pesticides. Herbicides, insecticides, and fungicides are each used on about 90 percent or more of the acreage, and about 65 percent receives a soil fumigant, growth regulator, defoliant or harvest aid (table 4.3.2, hyperlink to .xls file). The largest increase in potato pesticides has been for treating diseases, mostly the potato blight. The share of acres in the surveyed States receiving fungicides in 1997 was over 95 percent, up from 55 percent in 1990. Also, the average number of fungicide acre-treatments increased from 3.5 to 7.8 between 1990 and 1997. Soil fumigants and defoliants or vine killers account for the largest amount of pesticides used on potatoes, but they were applied to a relatively small area.

Other Vegetables and Fruits. Orchards, vineyards, and vegetable farms generally have much higher net returns per acre than in field crops, and fruit and vegetable growers have found it profitable to use insecticides and fungicides on a higher percentage of acreage than growers of most field crops do. More than 85 percent of the bearing acreage of the four largest fruit crops -- grapes, oranges, apples, and grapefruit, -- received at least one treatment with an herbicide, insecticide, or fungicide in 1997, and the majority of acres were treated with all three types (table 4.3.3, hyperlink to .xls file). Herbicides, insecticides, and fungicides were used to treat 91, 88, and 65 percent of the U.S. orange acreage in 1997, for example, and 60, 96, and 90 percent of the apple acreage. For most fruit crops, the volume of insecticides and fungicides used is generally higher than the volume of herbicides used.

Among vegetables other than potatoes, herbicides and insecticides were used on 90 and 74 percent of processing sweet corn acreage, the largest vegetable crop, in 1996. Herbicides, insecticides, and fungicides were used on 78, 71, and 90 percent of the second largest crop -- tomatoes grown for processing. Pesticide surveys from the 1960's and 1970's also showed that the majority of fruit and vegetable acreage received pesticides (Osteen and Szmedra, 1989).

Consumer expectations of cosmetically perfect fruits and vegetables, with no blemishes from insects or disease, dictate insecticide and fungicide use. Fresh-market vegetable acreage often receives more pesticides than the processing market crop. For example, a larger share of the fresh-market sweet corn and tomato acreage received fungicide and insecticide treatments than did sweet corn and tomatoes grown for processing. Among fresh-market vegetables, 98 percent of head lettuce, 89 percent of sweet corn, 96 percent of broccoli, and 93 percent of tomato acreage received insecticide treatments in 1996 (table 4.3.3, hyperlink to .xls file). Fungicides were used on 76 percent of head lettuce, 65 percent of watermelon, 78 percent of carrot, and 90 percent of tomato acreage.

Regional differences in rainfall, humidity, soil types, and other growing conditions influence the severity of pest problems and the intensity of pesticide use. Insecticide applications on grapes in 1997 ranged from 14 percent of the crop area in Oregon to 96 percent in Michigan (appendix table 4.3.4, hyperlink to .xls file), with a similar pattern occurring in 1995. Processing sweet corn receiving insecticides ranged from 60 percent in Oregon to 85 percent in Minnesota in 1996 and from 41 percent in Washington to 80 percent in Minnesota in 1994.

Pest problems and the available alternatives for managing pests, vary over time as well as by crop and region. However, there were no dramatic changes in proportion of area treated with pesticides for fruit crops between 1995 and 1997 or for vegetable crops between 1994 and 1996. A number of U.S. food processors are seeking to reduce the amount and frequency of pesticide use among its growers, and have been encouraging the use of Bt, parasitic wasps, mating-disrupting pheromones, disease-forecasting systems, and other biological and pesticide-reducing technologies (Orzalli, Curtis, and Bolkan, 1996).

Pesticide Expenditures

Annual pesticide expenditures for all farm uses increased from $6.3 billion to $8.8 billion over 1991-97 -- a 40-percent increase (USDA, ERS, 1998a). They increased from 4 to 5 percent of total production expenses. Pesticide costs per acre increased for corn (20 percent), cotton (19 percent), soybeans (25 percent), and wheat (10 percent) between 1991 and 1997 (USDA, ERS, 1998b). Pesticide costs for corn were about $27 per acre in 1997, accounting for 13 percent of total fixed and variable cash production expenses. Pesticide expenditures on cotton, with the largest cost for insecticides, were about $57 per acre in 1997 and accounted for 16 percent of cash production expenses. Pesticide costs on soybeans ($28 per acre) accounted for 22 percent of cash production expenses, while costs on wheat ($6 per acre) accounted for 6 percent.

Major Target Pests of Field Crops.

For corn, soybeans, cotton, wheat, and potatoes in 1996, weeds were by far the most targeted pest in terms of the share of pesticide treatments (table 4.3.4), as well as in terms of expenditures used to control them (Fernandez-Cornejo and Jans, 1995). The share of all pesticide acre-treatments used to control weeds is 83 percent for corn, almost 100 percent for soybeans, and around 90 percent for wheat. Only for potatoes and cotton do other pest classes have larger shares of total acre-treatments than weeds among major crops. Pathogens, which cause diseases, account for 56 percent of all potato acre-treatments. Insects account for 45 percent of all cotton pesticide treatments. Desiccants, defoliants, and growth regulators represent 18 and 10 percent of treatments on cotton and potatoes.

Among the more important weed species in 1996, in terms of share of treatments, were foxtail, other annual grasses, and annual broadleafs for corn and soybeans; and annual and perennial broadleafs for wheat. Cotton and field corn are the two largest markets for insecticides, even though only 16 percent of field corn acre-treatments were for insects. Beetles, weevils, or wireworms (labeled “other” in table 4.3.4), which include boll weevils, were identified as the primary target pest for the largest share of cotton insecticide treatments. (In 1996, there was an active boll weevil eradication program in parts of Texas, the largest cotton-producing State.) Moths or caterpillars, including pink bollworm and tobacco budworm, were identified for the second largest share. Corn rootworm was identified as the primary target pest for the largest share of corn insecticide treatments.

Efficient Pesticide Use Practices.

Producers make a variety of decisions about the application of pesticides that affect efficiency, including pesticide selection, pesticide combinations, timing, method of application, application rate, application equipment, and spray additives (Barrett and Witt, 1987). Many use information about pest infestations obtained through scouting or monitoring and economic thresholds to make such decisions (discussed below under “Decision Criteria and Information”).

For example, most farmers broadcast pesticides across the field, but an alternative technique--banding applications--can lower herbicide application rates substantially (Lin and others, 1995a). However, mechanical cultivation to control weeds between rows is often required, and growers have not increased their use of banding during the 1990's. About 10 percent of the U.S. corn, 49 percent of cotton, and 8 percent of soybean area treated with herbicides in 1997 was banded. Another efficiency tool is the use of drip pans for spray equipment to catch "overspray." Also, an increasing portion of herbicide applications on corn, soybeans, and cotton are made after planting, which reflects the change in type of pesticides used.

Pesticide Resistance.

Pesticide resistance is most likely to develop when a pesticide with a single mode of action is used over and over in the absence of any other management measures to control a specific pest. If a weed, insect, or fungi species contains an extremely low number of biotypes resistant to the killing mode of the pesticide, then those species that survive the pesticide treatment reproduce future generations containing the pesticide-resistant trait. As this process repeats, the resistance trait multiplies and begins to account for a significant share of the species' population.

Although herbicide-resistant weeds have been documented since the early 1950's, their prominence in the last two decades has increased, resulting in management strategies that seek to minimize development of pesticide-resistant species. Rotating pesticides with different modes of action, applying mixtures of herbicides, reducing application rates, and combining mechanical or nonchemical control practices are some management strategies to reduce pesticide resistance (Meister Publishing, 1996). Resistance to triazine herbicides (atrazine, cyanazine, and simazine) is one of the more common weed-resistant problems in corn and sorghum. Farmers responding to USDA's Cropping Practices Survey in 1994 reported that 16 percent of the corn acreage had triazine-resistant weeds. To deter these and other weed resistance problems, producers reported that they alternated herbicides on the majority or corn, soybean, and cotton acreage. In recent years, producers also have reported using different active ingredients on each treated acre and lowering the application rates, both practices prescribed to deter herbicide resistance.

Similar to the development of weeds resistant to herbicides, the incidence of insects, mites, and disease-causing fungus species resistant to pesticides also causes producers to switch to different pesticides or other management practices (National Academy of Sciences, 1986). Once insect or fungi species develop resistance to one ingredient, the time required to develop resistance to other ingredients of the same chemical family is often greatly reduced. Over a short time, species resistant to an entire family of ingredients can develop and require a different mode of treatment. Partly due to insecticide resistance, cotton insecticide families shifted from mostly organochlorines prior to the 1970's to organophosphates and carbamates and more recently to synthetic pyrethroids (Benbrook, 1996). Scouting to determine economic thresholds for treatments, alternating the use of pesticide families, and several other management strategies to combat resistance are now in use.

In 1996, alternating pesticide active ingredients to manage pest resistance was reported on about 30 percent of corn and soybean acreage, 40 percent of cotton acreage, 70 percent of potato acreage, 13 percent of winter wheat acreage, and 38 percent of spring wheat acreage (table 4.3.5). This practice was also reported on a high proportion of fruit and vegetable acreage. Growers used this practice on over 60 percent of the apple, orange, and peach acreage and over 70 percent of the strawberry and fresh-market tomato acreage (table 4.3.6, hyperlink to .xls file).

Biological Pest Management Practices

Biological pest management includes the use of pheromones, plant regulators, and microbial organisms such as *Bacillus thuringiensis* (Bt), as well as pest predators, parasites, and other beneficial organisms. EPA currently regulates biochemicals and microbial organisms and classifies them as "biorational pesticides." Another major biological tactic has been to breed crop varieties with "host plant resistance" to insects and disease.

Table 4.3.4 -- Pesticide treatments distributed by primary target pests, field crops in major producing States 1996

Item	Corn	Soybeans	Cotton	Fall potatoes	Winter wheat	Spring wheat	Durum wheat
	Percent of acre-treatments						
Insects and other arthropods:	16	--	45	20	12	2	1
Aphids	*	--	2	4	7	1	--
Beetles, weevils, or wireworms							
Corn rootworm - adult	3	--	--	--	--	--	--
Corn rootworm - larvae	7	--	*	--	--	--	--
Other[1]	1	**	20	14	**	--	--
Cutworms or armyworms	2	*	2	--	2	--	--
Moths or caterpillars							
Pink bollworm	**	--	4	--	--	--	--
Tobacco budworm	--	**	3	--	--	--	--
Other[2]	3	**	4	1	--	--	--
True bugs[3]	*	*	4	1	2	--	--
Whitefly, mealybugs, or leaf hoppers	--	--	1	**	--	--	--
Grasshoppers or crickets	**	**	**	--	*	--	**
Mites	*	--	2	*	1	--	--
Flies or maggots	--	--	**	--	--	1	1
Thrips	**	--	3	**	**	--	--
Pathogens:[4]	--	--	2	56	1	2	1
Nematodes	--	--	1	2	--	--	--
Fungus diseases	--	**	1	49	1	2	1
Virus diseases	--	--	**	5	*	--	--
Weeds:	83	100	38	16	87	97	99
Annual grasses							
Foxtail	21	19	*	*	1	7	5
Other annual grasses	17	22	7	1	7	14	15
Perennial grasses							
Shattercane	1	1	**	--	1	--	--
Johnsongrass	2	4	4	--	1	--	--
Quack grass	1	1	**	*	**	1	*
Other perennial grasses	4	6	4	1	2	8	1
Perennial broadleafs	9	8	4	3	20	13	21
Annual broadleafs	28	40	19	11	55	54	57
Others[5]	*	**	18	10	*	--	--

1 Includes other beetles, weevils, or wireworms.

2 Includes other moths or caterpillars such as loopers, leafminers, leaf perforators, leafworms, corn borers, webworms, and leafrollers.

