Production Practices for Major Crops in U.S. Agriculture, 1990-97. By Merritt Padgitt, Doris Newton, Renata Penn, and Carmen Sandretto. Resource Economics Division, Economic Research Service, U.S. Department of Agriculture. Statistical Bulletin No. 969.

Abstract

This report presents information on nutrient and pest management practices, crop residue management, and other general crop management practices in use on U.S. farms. The public has expressed concerns about the possible undesirable effects of contemporary agricultural practices on human health and natural resources. Partly as a response to these concerns, the U.S. Department of Agriculture began collecting information from farmers on their agricultural production practices in 1964. In 1990, through the President's Water Quality Initiative, the USDA expanded its data collection efforts. The information presented in this report is largely for the 1990's. Although the information cannot contribute to the science underlying the debate about the effects of agriculture on human health and environmental risk, it can provide information on the use of relevant inputs and production practices that are likely to abate, or to exacerbate, undesirable effects.

Keywords: Crop rotation, nutrient management, pest management, pesticide use, tillage systems.

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Contents

Highlights

This report presents information on nutrient and pest management practices, crop residue management, and other general crop management practices in use on U.S. farms. Farmers are the primary decisionmakers on how they combine their production resources and management skills to produce food and fiber. Changes in farmer practices over time, but especially since the end of World War II, have greatly increased agricultural productivity. However, the public has expressed concerns about the possible undesirable effects of contemporary agricultural practices that rely heavily on commercial fertilizers and chemical pesticides. Partly as a response to these concerns, the U.S. Department of Agriculture (USDA) began collecting information from farmers on their chemical inputs and agricultural production practices in 1964. In 1990, through the President's Water Quality Initiative, the USDA expanded its data collection efforts. The information presented in this report is largely for the 1990's. Although the information cannot contribute to the science underlying the debate about the effects of agriculture on human health and environmental risk, it can provide information on the use of relevant inputs and production practices that are likely to abate, or to exacerbate, undesirable effects.

Nutrient Management

In the 1996 National Water Quality Inventory, the U.S. Environmental Protection Agency reported that agriculture ranks first as the leading source of water quality problems for lakes and rivers and ranks fifth for contributing to the degradation of estuaries. More than 20 million tons of commercial fertilizer nutrients are used in the United States annually, and most of it is applied to agricultural land. Different nutrient management practices can affect both the quantity of commercial fertilizer needed for crop production and any potential movement of applied nutrients by leaching, runoff, or volatilization. The USDA survey findings about nutrient management practices are highlighted below:

- Three-fourths of the cropland acres represented by the surveys were treated with commercial fertilizers (the surveys represented approximately 60 percent of U.S. cropland used for crops). Nitrogen, the most widely used nutrient, was applied to 71 percent of the area and accounted for half of the total quantity of all primary nutrients applied. Phosphate was applied to 60 percent of the area and potash to 44 percent.
- Corn, with 99 percent of its planted area treated, accounted for 45 percent of the total area of the surveyed crops receiving fertilizer. The average application rate across all corn acres receiving nitrogen fertilizer was 132 pounds per acre. Vegetable crops and potatoes had the most intensive use of nitrogen fertilizer. Although average application rates for vegetables and potatoes often exceeded 200 pounds per acre, the nitrogen applied to these crops accounted for only 1 percent of the total use of nitrogen.
- Nutrient application rates vary widely among fields planted to the same crop depending on yield expectations and growing conditions. For corn, the lowest 20 percent of the acreage (14 million acres) received nitrogen applications of 80 pounds or less per acre while the highest 20 percent received applications of more than 180 pounds per acre.
- Timing fertilizer applications to coincide with the crop's biological nutrient needs or to reduce potential nutrient losses from leaching, runoff, or volatilization can reduce seasonal application rates. About three-fourths of the nitrogen fertilizer was applied before or at planting time. About 28 percent of all nitrogen was applied in the fall, and most of that was for crops to be planted in the following spring. The fall applications reduce peak spring labor demands when weather can limit available working days, but fall-applied nitrogen has a greater potential for loss.
- Laboratory tests of soil samples can help farmers determine their need for commercial fertilizers. Soil tests were conducted for about one-fifth of the represented cropland. The practice was most common on land planted to fruits, vegetables, and cotton. About half of the corn acreage having soil tests included a test for nitrogen.
- Livestock manure is a source of plant nutrients, but its use is mostly limited to farms that have both crop and livestock enterprises. About 8 percent of the represented cropland, mostly planted to corn, had manure applied. The manure was analyzed for its nutrient content on about 10 percent of the area receiving manure.

Pest Management

The use of pest-resistant crops as well as various kinds of cultural practices can reduce farmers' reliance on pesticides. About 900 million pounds of pesticides are used annually by U.S. agriculture to control weeds, insects, diseases, and other pests. Their use has raised concerns about their potential risk to human health and the possible environmental impacts on wildlife species and their habitats. The survey findings about pest management practices are highlighted below:

- Pest management on most cropland includes both cultural practices and the use of pesticides. At least some pesticides—herbicides, insecticides, fungicides, growth regulators, defoliants, or desiccants—were applied to 90 percent of the represented cropland.
- Corn, with 98 percent of the area treated with some pesticide, accounted for 39 percent of the total pounds of pes-

ticides applied to all surveyed commodities. All but 7 percent of the quantity applied to corn was for weed control.

- Cotton farmers were the largest users of insecticides. Representing only 7 percent of the surveyed commodity area, cotton accounted for 32 percent of the total pounds of insecticides.
- Fruits, vegetables, and potatoes accounted for 98 percent of all pesticides applied to control diseases (fungicides).
- Between 1990 and 1997, planted crop area and total pounds of pesticides applied remained relatively unchanged. However, the share of acres treated with pesticides increased as did the number of treatments applied per acre. The amount of pesticide applied with each treatment declined with the adoption of products applied at ultra-low rates, band treatments, and reduction in the application rates for some ingredients.
- The boll weevil and boll worm were the leading target pests for cotton insecticide treatments, while corn rootworm and corn borers were the leading target pests for corn insecticide treatments. Bt-transgenic corn and cotton seeds, crop rotations, and other pest management practices are used to reduce the reliance on pesticides to control these major pests.
- Pest-monitoring practices include field scouting, soil and plant tissue testing, traps baited with attractants, and field mapping for weeds. Nearly 80 percent of the surveyed crop acres were scouted; pheromone traps were used on nearly one-fourth of the cotton, fruit, and vegetable acres, and weed mapping was used on about one-fifth of the field crop acres. Soil and tissue testing for pests was used on about 4 percent of the surveyed crop acres. Pest monitoring was prevalent on crops receiving the most intensive treatments with insecticides and fungicides.
- Many insecticide application decisions are made by comparing the insect infestation level to a calculated threshold where the economic losses, if left untreated, are expected to exceed the cost of treatment (economic threshold). For nearly 45 percent of the surveyed crop acres receiving insecticides, a threshold concept was used to make the treatment decision. For most of the remaining acreage, treatment decisions were based on historic information or preventive schedules.
- Pest preventive practices, such as crop rotation, planting disease-resistant seeds/rootstocks, or adjusting planting dates to avoid certain pests, were widely applied. Over 80 percent of the row crop acreage (corn, soybeans, cotton, and potatoes) was in some type of crop rotation, and half of the represented acreage used resistant varieties/rootstocks and about 35 percent adjusted planting dates.

Crop Rotation

Crop rotation is used to reduce soil erosion, increase soil productivity, break pest cycles, and reduce the development of pesticide-resistant pests. The survey findings about the use of crop rotations are highlighted below:

- Eighty-two percent of the represented acreage of major field crops (corn, soybeans, wheat, and cotton) was in a crop rotation. Cotton was the only field crop where the same crop was planted for at least 3 consecutive years (monoculture) on a large share of the acres. A monoculture system was used on 60 percent of the land planted to cotton.
- About three-fourths of the wheat acres were in a crop rotation. A wheat-fallow system is commonly used in the Northwestern growing regions. The monoculture system for growing wheat was most common in the Southern Plains.
- About 85 percent of the corn acreage was in a crop rotation. Until the recent development of resistant species, rotating corn with just about any other crop prevented damaging infestations by corn rootworm—the major target pest for corn insecticide treatments. Continuous corn production was most common in Nebraska and Kansas, States where corn rootworm treatments were most prevalent.
- Rotations that include hay, meadow, or pasture provide protection against soil erosion, and those that include a legume crop can reduce nitrogen fertilizer needs. Only about 3 percent of the surveyed crop area had a meadow or pasture crop in either of the preceding 2 years.