3 True bugs include fleahoppers, lygus bugs, stink bugs, chinch bugs, and tarnish plant bugs.

4 Survey excludes treated seed and seed treatments for seedling diseases.

5 Treatments of desiccants, defoliants, and growth regulators.

* = Less than 0.5 percent.

** = Less than 0.1 percent.

-- = No responses.

Source: USDA, ERS and NASS 1996 ARMS Survey.

According to a recent Office of Technology report, the market for biologically based pest controls is small but fast-growing. The market value of biologically based products -- natural enemies, pheromones, and microbial pesticides -- sold in the United States during the early 1990's was estimated at $95-$147 million, 1.3 to 2.4 percent of the total market for pest control products (U.S. Congress, 1995). At least 30 commercial firms or "insectaries" produce natural enemies. Even though the current market for biological products is growing and large pest control companies are beginning to participate, the market is still so small that biologicals are unlikely to replace pesticides in the foreseeable future unless major research and development activities are started (Ridgway and others, 1994).

Microbial Pesticides and Pheromones

Biorational pesticides, such as Bt and pheromones, have differed significantly from chemical pesticides in that they have generally managed rather than eliminated pest populations, have had a delayed impact, and have been more selective (Ollinger and Fernandez-Cornejo, 1995). Growers have dramatically increased use of Bt, which produces toxins that causes disease in some insects, during the 1990's -- especially under biointensive and resistance-management programs -- because of environmental safety, improved performance, cost competitiveness, selectivity, and activity on insects that are resistant to chemical pesticides. Foliar-applied Bt is used in certified organic production. New Bt strains can affect insects not previously found to be susceptible to be susceptible to Bt. Current research is devoted to improving the delivery of Bt to pests and to increasing the residual activity and efficacy of Bt.

Bt was used on more than 1 percent of the acreage of 12 fruit crops in 1997, up from 5 crops in 1991 (table 4.3.7). Between 10 and 43 percent of the apple, blueberry, grape, nectarine, plum, prune, sweet cherry, blackberry, and raspberry acreage received Bt applications in 1997. The acreage of vegetable crops treated with Bt increased for 10 of the 18 crops surveyed by USDA between 1992 and 1996. Bt was used on about half or more of the cabbage, celery, eggplant, fresh tomato, and pepper acreage in 1996. Foliar-applied Bt (excluding use of Bt seed varieties) has been applied to a smaller percentage of field crop acreage: 1 percent of corn acreage treated in 1997. Bt-treated cotton acreage increased from 5 percent in 1992 to 9 percent in 1994 and 1995, but fell to 2 percent in 1997; the decrease may be associated with the increased planting of Bt cotton seed (15 percent of acres in 1996) and resistance management. Depending upon the formulation, Bt can be applied with conventional ground, aerial, or sprinkler irrigation equipment.

Pheromones are used to monitor populations of crop pests and to disrupt mating in organic systems and some IPM programs. Pheromones were used for monitoring on 69 percent and for insect control on 15 percent of surveyed apple acreage (in 1993), for monitoring on 32 percent and for control on 21 percent of peach acreage (in 1995), and on 20 percent or less of grape, orange, tomato, and strawberry acreage (in 1993-94) (table 4.3.8). In 1996, pheromones were used for monitoring on 33 percent and for pest control on 7 percent of cotton acres (table 4.3.7); they were used on a much smaller portion of other field crops.

Beneficial Organisms

Natural enemies of crop pests, or "beneficials," may be imported, conserved, or augmented. Natural enemy importation and establishment, also called classical biological control, has been undertaken primarily in university, State, and Federal projects; 28 States operate biocontrol programs and most have cooperative efforts with USDA agencies (U.S. Congress, 1995). Some crop pests, such as the woolly apple aphid in the Pacific Northwest, have been largely controlled with this method. Many crop pests are not native to this country, and USDA issues permits for the natural enemies of these pests to be imported from their country of origin.

Table 4.3.5 --Scouting and other pest management practices for major field crops in major producing States, 1996						
Item	Corn	Soybeans	Winter wheat	Spring wheat	Cotton	Fall potatoes
	Percent of planted acres					
Scouting for weeds	78	79	85	90	72	94
Source of scouting:						
Operator, partner, family member	59	68	73	77	46	59
Employee	2	1	*	*	3	7
Chemical dealer	8	6	6	9	4	17
Consultant or commercial scout	8	3	5	4	19	12
Scouting for insects	66	59	74	64	88	98
Source of scouting:						
Operator/family member	49	51	62	56	24	56
Employee	2	1	*	*	3	7
Chemical dealer	7	3	5	3	10	19
Consultant or commercial scout	8	3	6	4	51	15
Scouting for diseases	51	53	66	60	53	91
Scouted and kept written/electronic records to track the activity of:						
Broadleaf weeds	19	19	17	23	28	26
Grass weeds	19	19	15	17	28	26
Insects	na	13	14	9	52	31
Other monitoring:						
Used pheromone lures to monitor pests [1]	1	*	*	4	33	3
Used soil biological testing to detect pests such as insects, diseases, or nematodes	2	3	2	0	9	46
Biological techniques:						
Considered beneficial insects in selecting pesticides	8	5	10	4	52	29
Purchased and released beneficial insects	*	*	*	*	*	0
Used pheromone lures to control pests	na	*	*	1	7	2
Pest-resistant varieties:						
Herbicide-resistant hybrid/variety	3	7	nap	nap	2	nap
Bt variety for insect resistance	1	nap	nap	nap	15	1
Gray leaf spot-resistant variety	2	nap	nap	nap	nap	nap
Potato scab-resistant variety	nap	nap	nap	nap	nap	1
Cultural techniques:						
Adjusted planting or harvesting dates [2]	5	6	19	11	25	7
Used mechanical cultivation for weed control	51	29	na	na	89	86
Used a no-till system	19	33	3	4	na	na
Crop rotations: [3]						
Continuous [4]	18	11	42	14	67	2
Rotation with other row crops [5]	54	63	2	2	15	2
Other [6]	28	26	56	83	18	96
Pesticide efficiency:						
Alternated pesticides to control pest resistance	31	28	13	38	41	69
Acres planted (1,000 acres)	70,250	50,970	28,598	16,350	11,915	787
1 For corn, pheromone lures were used to monitor black cutworm. 2 Adjust planting dates only for corn.						
3 Crop rotations include 1994, 1995, and 1996. 4 The same crop was planted in 1994, 1995, and 1996.						

5 A crop sequence, excluding continuous same crop, where only row crops (corn, soybeans, sorghum, cotton, and peanuts) were planted for 3 consecutive years. 6 Excludes continuous same crop and rotation with row crops and includes fallow. na= not available. nap= not applicable. * Less than 0.5 percent
Source: USDA, ERS and NASS, 1996 ARMS survey.

Natural enemies may be conserved by ensuring that their needs -- or alternate hosts, adult food resources, overwintering habitats, a constant food supply, and other ecological requirements -- are met, and by preventing damage from pesticide applications and other cropping practices (Landis and Orr, 1996). Over half of the certified organic vegetable growers in 1994 and a third of the certified organic fruit growers in 1995 provided habitat for beneficials (table 4.3.6, hyperlink to .xls file).

Augmentation boosts the abundance of natural enemies (native and imported) through mass production and inundative or inoculative releases in the field (Landis and Orr, 1996). An inundative release, the most common augmentation method, can be timed for when the pest is most vulnerable and is used when the natural enemy is absent or when its response to the pest pressure is insufficient. An inoculative release may be made in the spring for a natural enemy that cannot overwinter in order to establish a population. Unlike importation and conservation, augmentation generally does not suppress pests permanently.

Beneficial insects were used on 3 and 19 percent of the surveyed vegetable and fruit acreage in the early 1990's (Vandeman and others, 1994). Nearly 46 percent of the certified organic vegetable growers surveyed in 1994 reported use of beneficials, while 20 percent of certified organic fruit growers surveyed in 1995 reported the purchase and release of beneficials for insect control (table 4.3.6, hyperlink to .xls file). Purchased beneficial insects were used on a relatively small portion of surveyed fruit and vegetable acreage, with the exception of strawberries (35 percent).

Protecting beneficial insects, which could involve changing pesticide practices or providing habitat, was reported on a high proportion of surveyed fruit and vegetable acreage (table 4.3.8). The practice was particularly high on grape (61 percent), apple (80 percent), fresh market-tomato (64 percent), and strawberry (59 percent) acreage. Among surveyed field crops in 1996, beneficial insects were considered when selecting pesticides on 52 percent of cotton and 29 percent of fall potato acres (table 4.3.5). Beneficial insects were purchased and released on less than 0.5 percent of field crop acreage.

Host Plant Resistance

Corn and soybean breeding for genetic resistance to insects, disease, and other pests has been the research and development focus of major seed companies, as well as USDA and Land Grant Universities, for many decades (Edwards and Ford, 1992). U.S. corn, soybean, and cotton acreage receives virtually no foliar fungicides. Fruit and vegetable growers reported use of resistant varieties on 37 percent of strawberry and fresh market tomato acreage in 1994, 44 percent of peach acreage in 1995, but less than 15 percent of grape, orange, and apple acreage in 1993 (table 4.3.6, hyperlink to .xls file). In 1994, 75 percent of certified organic vegetable growers and 20 percent of certified organic fruit growers reported using resistant varieties (Fernandez-Cornejo and others, 1998b).

Cultural Pest Management Practices

A number of production techniques and practices -- including crop rotation, tillage, alterations in planting and harvesting dates, trap crops, sanitation procedures, irrigation scheduling, fertilization, physical barriers, border

Table 4.3.7--Agricultural applications of Bacillus thuringensis (Bt), selected crops in surveyed States, 1991-97

Crop [1]	1996/97 planted acres [2]	1991	1992	1993	1994	1995	1996	1997
		Area receiving application						
	1,000 acres	Percent of acres						
Field crops:								
Corn	62,150	*	*	na	1	1	1	1
Cotton, upland	13,075	na	5	8	9	9	3	2
Potatoes, fall	944	na	na	2	1	*	*	na
Tree and bush fruits:								
Grapes	894	na	-	2	-	6	-	11
Oranges	833	2	-	7	-	3	-	4
Apples, bearing	351	3	-	13	-	12	-	16
Peaches	136	na	-	3	-	5	-	12
Prunes	101	na	-	na	-	9	-	10
Pears	68	na	-	1	-	2	-	1
Cherries, sweet	48	na	-	8	-	9	-	11
Plums	44	na	-	na	-	14	-	28
Nectarines	38	na	-	10	-	22	-	39
Blueberries	34	11	-	8	-	5	-	14
Raspberries	13	49	-	45	-	52	-	43
Blackberries	6	18	-	na	-	23	-	20
Vegetables/other fruit:								
Tomatoes, proc.	318	-	6	-	5	-	5	-
Lettuce, head	195	-	18	-	20	-	33	-
Sweet corn, fresh	146	-	3	-	3	-	1	-
Onion	127	-	na	-	1	-	na	-
Cantaloupe	113[3]	-	32	-	8	-	9[3]	-
Honeydew	113[3]	-	28	-	10	-	9[3]	-
Broccoli	106	-	7	-	14	-	14	-
Tomatoes, fresh	89	-	31	-	39	-	64	-
Snap beans, fresh	67	-	20	-	29	-	17	-
Lettuce, other	74	-	39	-	22	-	13	-
Bell peppers	65	-	35	-	37	-	49	-
Cabbage, fresh	64	-	48	-	64	-	52	-
Cucumbers, fresh	49	-	19	-	22	-	27	-
Cauliflower	44	-	12	-	20	-	19	-
Strawberries	45	-	24	-	33	-	31	-
Celery	26	-	51	-	61	-	49	-
Spinach, fresh	12	-	13	-	21	-	15	-
Eggplant	3	-	13	-	48	-	54	-

* Applied on less than 1 percent of the acres. na = Not available (insufficient reports to publish the data). -- = Not a survey year for that commodity. 1 Bt use was too small to report on soybeans, wheat, and on other surveyed fruit and vegetable crops. 2 Planted acres in the surveyed States. The survey accounted for between 79 and 90 percent of U.S. total planted corn acreage, between 70 and 78 percent of the total upland cotton acreage, and over 70 percent of fruit and vegetable acreage. 3 Acreage for cantaloupes and honeydews combined.

Source: USDA, ERS and NASS, Chemical Use Survey data.

Table 4.3.8 --Insect decision criteria and primary source of pest management information for major field crops, major producing States, 1996						
Item	Corn	Soybeans	Winter wheat	Spring wheat	Cotton	Fall potatoes
Decision criteria used:	Percent of planted acres					
Compared scouted data to University or						
extension guidelines for infestation thresholds	na	11	12	23	46	24
Used standard practice or history						
of insect problems	na	30	20	29	22	55
Used local information (other farmers, radio						
TV, etc) that the pest was or was not present	na	12	9	11	7	20
Used the operator's own determination						
of the pest infestation level	na	54	69	65	55	83
Pest management information sources:						
Extension advisors	7	8	9	14	17	23
Farm supply/chemical dealer	69	74	42	52	22	54
Commercial scouting service	2	1	4	1	15	2
Crop consultant/pest control advisor	9	4	10	6	30	15
Other growers/producers	3	2	11	4	5	1
Producer associations-						
newsletters or trade magazines	1	1	2	2	*	3
TV or radio programs, newspapers	*	*	1	0	*	*
Electronic information services						
(World Wide Web, DTN, etc.)	*	*	0	0	*	*
Other	1	2	3	7	4	*
None	3	6	16	13	7	1
Acres planted (1,000 acres)	70,250	50,970	28,598	16,350	11,915	787
* Less than 0.5 percent.						
na = not available.						
Source: USDA, ERS and NASS/ERS, 1996 ARMS survey.						

sprays, cold air treatments, and providing habitat for natural enemies of crop pests -- can be used for managing crop pests. Cultural controls work by preventing pest colonization of the crop, reducing pest populations, reducing crop injury, and increasing the number of natural enemies in the cropping system (Ferro, 1996).

Research on new cultural techniques such as solarization – heating the soil to kill crop pests – continues to emerge. However, most cultural practices do not involve a marketable product, and research and development depends almost entirely on public sector funding (U.S. Congress, 1995).

Crop rotation is one of the most important of the current cultural techniques. In 1996, 82 percent of U.S. corn acreage was in rotation with other crops, up slightly from 76 percent in 1990 (table 4.3.5). Over half of the corn in 1996 was being grown in rotation with other row crops; mostly soybeans. Corn producers rotating corn with other crops used insecticides less frequently than did those planting corn 2 years in succession (11 percent of acres versus 46 percent) (USDA, ERS, 1997). Corn is often grown as a monocrop in heavy livestock areas and where climate limits the soybean harvest period (Edwards and Ford, 1992).

About 89 percent of soybeans were grown in crop rotations in 1996. Crop rotation was much less prevalent for cotton -- 33 percent of acreage. Crop rotation was used on 85 percent of the spring wheat crop but only 58 percent of the winter wheat crop in 1995. Crop rotation was used for virtually all of the potato acreage.

Cultivation for weed control is widely practiced for field crops, mostly in conjunction with herbicide use. Almost all of the potato and cotton acreage received cultivations in 1995, along with 66 percent of corn (USDA, ERS, 1997). For soybeans, cultivations dropped from 67 percent in 1990 to 41 percent in 1995. In 1996, over 85 percent of cotton and potato acres, but only 51 percent of corn and 29 percent of soybean acres, were cultivated (table 4.3.5).

Field sanitation and water management, such as scheduling or timing of irrigation, are widely used on fruit and nut crops, with 60 percent and 31 percent of the acreage under these practices in the early 1990's (Vandeman and others, 1994). Water management was used by 44 percent of the certified organic vegetable producers. Surveys showed that a high percentage of certified organic fruit and vegetable growers use cover crops and mulches and that a high percentage of the organic fruit growers also use mechanical tillage (table 4.3.6, hyperlink to .xls file).

In 1994, planting dates were adjusted on 15 percent of the strawberry acreage and 11 percent of the fresh-market tomato acreage (table 4.3.6, hyperlink to .xls file). Over half of the certified organic vegetable growers adjusted planting dates to manage pests in 1994 (Fernandez-Cornejo and others, 1998b).

Some field crop producers adjust planting and harvesting dates to minimize pest damage. In 1996, harvest dates were adjusted on 25 percent of cotton acreage, 19 percent of winter wheat acreage, 11 percent of spring wheat acreage, and less than 10 percent of soybean and potato acreage (table 4.3.5). Planting dates were adjusted on 5 percent of corn acreage.

Decision Criteria and Information

Pest scouting or monitoring, economic thresholds, and other tools help producers to optimize pest management practices. "Expert systems" have integrated these tools into decision management software. These practices may improve the effectiveness of pest control and reduce pesticide risks through lower rates, less toxic materials, or fewer applications.

Scouting and Economic Thresholds

Entomologists have been developing scouting techniques to monitor the populations of major insect and other arthropod pests for several decades. Field trials were conducted to determine the crop-damage functions associated with these pests in order to set economic thresholds -- pest population levels above which economic damage to the crop would occur without pesticide application. These scouting techniques and thresholds were designed to replace routine, calendar-based insecticide applications.

While scouting techniques and thresholds have been developed for most major insect pests in agriculture, weed scientists and ecologists have only recently begun exploring whether economic thresholds are applicable for weed management (Coble and Mortensen, 1992). Economic thresholds are rarely used for plant pathogens since infections generally spread too quickly to use fungicides after the disease is detected. However, disease prediction models that result in disease advisories for some major fruit and field crops have been developed and commercialized.

Scouting is widespread in specialty crop production. Recent surveys showed scouting on 70 to 90 percent of grape, orange, apple, and peach acreage, and thresholds used on a significant proportion of that acreage (table 4.3.6, hyperlink to .xls file). Over 90 percent of the strawberry and fresh-market tomato acres were scouted in 1994, and thresholds were used on 70 percent of the tomato acreage. Also, 97 percent of the certified organic vegetable producers in 1994 and 76 percent of the certified organic fruit producers used scouting in 1995.

The 1996 Agricultural Resource Management Study (ARMS) survey showed scouting on field crops for weeds, insects, and diseases (table 4.3.5). Scouting for weeds ranged from 72 percent of the acreage for cotton to 94 percent for fall potatoes. Corn and soybean farmers reported scouting for weeds on 78 and 79 percent of their acreage. Calculating a weighted average of all major field crops, scouting for weeds reached 80 percent in 1996. The farm operator or family member scouted on 45 percent or more of the planted acres. However, 19 percent of cotton acres were scouted for weeds by a crop consultant or commercial scout.

Scouting for insects on field crops ranged from 59 percent for soybean acreage to 98 percent for fall potatoes, with 66 and 88 percent of the corn and cotton acreage also scouted (table 4.3.5). On average, scouting for insects reached 67 percent among all field crops in 1996. The primary source of scouting for insects was the farm operator or family member for all field crops except cotton, where 51 percent of the planted acres were scouted by crop consultants or commercial scouts. Scouting for diseases occurred on more than half of the planted acres for field crops. Scouting for insects and diseases appears relatively infrequent for corn and soybeans, because insect problems treatable with pesticides are not prevalent for those crops in many States. This is also reflected in the low percentage of corn and soybean acreage treated with insecticides (table 4.3.2, hyperlink to .xls file).

USDA, NASS (1998) reported a smaller percentage of acres scouted for weeds, insects, or diseases in 1997. NASS estimated that scouting for pests in 1997 was used on 47 percent of corn, 73 percent of cotton, 45 percent of soybean, 35 percent of all wheat, 80 percent of fruit and nut, and 81 percent of vegetable acreage. Its 1997 Fall Area Survey differed from the 1996 ARMS survey by not specifying the type of pest scouted, but adding the wording "using a systematic method."

The 1996 ARMS survey paired scouting by pest class with pest recordkeeping, either written or electronic. For all field crops, a lower percentage of farmers scouted and kept records as compared to just scouting (table 4.3.5). The one anomaly -- scouting and recordkeeping for insects on cotton (52 percent of acreage) -- corresponds to the percentage of cotton acreage scouted for insects by crop consultants or commercial scouts (51 percent of planted acres).

The 1996 ARMS survey also collected information on decision criteria for applying insecticides (table 4.3.8). A large portion of the crop acreages with major insects problems, like cotton and fall potatoes, received applications based on scouted data compared to university or extension infestation thresholds (46 and 24 percent of the cotton and fall potato planted acres). On the other hand, soybeans and winter wheat, which have far fewer insect problems, used thresholds on only 10 percent of their acreages.

Sources of Pest Management Information
Growers obtain pest management information from a variety of sources. Farm supply/chemical dealers provide

information on 40 to 75 percent of field crop acres except cotton, followed by extension advisors and crop consultants/pest control advisors (table 4.3.8). For cotton, the largest source is crop consultants/pest control advisors.

Chemical dealers were the most-used source of pest management information for apples, grapes, peaches, oranges, and strawberries in surveys conducted from 1993 to 1995; professional scouting services and extension advisors were also widely used on these crops (table 4.3.9). Professional scouting services were the most used source for fresh market tomatoes.

Expert Systems.
"Expert systems" integrate information on pest density, economic thresholds, application methods, and other elements of pest management into a computer software package that helps the farmer determine when to make pesticide applications, which pesticides to use, and how much to use. For example, a threshold-based model for corn and soybeans (NebraskaHERB) determines whether it is cost-effective to manage weeds in a field, and identifies whether broadcast or band-applied herbicides or cultivation is the most cost-effective treatment. The Nebraska Extension Service reports use in Nebraska is small but growing (USDA, 1994). The use of "expert systems" (decision support) software is still well under 1 percent in U.S. corn and soybean production, according to recent ERS surveys (Padgitt, 1996). Several university expert systems, which forecast diseases in some major fruit and vegetable crops, have recently become available commercially through IPM product suppliers, including the "Penn State Apple Orchard Consultant" and the University of Wisconsin's WISDOM software.

Precision Farming.
Precision farming is an emerging technology that may allow a more efficient application of inputs by using yield monitors, satellite images, GIS, and other developing information technologies to tailor inputs to the different conditions in each field. Soil leachability, pH, and other characteristics often vary, sometimes substantially, within the farm field, and better tailoring of inputs to site-specific field conditions can increase crop yields. Most precision farming has addressed nutrient management, but research on pest management using this technology is emerging. Recent industry surveys indicate that only a small number of corn growers are experimenting with precision farming. The yield monitors and equipment necessary for many other crops, especially vegetable crops, have not been developed yet. USDA, the chemical industry, and other organizations are examining the potential for this technology to increase yields or reduce pesticide use. The few existing studies on the potential of precision farming to provide environmental benefits are inconclusive about its effect on pesticide use.

Factors Affecting Pest Management Decisions

According to economic efficiency criteria, producers would choose the combination of pest control methods that maximizes the difference between the value of pest damage reductions and control costs. They should increase the use of a pest control input until the marginal value of damage reduction of the last unit of input equals the marginal cost. As a result, the use of pest management practices, including pesticides, should be influenced by pest infestations, yield and quality losses caused by those infestations, as well as by crop prices and the costs of pesticides and alternative control methods.