Crop Residue Management

Crop residue management (CRM) systems use fewer and/or less intensive tillage operations, often combined with cover crops and other conservation practices, to provide sufficient residue cover to help protect soil from wind and water erosion. CRM is generally a cost-effective method of erosion control (requiring fewer resources than intensive structural measures such as terraces) that can be implemented in a timely manner to meet conservation requirements and environmental goals. Decreasing the intensity of tillage or reducing the number of operations with CRM can potentially result in cost savings to farmers through reduced fuel, labor, machinery, and time requirements. However, any potential cost savings may be offset somewhat by increases in chemical costs, depending on the herbicides selected for weed control and the fertilizers required to attain optimal yields. Surveys conducted by the Conservation Technology Information Center and USDA's surveys of field crops found that:

- Conservation tillage (no-till, ridge-till, and mulch-till) was used on almost 110 million acres in 1997, more than

37 percent of U.S. planted cropland area. Most of the growth in conservation tillage since 1990 came from expanded no-till and a concurrent decline in conventional tillage.

- Conservation tillage was used mainly on corn, soybeans, small grains, and sorghum in 1997. More than 47 percent of the total acreage planted to corn and soybeans was conservation-tilled. Expanded use of no-till has been significant on all major crops since 1990, but no-till use continues to be greater for corn and soybeans than for small grains or sorghum.

- Cultivation of row crops is primarily used to kill weeds and thereby reduce the need for herbicide treatments, but cultivations are also used to shape the surface for furrow irrigation or to maintain ridges in ridge-till systems. Nearly two-thirds of the corn area, 40 percent of the soybeans, and nearly all cotton received at least one cultivation. Fields receiving three or more cultivations used less herbicide for weed control than fields receiving fewer or no cultivations.

Production Practices for Major Crops in U.S. Agriculture, 1990-97

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Introduction

Changes in U.S. farming practices since the end of World War II have brought large increases in agricultural productivity. However, soil erosion, sedimentation in streams and reservoirs, pollution of surface waters, contamination of ground water, and degradation of wildlife habitats have, at least partially, been attributed to the use of agricultural chemicals and changes in crop production practices [NRC, 1989]. The potential exposure to agricultural chemicals poses a health risk to farmers and farmworkers [Litovitz, Schmitz, Bailey, 1990; Ciesielski, Looms, Miss, and Amer, 1994], while the possibility of chemical residues in drinking water or food is a concern of consumers [Alavanja, Blair, McMaster, and Sandler, 1996; van Ravenswaay, 1995; Buzby and Skees, 1994; Collins, 1992; NRC, 1993]. Farmers are the primary decisionmakers on how they combine their production resources and management skills to produce food and fiber, but increasingly they face pressures to use production systems that are friendlier to the environment and pose fewer potential health risks.

This bulletin reports the results of farm commodity surveys conducted between 1990 and 1997 by USDA. The surveys provide information on chemical inputs in agriculture and the use of farming practices that may affect the intensity with which fertilizers and pesticides are used or their potential cost to the environment. How agricultural chemicals and practices ultimately affect human health or the environment is a complex process and requires research beyond the scope of this report. Data in this report, however, can help answer questions about how intensively agricultural chemicals are used and what practices are used that may abate (or exacerbate) undesirable effects. Besides supporting research on such environmental and social issues, the data can also help private industry to assess potential markets for biotechnology or other production inputs that may offer both environmental and health benefits.

Historical Trends in Farming Practices

Farming practices have evolved considerably throughout U.S. history. In the last 200 years, U.S. farming technology has evolved from an individual, labor-intensive process into a capital-intensive and highly skilled but labor-efficient one. Changes in mechanical, chemical, and biological technologies are often cited as responsible for the changes in agricultural production practices. Each period has brought new technologies and practices that have unleashed large gains in agricultural productivity, but sometimes at the cost of increased stresses on natural resources.

In the precolonial and colonial periods, agriculture was labor-intensive and conducted with crude tools and limited use of draft animals [Edwards, 1940]. Labor was scarce and new land was plentiful, so farmers made little effort to protect their soil from erosion or to replenish soil nutrients. The moldboard plow became widely used to till the soil and prepare weed-free seedbeds for good early plant growth. The practice, however, disturbed the soil structure and removed vegetative cover, leaving the land more susceptible to soil erosion and a potential source of water quality problems.