However, financial risk (variability of returns) and uncertainty (incomplete information about outcomes) are also important considerations. Farmers do not know precisely what pest damage will occur without control, the reduction in damage from using a control, and the value of the reductions. They must develop expectations of crop value and potential yield savings from control. Rational decisions will ultimately appear suboptimal if pest infestations or crop values were different than expected. Because reducing the risk of large financial losses is important to many producers, some may find it rational to apply pesticides or other inputs in excess of profit-maximizing levels.

Many other factors affect the use of pesticides and other practices. Changes in planted acres or shifts in production between commodities and regions can affect the number of acres treated and applied quantities. Pest cycles and annual fluctuations caused by weather and other environmental conditions often determine whether infestation levels reach treatment thresholds. Changes in pesticide regulations, prices, new chemical and nonchemical options, and pest resistance to pesticides also affect the producer's selection of pest management practices. Scarcity of labor or high wages can constrain the use of labor-intensive practices.

Pesticide Prices

Aggregate pesticide prices, as measured by the USDA agricultural chemicals price index, increased 17 percent from 1991 to 1996 (table 4.3.10, hyperlink to .xls file). Herbicide prices increased about 17 percent, fungicide prices nearly 14 percent, and insecticide prices about 24 percent. Prices may be rising in response to increased use of pesticides since 1990, as discussed above (table 4.3.1, fig. 1). Some research shows that aggregate demand for pesticide use is negatively related to changes in pesticide prices, but is price inelastic so that the percentage change in use is less than the percentage change in pesticide prices (Fernandez-Cornejo, 1992;

Table 4.3.9 -- Source of pest management information, selected fruits and vegetables in major producing States, 1993-95

Item	Apples	Grapes	Peaches	Oranges	Tomatoes	Strawberries
	Percent of planted acres					
Extension advisor	19	22	23	18	14	17
Chemical dealer	49	43	34	54	37	41
Professional scouting service	23	17	32	20	43	35
Media or demonstration event	2	2	4	5	1	2
Other information source	6	17	7	4	5	4

1 Apple, grape, and orange data are from the 1993 USDA Chemical Use Survey for fruits; peach data are from the 1995 USDA Chemical Use Survey for fruits; and strawberry and tomato data are from the 1994 USDA Chemical Use Survey for vegetables. For major States surveyed, see A Chemical Use Survey in the appendix.

Source: USDA, ERS and NASS, Chemical Use Survey data.

McIntosh and Williams, 1992; Oskam and others, 1992). However, Chambers and Lichtenberg (1994) estimated that, in the longer run, the aggregate demand would be more price elastic so that use would change proportionately more than price changes.

Use of individual products can vary significantly from year to year even if aggregate pesticide use does not. When different pesticide products are perfect or near-perfect substitutes, small price changes can result in significant changes in the mix of products used as farmers attempt to maximize profits. Index numbers are useful aggregate measures for monitoring price changes, but indexes can mask movements in individual components. Common pesticide active ingredients showed different price trends between 1991 and 1996 (table 4.3.10, hyperlink to .xls file). These price changes typically reflect shifts in factors such as cost of manufacturing and distribution, price of competing products, patent protection, and planted acreage of the treated crop.

Among insecticides, carbaryl, methyl parathion, and phorate had price increases of 25 percent or more. These insecticides are widely used on corn as well as several fruit and vegetable crops. Most fungicide prices rose over 10 percent while captan and chlorothalonil increased more than 20 percent. Both captan and chlorothalonil are used extensively on fruit, vegetable, and nut crops such as apples (captan) and peanuts (chlorothalonil). Sulfur (which dropped in price) is heavily applied to grapes.

Among herbicides, the price of sethoxydim dropped, while prices for 2,4-D, atrazine, cyanazine, dicamba, and MCPA rose. With the exception of MCPA, which is used primarily on wheat and barley, the herbicides with the greatest price increases were extensively used in corn production. However, 2,4-D and dicamba are also used on pasture and wheat land, atrazine is heavily used on corn and sorghum, and cyanazine is a major cotton herbicide.

Effects of Longer-Term Relative Price Trends

One argument for the increase in pesticide use from 1945 through 1980 is that pesticides often cost less and contributed to higher, less variable yields than previously used nonchemical methods. Fernandez-Cornejo and others (1998a) reviewed pesticide productivity studies and found that most showed pesticides to be cost-efficient inputs from the farmer's perspective (Headley ,1968; Campbell ,1976; Hawkins, Slife, and Swanson, 1977; Miranowski, 1975; Duffy and Hanthorn, 1984; Carrasco-Tauber and Moffitt, 1992; Lin and others, 1993; Fernandez-Cornejo and others, 1996). Some studies indicate that the marginal return of pesticide use (the return to the last unit used) is declining, which is to be expected as use increases.

Trends in pesticide prices relative to other input and crop prices could have encouraged pesticide use. Between 1965 and 1980, a period of rapid growth in pesticide use, pesticide prices increased (64 percent) less than wages (233 percent), fuel prices (123 percent), and crop prices (135 percent) (USDA, Crop Reporting Board, 1981). These trends would encourage the substitution of pesticides for labor, fuel, and machinery used in pest control (Daberkow and Reichelderfer, 1988). Crop prices that increase relative to pesticide prices would also encourage greater pesticide use. These trends may also have induced technological change to take advantage of relatively cheap pesticides (Capalbo and Vo, 1988). Public and private research introduced new pesticides (and other innovations) that could increase yields and substitute for some farm labor, machinery, and fuel.

However, recent price trends may have curbed pesticide use relative to its rapid growth prior to 1980, but there may still be a price incentive to substitute pesticides for labor. The 19-percent increase in pesticide prices from 1991 to 1997 as measured by the USDA agricultural chemicals price index, was greater than the increases for the crop price index (15 percent) and the fuel price index (4 percent), but less than the increase for the wage index (22 percent) (USDA, NASS, 1998a).

Federal Agricultural Programs

Federal commodity and conservation programs provide mixed incentives to both increase and decrease pesticide use. Acreage restrictions and set-aside provisions in past commodity programs and the Conservation Reserve Program reduced planted acreage and, hence, pesticide use. Pesticide use dropped in 1983 with the large feedgrain acreage idled under the payment-in-kind program (PIK) and has subsequently paralleled other major changes in planted acreage. On the other hand, when planted acreage was constrained and price expectations included program payments, producers tended to substitute nonland inputs, -- including fertilizer and pesticide -

- for land to boost per-acre yields and capture higher returns on their eligible planted acreage. Participants in Federal commodity programs applied nitrogen fertilizer and herbicides at higher rates than did nonparticipants (Ribaudo and Shoemaker, 1995).

The Federal Agriculture Improvement and Reform Act of 1996 removed the link between income support payments and current farm production and should remove most farm program incentives to increase pesticide and fertilizer use per acre of planted land. However, producers' greater planting flexibility could lead to increased pesticide use as idled land returns to production. Producers are now permitted to plant 100 percent of their total base acreage plus additional acreage to any crop (with some exceptions for fruits and vegetables) without loss of Federal subsidy.

Pesticide Regulatory Issues

The U.S. Environmental Protection Agency (EPA) regulates pesticides under the Federal Insecticide Fungicide and Rodenticide Act (FIFRA) and pesticide residues in food under the Federal Food, Drug, and Cosmetic Act (FFDCA). (See box, "Important Pesticide Legislation.") Under FIFRA, EPA decides which pesticides are registered for which uses and prescribes other restrictions on their use (such as application rate, when and how they are to be applied, and what safety precautions are to be used during and after application) to prevent unreasonable adverse effects on health and the environment. As part of registering a pesticide for food uses, EPA establishes tolerances, or limits, for residues of the pesticide in each food. These tolerances are enforced through monitoring and inspections conducted by the Food and Drug Administration and USDA. (See box, "Pesticide Residues in Food.")

The Clean Air Act (1970), Clean Water Act (1972), Resource Conservation and Recovery Act (1976), and the Comprehensive Environmental Response, Compensation, and Liability Act (1980) (or Superfund) also contain provisions that affect pesticide manufacturers. The Clean Air Act mandates discharge limits on pollutants, RCRA specifies how to dispose of toxic substances, and the Superfund stipulates who pays for the cleanup of toxic dump sites.

Most States have some regulations related to pesticide use in agriculture and/or lawn care, and over half have groundwater laws, posting requirements, and pesticide reporting regulations (Meister Publishing, 1996). Over a third of the States have health advisory levels, containment regulations, and bulk chemical regulations, and 13 States have requirements for reporting pesticide illnesses. Most States also have pesticide registration fees, many of which have increased in the last several years. Nine States tax pesticide products or have other special taxes (Meister Publishing, 1996) that have been used to fund research on pesticide alternatives. For example, the Leopold Center for Sustainable Agriculture at Iowa State University, which conducts research on environmentally friendly alternatives, is partially supported from a tax on pesticide and fertilizer sales in Iowa.

The Food Quality Protection Act and Tolerance Reassessment

The Food Quality Protection Act of 1996 (FQPA) amended FIFRA and FFDCA (Public Law 104-170, 1996). An important provision is a uniform safety standard for pesticide-related risks in raw and processed foods: "a reasonable certainty of no harm from aggregate exposure to the pesticide chemical residue." Previously, the "Delaney Clause" of the FFDCA prohibited processed foods, but not fresh foods, from containing even trace amounts of carcinogenic chemical residues. In setting tolerances, EPA must consider dietary exposures to a pesticide from all food uses and from drinking water, as well as nonoccupational exposure, such as homeowner

Important Pesticide Legislation

The Insecticide Act of 1910 -- Prohibited the manufacture, sale, or transport of adulterated or misbranded pesticides; protected farmers and ranchers from marketing of ineffective products.

Federal Food, Drug, and cosmentic Act of 1938 (FFDCA) --Provided that safe tolerances be set for residues of unavoidable poisonous substances (such as pesticides) in food.

Federal Insecticide, Fungicide, and Rodenticide Act of 1947 (FIFRA) -- Required pesticides to be registered before sale and that the product label specify content and whether the substance was poisonous.

Miller Amendment to FFDCA of 1954 --Amended FFDCA to require that tolerances for pesticide residues be established (or exempted) for food and feed (Section 408). Allowed consideration of risks and benefits in setting tolerances.

Food Additives Amendment to FFDCA of 1958 -- Amended FFDCA to give authority to regulate food additives against a general safety standard that does not consider benefits (Section 409); included the Delaney Clause, which prohibited food additives found to induce cancer in humans or animals. Pesticide residues in processed foods were classified as food additives, while residues on raw commodities were not. When residues of a pesticide applied to a raw agricultural commodity appeared in a processed product, the residues in processed foods were not to be regulated as food additives if levels were no higher than sanctioned on the raw commodity.

FIFRA Amendments of 1964 -- Increased authority to remove pesticide products from the market for safety reasons by authorizing denial or cancellation of registration and the immediate suspension of a registration, if necessary, to prevent an imminent hazard to the public.

Federal Environmental Pest Control Act (FEPCA) of 1972 -- Amended FIFRA to significantly increase authority to regulate pesticides. Allowed registration of a pesticide only if it did not cause "unreasonable adverse effects" to human health or the environment; required an examination of the safety of all previously registered pesticide products within 4 years (of the act) using new health and environmental protection criteria. Materials with risks that exceeded those criteria were subject to cancellation of registration. Specifically included consideration of risks and benefits in these decisions.

FIFRA Amendment of 1975 -- Required consideration of the effects of registration cancellation or suspension on the production and prices of relevant agricultural commodities.

Federal Pesticide Act of 1978 -- Identified review of previously registered pesticides as "reregistration"; eliminated the deadline for reregistration but required an expeditious process.

FIFRA Amendments of 1988 -- Accelerated the reregistration process by requiring that all pesticides containing active ingredients registered before November 1, 1984, be reregistered by 1995; provided EPA with additional financial resources through reregistration and annual maintenance fees levied on pesticide registrations.