The mechanical revolution (mid-1800's to the beginning of World War II) brought rapid changes in farm power sources, farm implements, and transportation [Hambidge, 1940]. Tractors replaced draft animals, and many other labor-saving machines allowed farmers to farm more land with less labor. Improved transportation and storage allowed farm products to be transported longer distances to growing markets. Mechanized agriculture allowed more intensive use of cropland and often brought more fragile land into production that had greater potential for soil erosion. The stress on the land and the need for natural resource protection became apparent from abandoned cropland, gullies dissecting fields, the high volume of silt in streams and rivers, and the 1930's "dust bowls" [Bennett, 1939]. Voluntarily, either at their own expense or with Federal subsidies, many farmers adopted contour and strip farming practices, installed terraces and grassed waterways, or used crop rotations and other means to protect their land [Parks, 1952].

Advances in chemical manufacturing following World War II introduced many new products to agriculture to supplement soil nutrients and to control pests [NRC, 1989; Blackman, 1997]. High-analysis chemical fertilizers such as super phosphate, urea, and anhydrous ammonia came to be substituted for manure, bloodmeal, and other organic materials previously used to supply plant nutrients. Commercial fertilizers restored nutrient-deficient soils and gave farmers the option for continued intensive production of crops. Synthetic pesticides greatly expanded pest management options and crop production choices. The ability to chemically control weeds significantly reduced the need for capital- and labor-intensive tillage methods and allowed farmers to further expand the size of their operations. Reducing the risk of damages from insects or disease with pesticides also helped to stabilize yields and prices. Pesticides that stimulated uniform growth patterns, defoliated plants, or caused simultaneous fruit ripening made machine harvesting feasible or more efficient and replaced agricultural laborers.

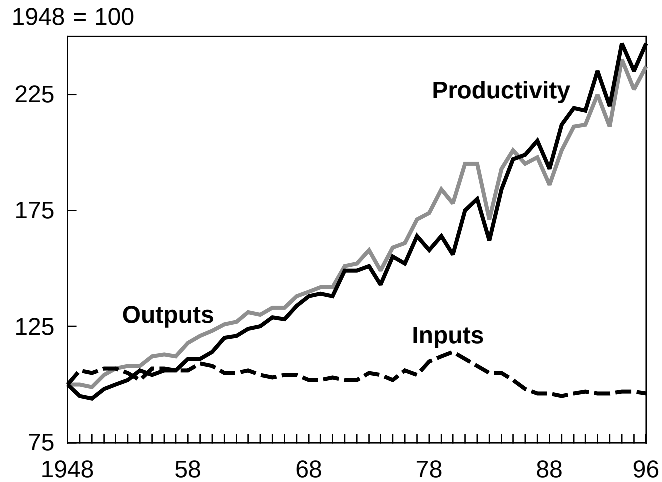
Other major innovations during this period included improvements in plant breeding and genetics. New seeds that were higher yielding, superior in grain quality, resistant to diseases, tolerant of a wide range of weather conditions, or uniform in size and maturity contributed to increased productivity [Gresshoff, 1997]. With these improvements came the need for additional fertilizer to support the higher yields. Genetic engineering, which develops seeds that can produce their own toxins against insect pests or that are resistant to the application of broad-based herbicides, now provides farmers with additional options for pest control that may lead to changes in pesticide use.

Growth in Productivity, Output, and Inputs, 1948-96

The effect of agricultural technologies is reflected in the indicators of growth in agricultural productivity (fig. 1A). Agricultural productivity is measured by comparing total outputs to total inputs in the agricultural sector for a given period. Productivity grows when real output increases faster than the growth in the use of combined inputs. Agricultural productivity rose more than 230 percent between 1948 and 1996, an annual rate of 1.9 percent [Ahearn, Yee, Ball, and Nehring, 1998]. The input indicator, an aggregate measure of all inputs, fell during this period, largely as a result of declines in labor input. The declines in labor use were offset by increases in other inputs such as farm machinery, improved seeds, fertilizers, and pesticides.