The Food Quality Protection Act of 1996 (FQPA) -- Amended FIFRA and FFDCA. Set a consistent safety standard for risks from pesticide residues in foods: "ensure that there is a reasonable certainty that no harm will result to infants and children from aggregate exposure." Pesticide residues are no longer subject to the Delaney Clause of FFDCA; both fresh and processed foods may contain residues of pesticides classified as carcinogens at tolerance levels determined to be safe. EPA is required to reassess existing tolerances of pesticides within 10 years, with priority to pesticides that may pose the greatest risk to public health. Benefits no longer have a role in setting new tolerances, but may have a limited role in decisions concerning existing tolerances. Included special provisions to encourage registration of minor-use and public health pesticides.

Pesticide Residues in Food

USDA's pesticide monitoring by the Agricultural Marketing Service (AMS) measures residues on both domestic and imported samples of fresh fruits and vegetables common in the diets of the U.S. population. Wheat was sampled in 1995, 1996, and 1997, and whole milk was sampled in 1996 and 1997. The AMS monitoring is used not only to respond to food safety concerns but also to provide the EPA with data to assess the actual dietary risk posed by pesticides. Without actual exposure data, the pesticide registration process assumes all producers apply the pesticide and that residues are at tolerance levels or levels observed in field trials conducted at maximum rates and number of applications and minimum preharvest interval. This assumed maximum risk might significantly exceed actual risk and jeopardize the registration process for products important to agricultural production. Pesticide use data can be used to reduce the percent of crop treated assumption from 100 percent.

Some pesticide residues were found on 71 percent of the fruit and vegetable samples in 1993 and 62 percent in (1994 USDA, AMS, 1995; USDA, AMS, 1996). In 1995, approximately 65 percent of the fruit and vegetable and 79 percent of the wheat samples had at least one residue (USDA, AMS, 1997). In 1996, about 72 percent of fruit and vegetable, 18 percent of milk, and 91 percent of wheat samples contained at least one pesticide residue (USDA, AMS, 1998b). Detections were more frequent on fresh produce (83 percent of the samples) than on processed products (39 percent of the samples). About 21 percent of all detections were from postharvest use on produce to prevent spoilage during storage and transportation. In 1997, 57 percent of fruit and vegetable samples contained at least one residue, including 70 percent of the fresh produce and 45 percent of the processed products. About 24 percent of those detections were due to postharvest uses (USDA, AMS, 1998a). Also 15 percent of milk, 80 percent of wheat, and 87 percent of soybean samples contained at least one residue.

However, few detections exceeded established tolerance levels in those years. In 1996, 4 percent of samples had presumptive violations (USDA, AMS, 1998b). In 1997, 6 percent of fruit and vegetable, 4 percent of wheat, and 1 percent of milk samples had presumptive violations (USDA, AMS, 1998a). Most violations were for residues for which no tolerance was established on the use.

use of a pesticide for lawn care. EPA must also consider the increased susceptibility of infants and children or other sensitive subpopulations to pesticide risks and the cumulative effects from other substances with a "common mechanism of toxicity." EPA must review all residue tolerances of currently registered pesticides against this new standard by 2006, with priority given to pesticides that may pose the greatest risk to public health. The timetable specifies 33 percent by 1999, 66 percent by 2002, and the remainder by 2006. If risk of a pesticide exceeds the standard, EPA will reduce residue limits or revoke tolerances for uses of the pesticide until the standard is met. If a common mechanism of toxicity is identified for a group of pesticides, the cumulative risk of the group must meet the standard.

In 1997, EPA gave high priority to organophosphates for the FQPA tolerance review and is currently conducting risk assessments of these materials. EPA also gave high priority to carbamates and probable human carcinogens. Organophosphate pesticides are a health concern because they affect the enzyme (acetylcholinesterase) that controls the nervous system. Exposure to these materials can occur through inhalation, skin absorption, and ingestion; some organophosphates are prone to storage in fat tissues. The most common symptoms from overexposure are headaches, nausea, and dizziness. However, they can cause sensory and behavior disturbances, incoordination, and depressed motor function, and, at high concentrations, respiratory and pulmonary failure. The long-term effects of these chemicals, especially when exposure is during early growth and development, are not fully known. Of the nearly 1,800 organophosphate tolerances, over 300 are for foods among the top 20 consumed by children. EPA also has expressed concern that organophosphates exhibit a common mechanism of toxicity, which requires a cumulative assessment of risk. In 1996, AMS detected organophosphate pesticide residues on many of the fruit and vegetable samples; however, only three samples exceeded the established tolerance level for the commodity (see box, “Pesticide Residues in Food”). Presumptive violations occurred on 90 samples where no tolerance was established but an organophosphate residue was detected.

Farmers have used organophosphate pesticides for many years. Many are insecticides that kill a broad spectrum of insects and have a longer persistence than some alternatives. Due to their large area planted, corn, cotton, and wheat account for most of the crop acreage treated with organophosphate; one or more organophosphates were applied to 17 percent of corn, 57 percent of cotton, and 9 percent of wheat acres (table 4.3.11, hyperlink to .xls file). However, a high percentage of fruit and vegetable acreage is treated with these materials. In particular, 94 percent of apple, 90 percent of pear, 90 percent of tart cherry, and 81 percent of peach bearing acres were treated with at least one organophosphate pesticide. In addition, large proportions of broccoli (75 percent), lettuce (67 percent), snap bean (67 percent), tomato (55 percent), potato (52 percent), grape (18 percent), and orange (35 percent) acres were treated. Organophosphates were applied to nearly half the acreage of crops identified as most common in the diets of infants and children (apples, peaches, pears, carrots, sweet corn, snap beans, peas, and tomatoes).pesticides classified as probable carcinogens are used on more acreage than organophosphates, while carbamates are used on less. On field crops in 1997, one or more probable carcinogens were used on 88 percent of the potato, 30 percent of the corn, and 24 percent of the soybean acreage (table 4.3.11, hyperlink to .xls file). In 1996, one or more were used on over 50 percent of the watermelon, strawberry, carrot, celery, eggplant, head and other lettuce, onion, bell pepper, fresh-market cabbage, fresh-market sweet corn, fresh market cucumber, fresh market snap bean, and fresh-market and processing tomato acreage. In 1995, they were used on over 50 percent of the apple, apricot, blackberry, blueberry, nectarine, peach, pear, prune, raspberry, and tart cherry acreage. One or more carbamates were used on more than 50 percent of the potato, strawberry, eggplant, head lettuce, bell pepper, fresh market tomato, and nectarine acreage; and on more than 70 percent of the celery, fresh-market sweet corn, apple, blueberry, and lime acreage.

The tolerance review could result in tolerance revocation, and thus cancellation, for some or all currently registered uses of these pesticides. If so, growers will have to find alternative practices for the canceled uses. Depending upon their cost-effectiveness, the use of the alternatives could lower yields or increase costs per acre. In some cases, one or more organophosphates (or carbamates or probable carcinogens) will be among the alternative practices for another. For some crops treated with these pesticides, grower returns could decline, production and acreage could decrease, and prices increase. In some cases, exports might decrease or imports increase. While they account for a small portion of total pesticide use, several fruit and vegetable crops are particularly vulnerable to large economic impacts.

A number of regulatory actions occurred as the tolerance review proceeded. In August 1999, the registrants of azinphos methyl and methyl parathion, both of which are organophosphates, took voluntary actions to reduce children’s dietary, worker safety, and ecological risks.

Important Regulatory Actions

EPA has taken a number of important regulatory actions against agricultural pesticides, while other are still pending (table 4.3.12). In 1994, EPA initiated a special review of triazine herbicides (atrazine, cyanazine, and simazine). In 1995, the manufacturer of cyanazine voluntarily withdrew its registration rather than proceed with the special review. Cyanazine, which is identified as a carcinogenic material, was the third most used erbicide on corn and cotton and was also commonly used on sorghum and other crops to control grasses and broadleaf weeds. The manufacturer agreed to stop selling products containing cyanazine by 1999.

In 1993, regulatory action was taken for methyl bromide under the Clean Air Act because of its adverse effect on the ozone layer in the upper atmosphere. Under that action, production and importation were to be terminated in 2001. However, the Clean Air Act was amended in October 1998 to extend the phaseout until 2005 and allow exemptions for quarantine, preshipment, and critical uses.

Pesticide Registration Costs

The EPA registration process requires manufacturers to provide scientific data to substantiate that a proposed product is safe and poses no unreasonable adverse effects to human health or the environment. Test pertaining to toxicology, reproduction disorders and abnormalities, and potential for tumors from exposure to the pesticide are required. Other required tests evaluate the effect of pesticides on aquatic systems and wildlife, farmworker health, and the environment. Registration can require up to 70 types of tests to substantiate the safety of the product.

All of these regulatory requirements affect the development time and cost of pesticide production. Ollinger and Fernandez-Cornejo (1995) estimated that the research and development of a new pesticide averages 11 years and can cost manufacturers between $50 and $70 million. They found that regulation encourages the development of less toxic pesticide materials but discourages new chemical registrations, encourages firms to abandon pesticide registrations for minor crops, and favors large firms over smaller ones. They also said that regulation encourages firms to develop biological pesticides as an alternative to chemical pesticides.

Regulatory Streamlining for Reduced-Risk Pesticides

The EPA has facilitated the development of biological pesticides by establishing a tier approval system in which, under some circumstances, several tests are waived. These reduced regulation costs have helped lower the development costs of biopesticides, which are estimated at around $5 million per product (Ollinger and Fernandez-Cornejo, 1995). Biological pesticides include microbial pesticides, plant pesticides, and biochemical pesticides. In 1997, the average time to register a biological pesticide was 11 months, compared to 38 months for a conventional pesticide.

Conventional pesticides can be classified as reduced-risk by having low impact on human health, low toxicity to nontarget organisms, low potential for groundwater contamination, lower use rates, low pest resistance potential, compatibility with IPM, or the potential to displace pesticides with human health concerns. The average time to register a reduced-risk pesticide (other than biological pesticides) is 14 months. EPA reports that it has registered between 13 and 19 reduced-risk pesticides per year from 1994 to 1998.

The EPA has also facilitated the use of minimum-risk pesticides by establishing a process for exemption from costly FIFRA requirements. Thirty-one substances deemed to pose insignificant risks to human health and the environment have recently been deregulated (see box, "Deregulated Minimum-Risk Pesticides"). EPA considered whether the substances were common foods, had nontoxic modes of action, were recognized by FDA as safe, and scientific evidence showed no significant adverse effects or persistence in the environment.