Figure 1A

Growth in productivity, outputs, and inputs, 1948-96



Source: Ahearn, Yee, Ball, and Nehring, 1998

Trends in Use of Fertilizer and Pesticide

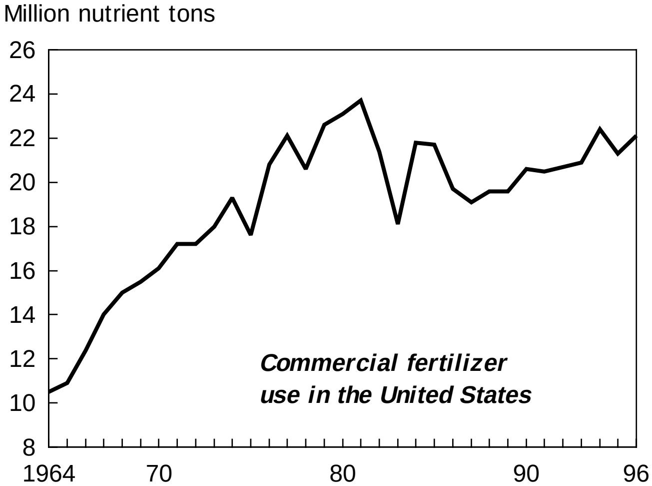
While the aggregate of all inputs in agriculture has dropped, the use of chemicals has increased (fig. 1B). The quantity of active ingredients in both nutrients and pesticides showed a continuous upward trend until the early 1980's. During this time, fertilizers and pesticides were applied to more acres, and application rates increased. Since about 1982, total agricultural chemical use has varied, mainly with changes in planted acreage, government set-aside requirements, weather, and levels of pest infestation.

Pesticide use, as conventionally reported in pounds of active ingredients, does not account for the many changes in pesticide products over the last several decades. Many newer products are more selective in the pests they control and less persistent in the environment. Newer products are frequently applied at lower application rates with equal or improved efficacy. When adjustments were made for such changes in quality and potency over time, the upward trend in the pesticide indicator continued after 1982 [Ahearn, Yee, Ball, and Nehring, 1998].

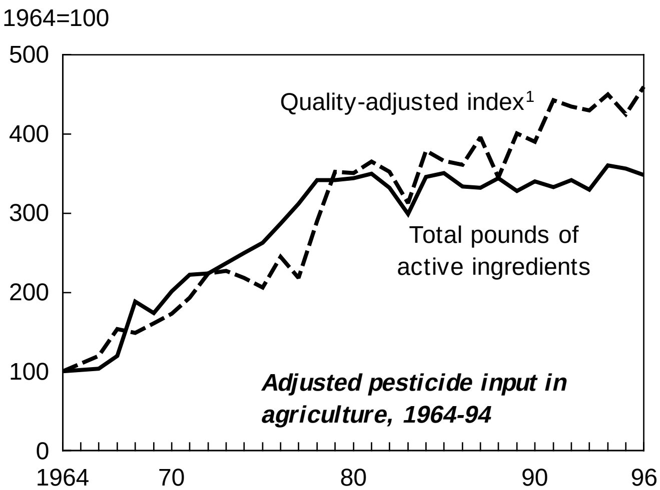
Environmental Effects from Agricultural Production

Agriculture affects the environment through many complex physical/biological relationships, not all of which are fully understood. The physical attributes, application methods, episodic weather events, and timing of chemical inputs along with soil and water management practices can have a major effect on the transport and risk exposure of agricultural chemicals to humans or wildlife species.

Figure 1B
Trends in use of fertilizer and pesticide



Source: USDA, ERS, 1997.



[1]Adjusted for changes in the mix of pesticide ingredients and their ability to kill selected target pests and in their effects on the environment.

Source: Ahearn, Yee, Ball, and Nehring, 1998

Even though major strides have been made in recent years to reduce surface water pollution from nonagricultural sources, surface water pollution continues to dominate water quality issues. In the National Water Quality Inventory (1996), the U.S. Environmental Protection Agency (EPA) reported that agriculture ranks first as the leading source of water quality problems for lakes and rivers, and ranks fifth for contributing to the degradation of estuaries. The combined effects of agricultural activities, including livestock facilities, were reported to have contributed to the impairment of 25 percent of the river miles, 19 percent of the lake areas, and 10 percent of estuary areas surveyed in the National Water Quality Inventory [EPA, 1999]. The survey represented approximately 19 percent of the rivers, 40 percent of the lakes, and 72 percent of the estuaries in the Nation. The results do not represent unsurveyed portions of these U.S. water resources. Of the impaired rivers, 18 percent were impaired by siltation, 14 percent by nutrients, and 7 percent by pesticides. Siltation and nutrients were also major contributors to the impairment of lakes and estuaries.