Table 4.3.12--EPA regulatory actions and special review status on selected pesticides used in field crops production, 1972 - October 1998

Pesticide	Regulatory action and date
Alachlor	Uses restricted and label warning, 1987; concerns about groundwater contamination to be addressed by State management plans.
Aldicarb	Use canceled on bananas, posing dietary risk, 1992. Use on potatoes allowed after new application techniques showed lower residues, 1995.
Aldrin	All uses canceled except for termite control, 1972.
Captafol	All uses canceled, 1987.
Chlordimeform	All uses canceled, 1988. Use of existing inventory until 1989.
Cyanazine	Manufacturers voluntarily phasing out production by 2000, but stock can be used until 2003.
DDT	All uses canceled except control of vector diseases, health quarantine, and body lice, 1972.
Diazinon	All use on golf course and sod farms canceled, 1990.
Dimethoate	Dust formulation denied and label changed, 1981.
Dinoseb	All uses canceled, 1989.
EBDC (Mancozeb, Maneb, Metiram, Nabam, Zineb)	Protective clothing and wildlife hazard warning, 1982; food uses of nabam canceled in 1989; 8 uses canceled and 45 retained, 1992.
EDB	All uses terminated except vault fumigation and quarantine fumigation of nursery stock, 1989.
Endrin	All uses canceled, 1985.
EPN	All uses canceled, 1987.
Ethalfluralin	Benefits exceeded risks, additional data required, 1985.
Heptachlor	All uses canceled except homeowner termite product, 1988.
Methyl Bromide	Annual production and importation limited to 1991 levels and then terminated in 2001, 1993. Clean Air Act amended to extend the phaseout until 2005 and allow exemptions for quarantine, preshipment, and critical uses, 1998.
Mevinphos	Voluntary cancellation of all uses, 1994.
Monocrotophos	All uses canceled, 1988.
Parathion	Use on field crops only, 1991; under EPA review with toxicological data requested.
Propargite	Registered use for 10 crops canceled, 1996. Use for other crops remains legal.
Toxaphene	Most uses canceled except emergency use for corn, cotton, and small grains for specific insect infestation, 1982.
Triazines (atrazine,simazine)	Under review because of concerns about carcinogenicity and ground- and surface-water contamination.
Trifluralin	Restrictions on product formulation, 1982.
2,4-D (2,4-DB, 2,4-DP)	Industry agreed to reduce exposure through label change and user education, 1992.
Methyl parathion	Voluntary cancellation of all fruit,some vegetable, and some non-food uses, 1999.
Azinphos methyl	Voluntary reduction of use on some fruit; cap on U.S. supply; cancellation of sugar cane use, cotton use east of Mississippi River, and ornomental and some tree uses, 1999.

Source: USDA, ERS, based on information in EPA, 1998.

Deregulated Minimum-Risk Pesticides

The following minimum-risk pesticides, mostly from common food substances, were exempted from costly Federal Insecticide, Fungicide, and Rodenticide Act requirements by the U.S. Environmental Protection Agency in a 1996 ruling: castor oil (U.S.P. or equivalent), cedar oil, cinnamon and cinnamon oil, citric acid, citronella and its oil, cloves and clove oil, corn gluten meal, corn oil, cottonseed oil, dried blood, eugenol, garlic and garlic oil, geraniol, geranium oil, lauryl sulfate, lemongrass oil, linseed oil, malic acid, mint and mint oil, peppermint and peppermint oil, 2-phenethyl propionate (2-phenylethyl propionate), potassium sorbate, putrescent whole egg solids, rosemary and rosemary oil, sesame and sesame oil, sodium chloride (common salt), sodium lauryl sulfate, soybean oil, thyme and thyme oil, white pepper, and zinc metal strips.
Source: EPA, 1996a.

Proponents felt that deregulation of these substances would particularly benefit small businesses and the organic industry and supported the expansion of this list in the future, while opponents were concerned about product effectiveness (U.S. EPA, 1996a).

New Pest Control Products and Technology

Each year, the EPA registers several new pesticides that producers may use on specified crops if the products offer improved pest control and are profitable. EPA reports registering between 22 and 31 new pesticides per year from 1994 to 1998, but not all are for food production. Acetochlor was granted conditional registration in 1994 as an herbicide for use on corn that would help reduce overall herbicide use. The registration allows automatic cancellation if the use of other herbicide products is not reduced or if acetochlor is found in ground water. In 1997, about 28 million pounds of the new product were applied to 24 percent of U.S. corn acreage (appendix table 4.3.2, hyperlink to .xls file). The reduced pounds of alternative herbicides (alachlor, metolachlor, atrazine, EPTC, butylate, and 2,4-D) more than offset the pounds of acetochlor.

Other pesticide products have significantly affected the quantity of total use. For example, imazethapyr, first registered for use on soybeans in 1989, has become the most widely used soybean herbicide in the United States. This herbicide, applied at less than 1 ounce per acre, often replaced trifluralin and other products, applied at rates many times higher.

Genetically Engineered Plants.

Genetic engineering to develop herbicide-tolerant varieties, plant pesticides, and other pest control products is augmenting traditional plant breeding. Seed and chemical companies have expanded research and development on plant biotechnology because of the increasing costs to develop chemical pesticides that meet human health and environmental regulations and are sufficiently toxic to kill target pests (Ollinger and Fernandez-Cornejo, 1995). Compared with traditional plant breeding, plant biotechnology reduces the time required to identify desirable traits. In addition, by inserting into the plant a gene that imparts some desirable properties, biotechnology allows a precise alteration of a plant's traits, facilitating the development of characteristics not possible through traditional plant breeding. This technology allows researchers to target a single plant trait, which decreases the number of unintended characteristics that may occur with traditional breeding techniques. The development of genetically modified plants takes about 6 years and costs about $10 million, while a chemical pesticide takes an average of 11 years at a cost of $50-$70 million (Ollinger and Fernandez-Cornejo, 1995).

A number of seed and chemical companies have been developing plant varieties with resistance to particular herbicides. Monsanto has developed a soybean variety that is not damaged by Monsanto's popular herbicide glyphosate (Roundup) and similar glyphosate-tolerant varieties are being developed for canola, cotton, corn, sugar beets, and rapeseed oil. Glufosinate ammonium-tolerant corn and bromoxynil-tolerant cotton are also available. This technology could provide growers with an incentive to use specific pesticides that are effective at lower application rates than other pesticides. In 1996, the use of herbicide-resistant hybrids or varieties was reported on 3 percent of corn, 7 percent of soybean, and 2 percent of cotton acreage (table 4.3.5). In 1997, the reported use increased to 4 percent of corn, 17 percent of soybean, and 11 percent of cotton acreage. By 1998, reported use increased to 18 percent of corn, 44 percent of soybean, and 26 percent of cotton acreage in surveyed States in 1998.

Concerns about this technology include the possibility of accelerated weed resistance, as well as the toxicity of the herbicide products for which the crop tolerance is developed. Danish scientists reported that the genes for herbicide resistance in transgenic oilseed rape had moved to field mustard, a wild relative, and that this weed demonstrated herbicide resistance (Kling, 1996).

In March 1995, the EPA approved, for the first time, a limited registration of genetically engineered plant pesticides to Ciba and Mycogen Plant Sciences, and in August 1995, granted conditional approval for full commercial use of a transgenic pesticide (Bt) to combat the European corn borer (EPA, 1995). Bt corn, cotton, and potato varieties are now marketed. This technology could reduce the need to apply conventional chemical insecticides for such pests as bollworm, tobacco budworm, pink bollworm and European cornborer. In 1996, Bt varieties were used on 15 percent of cotton acreage and 1 percent of corn and potato acreages (table 4.3.5). In 1997, use increased to 8 percent of corn acreage and 3 percent of potato acreage (and remained at 15 percent of cotton acreage). By 1998, use increased to 19 percent of corn acreage and 17 percent of cotton acreage in the surveyed States. Bt seed was planted on 35 percent of cotton acreage in the Mississippi Delta States, where a major portion of insecticide treatments is for bollworms and budworms.

However, some scientists are concerned that the plants do not produce sufficient levels of pesticides and that the pest survival rates will encourage pest resistance to Bt, including Bt sprays. This is especially a concern for the growing number of producers who rely on the foliar-applied Bt, and has led the EPA to approve the new pesticides conditional on the monitoring for pest resistance and the development of a management plan in case the insects become resistant. In addition, some scientists have raised concerns about the impact of Bt varieties on nontarget Lepidopteran insects, such as Monarch butterflies.

The techniques used for developing disease-resistant plants are similar to the immunization of humans by vaccines. Small amounts of plant viruses are inserted into the plants, which subsequently become immune to the diseases (Salquist, 1994). The plants are capable of passing this trait from generation to generation. For example, researchers have developed squash varieties that are naturally virus-resistant, thus preventing insect-borne viruses that can destroy up to 80 percent of the squash crop. A number of seed and chemical companies and several universities have been field-testing insect- and virus-resistant plants, developed with these genetic engineering techniques, for several major field crops and vegetables.

Consumer concern over pesticide use has prompted biotechnology firms to enter the genetically engineered plant market. As agricultural biotechnology products attain commercial success, some private investment funding may shift from the smaller pharmaceutical markets toward agricultural crop protection (Niebling, 1995).

On the other hand, consumer acceptance of the bioengineered Bt corn, Bt cotton, and other genetically engineered crops has not yet been demonstrated in major U.S. markets. Hoban (1998) found U.S. consumers willing to accept biotechnology in food products if they perceive benefits, such as better flavor or reduced pesticide use, and a low level of risk from the technology. He also said that consumers in some European countries are less willing to accept biotechnology in foods, as reflected by European Community resistance to importing "genetically altered" commodities from the U.S. These concerns could limit the marketability and adoption of genetically altered commodities.

The Animal and Plant Health Inspection Service (APHIS) regulates the importation, interstate movement, and environmental release of certain genetically engineered plants and microorganisms. As of November 30, 1997, APHIS had approved or acknowledged 876 field releases for insect-resistant varieties since 1987 (24 percent of the total field trials approved or acknowledged), 359 to test viral resistance (9.8 percent), 153 for fungal resistance (4.2 percent), and 1,058 field releases for herbicide tolerance (29 percent).

Alternative Pest Management Programs and Initiatives

Pest management systems in the future will reflect public and scientific concerns about the ecological and health impacts of chemical use. USDA, EPA, and other government agencies have initiated a number of programs to encourage biological and cultural pest management, and the agricultural industry has initiated voluntary measures to reduce pesticide use. USDA's integrated pest management (IPM) programs research and promote a combination of cultural, biological and pesticide efficiency tools. USDA's areawide pest management program implements IPM and biological approaches on an areawide basis. And a new grant program in USDA focuses exclusively on biologically based pest management. In addition, some of the research done in USDA's farming systems programs focuses on alternative pest management (see chapter 4.1 Production Management Overview).

IPM Research and Education.
On September 22, 1993, the EPA, USDA, and the Food and Drug Administration (FDA) presented joint testimony to Congress on a comprehensive interagency effort designed to reduce the pesticide risks associated with agriculture. The three goals of this effort are to (1) discourage the use of higher risk products, (2) provide incentives for the development and commercialization of safer products, and (3) encourage the use of alternative control methods that decrease the reliance on toxic and persistent chemicals (Browner and others, 1993). This joint testimony also expressed support for "a goal of developing and implementing IPM programs for 75 percent of total U.S. crop acreage" by the year 2000, ecosystem-based programs to reduce pesticide use, market-based incentives such as reduced-pesticide-use food labels, and other efforts to help reduce pesticide risks.

The first national study of biologically based IPM in the early 1990's sponsored by USDA and EPA, concluded that dozens of technical, institutional, regulatory, economic, and other constraints need addressing in order to achieve broader adoption (Zalom and Fry, 1992). Three constraints were identified for all commodity groups: (1) lack of funding and personnel to conduct site-specific research and demonstrations; (2) producer perception that IPM is riskier than conventional methods, more expensive, and not a shortrun solution; and (3) educational degree programs that are structured toward narrow expertise rather than broad knowledge of cropping systems (Glass, 1992)

The current IPM initiative in USDA attempts to address the funding constraint and the need for IPM demonstrations and highlights stakeholder involvement in priority setting for IPM research (Jacobsen, 1996). A number of IPM research projects have started to examine biocontrols and cultural practices for several commodities, especially those that may not have adequate pest management alternatives because of current or pending EPA regulatory actions or voluntary pesticide registration cancellations.

USDA-CSREES has programs to fund IPM research and extension in the Land Grant universities. A regional competitive grants program funds research to develop IPM systems and practices, including decision models, resistant cultivars, and biological and cultural practices to control pests and reduce pesticide use. The extension program supports IPM education and implementation in every State and also supports an IPM coordinator at each Land Grant university to develop and coordinate IPM research and extension programs. The Pest Management Alternatives Program was established in 1996 to fund projects to develop and demonstrate replacement technologies for pesticides under consideration for USEPA regulatory action and for which effective alternatives are not available. The program also funds projects to summarize production and pest control practices and alternatives for high priority pesticides for FQPA tolerance review.

The State Extension Service IPM programs are overseen by designated IPM coordinators, who focus on developing interdisciplinary pest management programs (Gray, 1995). Over half of U.S. farmers are using a minimum level of IPM -- including scouting for insect pests and applying insecticides when economic thresholds are reached (Vandeman and others, 1994) -- as opposed to preventative, calendar-based spraying. Economic and environmental studies have reported mixed results in terms of the impacts of IPM scouting and thresholds on pesticide use (Rajotte and others, 1987; Mullen, 1995; Ferguson and Yee, 1995; Fernandez-Cornejo, 1996).

Areawide Pest Management Systems

USDA is also implementing an areawide pest management approach -- through partnerships with growers, commodity groups, government agencies, and others -- to contain or suppress the population levels of major insect pests in agriculture over large definable areas, as opposed to on a farm-by-farm basis (Calkins and others, 1996). Biological and cultural methods are the focus of most of these areawide programs.

Some biological control tactics, such as sterile insect releases, are most effective if implemented on a large area that encompasses many farms (U.S. Congress, 1995). For example, corn rootworm is a highly mobile pest as an adult and more effectively managed over a large area. The areawide program seeks to provide more sustainable pest control, at costs competitive with insecticide-based programs, and to reduce the use of chemical insecticides in agriculture. One successful biologically based areawide program was launched against the screwworm, a major parasitic pest of livestock, pets, and humans. USDA began releasing sterile male screwworm flies into wild populations in the 1950's, and by the early 1980's the screwworm became the only pest successfully eradicated from the United States (U.S. Congress, 1995).

USDA currently has seven areawide projects in various stages of evaluation, pilot testing, and large area implementation (table 4.3.13). The oldest, the **Areawide Bollworm/Budworm Project** in Mississippi, was initiated in 1987. Under this project, serious insect pests of Delta crops, especially cotton, were managed successfully with natural insect pathogens in small field tests. The project went into a large-area testing phase with 215,000 acres in 1994 and 1995, expanded to 850,000 acres in 1998, and was completed in 1999. A competitive technology, transgenic insect-resistant cotton varieties, became widely available in 1998, and grower interest in the areawide insect pathogen technology declined.

A regional **Codling Moth Areawide Management Program** (CAMP) was started in 1995, and uses pheromone mating disruption to control the coddling moth, the primary insect pest of apples in California, Oregon, and Washington. CAMP is a cooperative effort between ARS and three Land-Grant universities, and it aims to reduce organophosphate insecticide use by 80 percent in these apple- and pear-producing States (Kogan, 1996). The coddling moth had grown resistant to the organophosphate insecticide, which required growers to triple applications of that chemical (Flint and Doane, 1996).

Pilot testing of the project began in 1995/96 on five sites in California and Washington and will continue on these sites until 2000; ecological and economic impacts are being monitored throughout this period. Initial results indicate substantial reductions in organophosphate use and a positive response from growers (Kogan, 1996).

One-year pilot tests are also being conducted on a number of sites in California, Oregon, and Washington. Growers participating in the 1997 and 1998 1-year pilot tests have overwhelmingly adopted this technology after the ARS/Land Grant university projects ended (table 4.3.14). In 1997, 170 growers with 4,683 acres in apple and pear production participated in 5 pilot tests, and 79 growers with 5,400 acres participated in 6 pilot tests in 1998. Crop size ranged from 6 acres per grower at the Manson, WA, site to 139 acres per grower at the Bench Road, WA, site.

An **areawide corn rootworm project** was started by ARS and Land Grant universities in 1996 to examine the use of attractants -- semiochemical baits with tiny amounts of insecticide -- to control this insect (Calkins and others, 1996). Pilot tests are being conducted in five 16-square-mile sites in Iowa, the Illinois and Indiana border, Kansas, South Dakota, and Texas. Over 150 growers are cooperating with the project at these sites. The sites are being monitored for adult corn rootworm insects, and populations are reduced by killing females before they can lay eggs. The proportion of corn acreage with rootworm populations high enough to require semiochemical treatments declined between 1997 and 1998 in four of the five sites.

The Federal Crop Insurance Corporation issued a crop insurance endorsement to cover any crop losses that might occur in testing sites, and a private-sector insurance company is exploring a policy that would cover growers who use this technology but are not at the test sites. Some private-sector adoption of this technology has occurred in Texas, where a group of growers has hired consultants to provide areawide implementation.

Carbaryl, a carbamate insecticide, is currently used in tiny amounts in the semiochemical products. ARS is evaluating several insecticides to replace carbaryl, including a microbial insecticide.

An **areawide leafy spurge project** was begun in 1997-98 by USDA's ARS and Animal and Plant Health Inspection Service, with a diverse group of Federal, State and local agencies. This is the first ARS areawide project to address a regional weed pest. Leafy spurge is an exotic noxious weed that has infested 5 million acres of land in 29 States, reducing rangeland productivity, plant diversity and wildlife habitat. The project targets the 21-million acre Little Missouri River drainage region, and four demonstration sites -- covering 62,000 acres in North Dakota, South Dakota, Montana and Wyoming -- have been set up to demonstrate ecologically based control to ranchers, parkland managers, and others.

Biological control is the foundation of the leafy spurge project, but multispecies grazing, herbicides, and other control strategies are being used in conjunction with biocontrol. Leafy spurge project personnel released 1.6 million brown and black flea grain insects because they beetles, the primary biocontrol agent, in 1998, and distributed 300,000 additional flea beetles to land owners and managers in the region. Various biocontrol and other research trials are underway, and baseline data are being collected.

ARS and Land Grant universities also started an **areawide project for stored wheat** in 1998. Areawide pest management is applicable for storedmove through the marketing system along with the grain. An areawide IPM approach, combining improved aeration, sanitation, and monitoring-based fumigation, was used in 13 elevators in Kansas and 15 elevators in Oklahoma in 1998. The project has developed insect sampling methods, and collected baseline data on insect densities and pest management costs and practices.

Biologically Based Pest Management

In 1997, USDA-CSREES developed a small Biologically Based Pest Management program under its National Research Initiative competitive grants program. The program is intended to complement IPM programs, and the research is expected to be quickly applicable. Research is conducted for the whole spectrum of crop pests, including weeds, insects, and disease. Biological control research areas include habitat conservation and enhancement, methods for mass production of biological control organisms, development of new agents, assessment of conventional and alternative pest management strategies, disease warning systems, and use of pheromones.

Several dozen projects have been funded under this program since 1997, and over half of these projects have had agricultural applications. An Iowa State University project has been developing a controlled release delivery system for pheromone mating disruptants and field-testing the system against corn and cranberry pests in Iowa and Wisconsin. Utah State University is experimenting with artificial food sources, such as sugar water, for wasps and other beneficial insects that eat crop pests. Other projects include the University of Minnesota's experiment with soil pathogens for suppressing potato scab and the University of Idaho's study on meadow hawkweed biocontrol. Issues related to biological control, such as the potential for gene flow between biocontrol agents modified using recombinant DNA methods and exotic pathogens, are also being researched in some of these projects.

USDA Incentive Payments

USDA's Environmental Quality Incentives Program (EQIP) provides assistance to eligible farmers and ranchers to address natural resource concerns on their lands in an environmentally beneficial and cost-effective manner. Under this program, cost-share payments may be made to implement one or more eligible structural or vegetative practices, such as animal waste management facilities or permanent wildlife habitat. Also, incentive payments can be made to implement one or more land management practices, including improved pest management. Needs and priorities are identified primarily by local work groups and at the State level.

In fiscal year 1997, pest management was one of the top conservation practices in EQIP contracts. Contracts for pest management, primarily scouting, were made on 1.2 million acres in fiscal 1997; following prescribed or improved grazing contracts on 2.8 million acres; and nutrient management contracts on 1.9 million acres. In fiscal year 1998, North Carolina and Indiana picked pesticide runoff as one of their top statewide natural resource concerns, and several local priority areas set pesticide reduction goals.

Voluntary Environmental Standards.

In addition to stronger pesticide regulations over the last decade, voluntary codes for environmental stewardship and responsible pesticide use in agriculture have begun to emerge. These codes are instituted by the private sector, enforced by firms themselves, use sanctions such as peer pressure for compliance, focus on life-cycle impacts, emphasize management systems, and let firms define their own performance standards. They can shift some of the environmental management costs to the private sector, expand a firm's environmental focus beyond the scope of regulation, help a firm integrate environmental and business objectives, and foster long-term changes in a firm's environmental consciousness (Nash and Ehrenfeld, 1996).

The Pesticide Environmental Stewardship Program (PESP) was initiated in 1992 by EPA, USDA, and FDA to facilitate this type of voluntary approach, inviting organizations that use pesticides or represent pesticide users to join as partners (U.S. EPA, 1996b). Partners agree to implement formal strategies to reduce the use and risk of pesticides and to report regularly on progress. By 1998, membership in this stewardship program had grown to 100 partners, including over 45 commodity groups across the country.

Only 15 of the partners to date, including 9 commodity groups, have completed the stewardship strategies that state how the partner will reduce risks from pesticides. Strategies included funding research for nonchemical practices, setting up demonstration sites, and supporting continued registration of conventional pesticides. While none of the commodity groups have set pesticide reduction goals in their strategies, a nonagricultural partner, the U.S. Department of Defense, set a goal in 1996 to reduce pesticide use by half by the end of fiscal year 2000.

The California Department of Agriculture has established a similar program, the IPM Innovators Program, to recognize leaders in voluntarily implementing systems that reduce pesticide risks (Brattesani and Elliott, 1996) and to inspire other groups that use pesticides to voluntarily adopt similar activities. Also, some States are examining the potential benefits of IPM certification, while Massachusetts is already operating a "Partners with Nature" program to recognize growers who follow a set of IPM certification guidelines (Van Zee, 1992).

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Pesticide Application Terminology

Amount of pesticide applied is the total pounds of all pesticide active ingredient (excluding carrier materials) applied. Because this sum can include materials with different toxicities applied at very different rates, differences in the amount applied do not necessarily represent differences in the intensity of the treatment or potential health and environmental risks.

Land receiving pesticides (acres treated) represents an area treated one or more times with a pesticide material. Pesticide materials include products used to kill weed, plant, and fungi pests, as well as products used as growth regulators, soil fumigants, desiccants, and harvest aids.

Number of acre-treatments applied represents total number of ingredient applications made throughout the growing season. A single treatment containing two ingredients is counted as 2 acre-treatments as is 2 treatments containing a single ingredient.

Number of ingredients applied represents the total number of different active ingredients applied throughout the growing season on a field. It does not reflect repeat applications of the same ingredient during the production year.

Number of treatments applied represents the number of application passes made over a field to apply pesticides. One or more pesticide materials may be applied with each treatment. This measurement reflects labor and use of pesticide application equipment.