Ground water quality has also been affected by agricultural residuals. The contamination of ground water is particularly important because ground water provides drinking water for half of the U.S. population and removing chemical residues is extremely difficult and costly. Because of the slow-moving nature of ground water, the concentration of contaminants can increase over time and persist for many years. Tumors (malignant or nonmalignant), reproductive disorders, and neurological problems are among the potential health concerns when threshold levels of certain pesticides are reached [Blair, 1992].

The National Survey of Drinking Water Wells conducted in 1988-90 provides some indication of agriculture's impact on ground water [EPA, 1995]. Nitrates were the most frequently detected chemicals in ground water used as a source for drinking water. The EPA reported that about 4.5 million people using water from community well water systems or rural domestic wells were exposed to nitrates exceeding maximum contaminant levels set by the EPA. Excess nitrates in drinking water have been linked to methemoglobinemia, a condition that impairs the ability of an infant's blood to carry oxygen, and have been suggested to increase cancer risk [National Research Council, 1995]. The U.S. Geological Survey's ground water monitoring found that wells in agricultural areas more often exceeded the maximum contaminant levels for nitrogen than wells in other areas [Mueller and Helsel, 1996]. The EPA survey estimated that less than 1 percent of the rural domestic wells or wells used for community water systems had any pesticide concentrations exceeding the lifetime health advisory levels. The most frequently detected pesticide in ground water supplied to public water systems was atrazine [EPA, 1995]. The uses of agricultural chemicals have also harmed wildlife through direct contact, destruction of food supplies, or alteration of habitats. Wetlands and aquatic ecosystems in agricultural watersheds are most vulnerable. Agriculture has been identified as a source of pollutants that caused fish kills [EPA, 1995]. In 1,454 fish kills reported in 32 States and other U.S. jurisdictions in 1992-93, pollution was the cause about one-third of the time. Toxic pollutants, which were most often agricultural pesticides, were the cause for about 5 percent of the kills.

Organization of Report

The estimates of cropping practices and chemical use presented in the following chapters are based on several independent commodity surveys. Estimates from these surveys have been consolidated to represent nearly 60 percent of the U.S. cropland used for crops. The commodities include major field crops (corn, soybeans, wheat, cotton, and fall potatoes) and 24 fruit and 21 vegetable crops. While the commodities included in the surveys represent a large share of cropland and chemical inputs in agriculture, other agricultural commodities also use significant quantities of commercial fertilizers and pesticides and may have environmental impacts. Crops not represented include both those that have relatively intensive use of inputs, such as rice, tobacco, and horticultural crops, as well as those that have lower input use, such as hay and fallow.

Chapters II and III present information on the use of fertilizer and nutrient management practices and pesticides and pest management practices. The next chapter discusses the use of general crop management practices such as crop rotations and cover crops and associated chemical usage. The last chapter presents information on tillage systems and other practices related to soil management and the chemical use associated with these practices. In addition to the appendix tables in this report, an electronic data product is available that provides State-level estimates and additional detail about the cropping practices reported in this bulletin.

Chapter II

Soil Nutrient Management Practices

This chapter presents information about fertilizer and nutrient management practices used in the production of major field crops, fruits, and vegetables. The estimates are developed from producer surveys in the major production States for the selected crops and from other information sources. See appendix A for a description of the surveys.

Managing soil fertility is essential for obtaining and sustaining high yields and making crop production profitable. While fertilizer expenditures account for a relatively small share of the total production cost for crops, commercial fertilizer is the largest cash expenditure in corn production as well as a significant share of the cash expenditures for other commodities [USDA, ERS, 1999]. Determining soil nutrient needs, selecting the right fertilizer material, and deciding when and how to apply commercial fertilizer are important decisions for profitable crop production. Yield expectations, soil characteristics, previous crops, the use of livestock manure or other waste materials, or other cultural practices are other factors that can affect the quantity of commercial fertilizer applied. Timely applications that make nutrients available at the time needed by the plants are important not only for high yields, but also to prevent nutrient losses from leaching, volatilization, runoff, and soil erosion. Excessive rainfall, drought, and other weather conditions also affect soil nutrient levels, nutrient use by crops, and losses to the environment.

Marginal productivity estimates of fertilizer inputs have been estimated both from field trials using incremental changes in application rates and at aggregate levels using econometric models. Early econometric studies [Griliches, 1963; Padgitt, 1969; and Headley, 1972] show a marginal value return of $3 to $5 for each additional dollar of fertilizer expenditure. In 1975, Miranowski reported lower returns for cotton and provided some empirical evidence that there may be some overuse of nitrogen by corn producers in some areas [Miranowski, 1975]. Field-level experiments for corn on highly productive, irrigated, silt loam soils in Kansas in 1991 estimated a maximum profit nitrogen application at about 160-170 pounds per acre [Schlegel and Havlin, 1995]. Maximum profit fertilization levels, however, can vary widely from this estimate depending on other inputs, production practices, and climatic conditions.