Table 4.3.13--Implementation status of USDA's areawide pest management projects 1/			
Project and objectives	Methods	Pilot test sites	Preliminary results
Cotton Bollworm & Tobacco Budworm, Mississippi (Cotton) *Objective* -reduce insecticide use and area treated, maintain yields, and reduce pest populations	• Monitoring with pheromone traps • Insect virus (Gemstar) used on early-season weed hosts	1990-93: 0-64,000 acres 2/ 1994-95: 215,000 acres 1996: 25,000 acres 1997: 215,000 acres 1998: 850,000 acres 1999: *project completed* *Location:* Mississipi	• More than 70% of moths killed • Reduced insecticide use • Yields were maintained • Input and management costs were lowered
Corn Rootworm Midwestern U.S. and Texas (Corn, soybeans, & sorghum) *Objective* - reduce insecticide use and area treated, maintain yields, and reduce pest populations	• Monitoring • Semiochemical traps • Semiochemical bait (includes tiny amounts of carbaryl) • Semiochemical spray	1996-98 (ongoing): 5 sites *Location:* South Dakota, Iowa, Illinois/Indiana, Kansas, & Texas *Size:* 16 sq. miles/site	• 90% or more of the adults were killed • Natural enemies increased • Increased management costs offset by decreased input costs • Some private-sector adoption
Coddling Moth, Pacific Northwest (Apples, pears) *Objective* - reduce broad spectrum neurotoxic insecticide use and maintain yields	• Mating disruption • Resistant cultivars • Sanitation • Natural enemies • Early season Bt • Sterile males	1995-96 (ongoing): 5 sites 1997: 5 additional sites 1998: 6 additional sites 1999: 5 additional sites (planned) *Location:* California, Oregon, & Washington *Size:* Approximately 900 acres/site	• Late-season pesticide use declined • Natural enemies increased • Secondary pests declined • Fruit damage was below 0.1% economic threshold • 1st generation moths were reduced 80% • Some private-sector adoption
Leafy Spurge, Mountains & Northern Plains (Rangeland, pastureland, parkland) *Objective* - develop and transfer economical and ecological leafy spurge management technologies	• Mass releases of weed predators (insects) • Grazing • Revegetation • Herbicide decision aids	1997-98 (ongoing): 4 sites *Location:* North Dakota, Montana, South Dakota, & Wyoming *Size:* 15,500 acres/site	• Baseline data collection, including leafy spurge area, flea beetle densities, geo-referencing, and soil samples.
Stored grain Insects, Plains States (Stored wheat) *Objective* - increase the effectiveness and reduce the cost of pest management	• Early grain aeration/ cooling in elevators • Sanitation • Safe-storage period forecasting • Monitoring-based fumigation	1998-99 (ongoing): 28 elevators *Location:* Kansas and Oklahoma *Size:* pilot project elevators handle 31 million bushels of wheat from 800,000 acres of farmland	• Baseline data collection, including insect densities and pest management costs and practices

1/USDA's Agricultural Research Service (ARS) is administering these projects through partnerships with other Federal agencies, universities, commodity associations, and other stakeholder groups. 2/ Pilot test acreage varied due to changes in funding and experiment design, and testing was canceled one year because of severe flooding.

Source: USDA, ERS, based on Calkins et al., 1996; Kogan, 1994; and personal communication with Carrol Calkins, USDA-ARS, Yakima, Washington, Laurence Chandler, USDA-ARS, Brookings, South Dakota; James Coppedge, USDA-ARS, College Station, Texas, and Dick Hardee, USDA-ARS, Stoneville, Mississippi; Jerry Anderson, USDA-ARS, Sidney, MT; David Hapstrum, USDA- ARS, Manhattan, Kansas.

Table 4.3.14--Private-sector adoption of areawide biological control for codling moth 1/					
ARS/USDA 1-year test projects	Commodity	Acres	Growers	Average acres / grower	Post-project grower adoption rate
	----------------Number-------------				Percent
1997 sites:					
Ukiah, CA	Pears	550	9	61	100
Brewster, WA	Apples	2,297	48	48	100
Manson, WA	Apples	410	71	6	100
Progressive Flat, WA	Apples	603	25	24	100
West Wapato, WA	Apples & pears	823	17	48	50
Total		4,683	170	28	95
1998 sites:					
Roges Mesa, CO	Apples	600	17	35	100
South Shore, WA	Apples	650	11	59	100
East Wenatchee,WA	Apples	500	12	42	100
Babcock Ridge, WA	Apples	700	7	100	100
Bench Road, WA	Apples & pears	1,250	9	139	100
Elephant Mt., WA	Apples & pears	1,700	23	74	100
Total		5,400	79	68	100

1/ USDA's Agricultural Research Service (ARS) is administering these projects through partnerships with other Federal agencies, universities, commodity associations, and other stakeholder groups. The post-project adoption rate reflects the number of growers who are using private-sector consultants to implement the areawide technology after the 1-year ARS pilot test is over.

Source: USDA, ERS, based on personal communication with Carrol Calkins, USDA-ARS, Yakima, WA.

Recent ERS Research on Pest Management Issues

"U.S. Organic Agriculture Gaining Ground" ***Agricultural Outlook,*** **AGO-270, April, 2000. (Catherine Greene). U.S.-certified organic cropland more than doubled during the 1990's, and eggs and dairy grew even faster. Markets for organic vegetables, fruits, and herbs have been developing for decades in the U.S., and organic grain and livestock markets are emerging. Under USDA's new proposal for regulating organic production and handling, purchasers of organic foods would be able to rely on uniform national standards for defining the term "organic."**

Pest Management in U.S. Agriculture. Agricultural Handbook Number 717, Aug .1999. (Jorge Fernandez-Cornejo, and Sharon Jans). The report describes the use of pest management practices, including integrated pest management (IPM), for major field crops and selected fruits and vegetables. The data came chiefly from the 1996 ERS/NASS Agricultural Resource Management Study (ARMS). Because different pest classes may dominate among different crops and regions, requiring different pest management techniques to control them, the extent of adoption of pest management practices varies widely. For example, insects are a major pest class in cotton production, while minor for soybeans. As insect management has a wider variety of nonchemical techniques than weed control, cotton growers are expected to be further ahead on the IPM continuum than soybean producers.

Production Practices for Major Crops in U.S. Agriculture, 1990-97. Statistical Bulletin 969, (Merritt Padgitt, Doris Newton, and Carmen Sandretto). The bulletin presents information on nutrient and pest management practices, crop residue management, and other general cropping practices in use on U.S. farms. It illustrates recent trends in chemical use in crop production, including the use of leading organophosphate and other pesticides. It also reports the use of cultural practices, such as scouting, soil and tissue testing, protection of beneficial organisms, and other pest management practices that often complement (or substitute for) the use of chemicals. Information about crop rotations, cover crops, and crop residue management practices that affect the intensity at which chemical inputs are applied or their potential movement through the environment is also reported.

"Sunk Costs and Regulation in the U.S. Pesticide Industry," ***International Journal of Industrial Organization*****, 16 (1998): 139-68. (M. Ollinger and J. Fernandez-Cornejo). This paper examines the impact of sunk costs and market demand on the number of innovative companies, the U.S. share of foreign-based firms, and merger choice in the U.S. Pesticide Industry. Results are consistent with Sutton's 1991 view of sunk costs and market structure in that rising endogenous sunk research costs, exogenous sunk pesticide regulation costs, and declining demand negatively affect the number of firms in the industry, have a stronger negative effect on the number of small firms, and encourage foreign-based firm expansion.**

"Environmental and Economic Consequences of Technology Adoption: IPM in Viticulture," ***Agricultural Economics*****, 18 (1998): 145-55 (J. Fernandez-Cornejo). The impact of integrated pest management (IPM) on pesticide use, toxicity and other environmental characteristics, yields, and farm profits is examined for grape growers. The method is generally applicable for technology adoption and accounts for self-selectivity, simultaneity, and theoretical consistency. IPM adopters apply significantly less insecticides and fungicides than nonadopters among grape producers in six states, accounting for most of the U.S. production. Both the average toxicity and the Environmental Impact Quotient decrease slightly with adoption of insect IPM, but remain about the same for adopters and nonadopters of IPM for diseases. The effect of IPM adoption on yields and variable profits is positive but only significant for the case of IPM for diseases, i.e., the adoption of IPM for diseases increases yields and profits significantly.**

"Innovation and Regulation in the Pesticide Industry," ***Agricultural and Resource Economics Review*****. 27 (1)(1998): 15-27. (M. Ollinger and J. Fernandez-Cornejo). This paper examines the impact of pesticide regulation on the number of new pesticide registrations and toxicity. Results suggest that regulation adversely affects new pesticide introductions but encourages the development of pesticides with fewer toxic side effects. The estimated regression model implies that a 10 percent increase in regulatory costs (about $1.5 million per pesticide) causes a 5 percent reduction in the number of pesticides with higher toxicity.**

Continued…

"Organic Vegetable Production in the U.S.: Certified Growers and their Practices," *American Journal of Alternative Agriculture*. 13 (2)(1998): 69-78, (J. Fernandez-Cornejo, C. Greene, R. Penn, and D. Newton). Organic farming systems differ fundamentally from conventional ones in their primary focus on management practices that promote and enhance ecological harmony. Organic farmers also tend to have a different socioeconomic profile. In this study, we summarize average socioeconomic characteristics and production practices of a national sample of about 300 certified organic vegetable growers from 14 states are then compared to a large sample of about 6,900 conventional vegetable growers. The specific materials used by organic growers for pest and nutrient management are also examined.

"Phasing Out Registered Pesticide Uses as an Alternative to Total Bans: A Case Study of Methyl Bromide," *Journal of Agribusiness*, Vol. 15, No. 1, 1997. (Walt Ferguson, Jet Yee) This article examines how a phase-out strategy, in place of an immediate ban on all crops, would affect consumers and producers and still achieve much of the human health and environmental benefits of an immediate and total ban.

Proceedings of the Third National IPM Symposium/Workshop: Broadening Support for 21st Century IPM, Miscellaneous Publication Number 1542, May 1997, (Sarah Lynch, Cathy Greene, and Carol Kramer-LeBlanc, editors). IPM program assessment was a major focus of the interdisciplinary IPM symposium/workshop held last winter in Washington DC. Several papers in this proceedings explore ways to incorporate the economic, environmental, and public health impacts of IPM programs into research and extension activities.

Organic Fruit Growers Survey, *AREI Updates*, No. 4, June 1997, (J. Fernandez-Cornejo, R. Penn, and D. Newton). This report presents selected pest and nutrient management practices used by these growers, as well as socioeconomic statistics describing the growers. About 190 certified organic fruit producers from 10 major fruit-producing states were surveyed in 1995. Most had become certified in the last 10 years. The majority of organic growers had at least some college education and 60 percent of the organic growers (and 63 percent of their spouses) worked entirely on the farm. Most of the surveyed organic growers scouted their fields and used mechanical tillage for weed control. Other important production practices included using composted manure and plant materials and planting legumes to increase available soil nitrogen.

Pest Management on Major Field Crops, *AREI Updates,* No. 1, February 1997 (Merritt Padgitt). This report breaks out the use of herbicides and insecticides on major field crops (corn, soybeans, winter wheat, cotton, and potatoes) in 1995 by the various tillage systems, crop rotations, plant densities, row sizes, and number of cultivations that were used in producing these crops.

"The Microeconomic Impact of IPM Adoption," *Agricultural and Resource Economics Review*, 25 (2) (1996): 149-60, (Jorge Fernandez-Cornejo). This report develops a methodology to calculate the impact of integrated pest management (IPM) on pesticide use, yields, and farm profits. While the methodology in this case study is applied to IPM adoption among fresh market tomato producers for insect and disease management, the method is of general applicability. It accounts for "self-selectivity" (IPM adopters may be better farm managers or differ systematically from nonadopters in some other way) and simultaneity -- farmers' IPM adoption decisions and pesticide use may be simultaneous -- and the pesticide demand and yield equations are theoretically consistent with a profit function. In this study, IPM was defined operationally as the use of scouting and thresholds for making insecticide and fungicide applications and the use of one or more additional IPM techniques for managing pests.

"The Diffusion of IPM Techniques by Vegetable Growers," *Journal of Sustainable Agriculture*, 7 (4)(1996): 71-102. (Jorge Fernandez-Cornejo and Alan Kackmeister). This study examines the adoption/diffusion paths of various integrated pest management (IPM) techniques among vegetable growers in 15 states, as well as grower education, regional research levels, and other factors that influence adoption. The authors concluded that the IPM techniques examined would reach 75 percent adoption between 2008 and 2036, except for scouting, which attains the 75 percent level during the 1990's.
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