Fertilizer use and nutrient management practices potentially can harm the environment [Mueller and Helsel, 1996]. Concentration of nitrogen and phosphate in surface water stimulates the growth of plants in lakes, streams, and estuaries and reduces their potential for recreational or other economic uses. High concentrations of nitrates in drinking water can also be a human health concern. Materials containing nitrogen or phosphate are the most widely used fertilizers and may contribute to these water quality problems. The U.S. Environmental Protection Agency reported that nutrient loadings were the leading cause of water quality impairment in both lakes and estuaries, and the third and sixth leading causes of impairment in rivers and wetland systems [EPA, 1995].

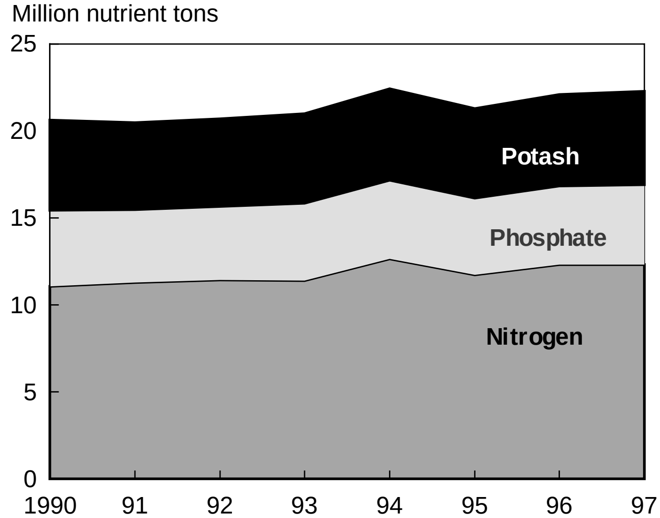
Primary Nutrient Consumption

Nitrogen and phosphate fertilizers are the nutrients applied to the largest share of acreage, according to USDA surveys. Nitrogen accounted for over half of fertilizer consumption, with some nitrogen fertilizer being applied to more than 70 percent of the cropland in the surveys. Nearly 60 percent of the cropland in the surveys received phosphate fertilizer and about 44 percent received potash (fig. 2A1). The total tonnage of potash, however, exceeded phosphate because of its higher application rates. Potash is a primary nutrient needed for plant growth, but it is less mobile and does not present the environmental concerns of nitrogen or phosphate. Many soils also contain sufficient levels of potash and require little or no supplemental application, at least on an annual basis.

Nitrogen and phosphate application intensities varied widely among crop production regions. High nitrogen and phosphate application rates corresponded closely to regions where there was a large acreage of corn or specialty crops. The highest application rates were in production regions where a high proportion of the cropland was used to grow potatoes, vegetables, or citrus fruit. However, some corn production areas in Illinois, Iowa, and Nebraska also received high application rates.

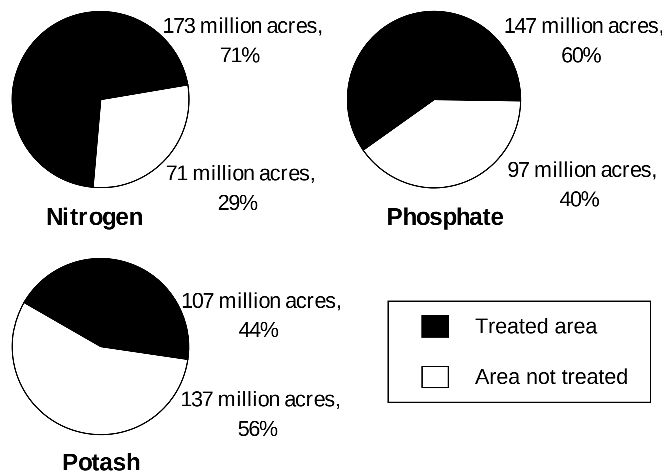
Figure 2A1

Primary nutrients applied remains stable



Source: Association of American Plant Food Control Officials, 1998.

Area treated with primary nutrients 1/



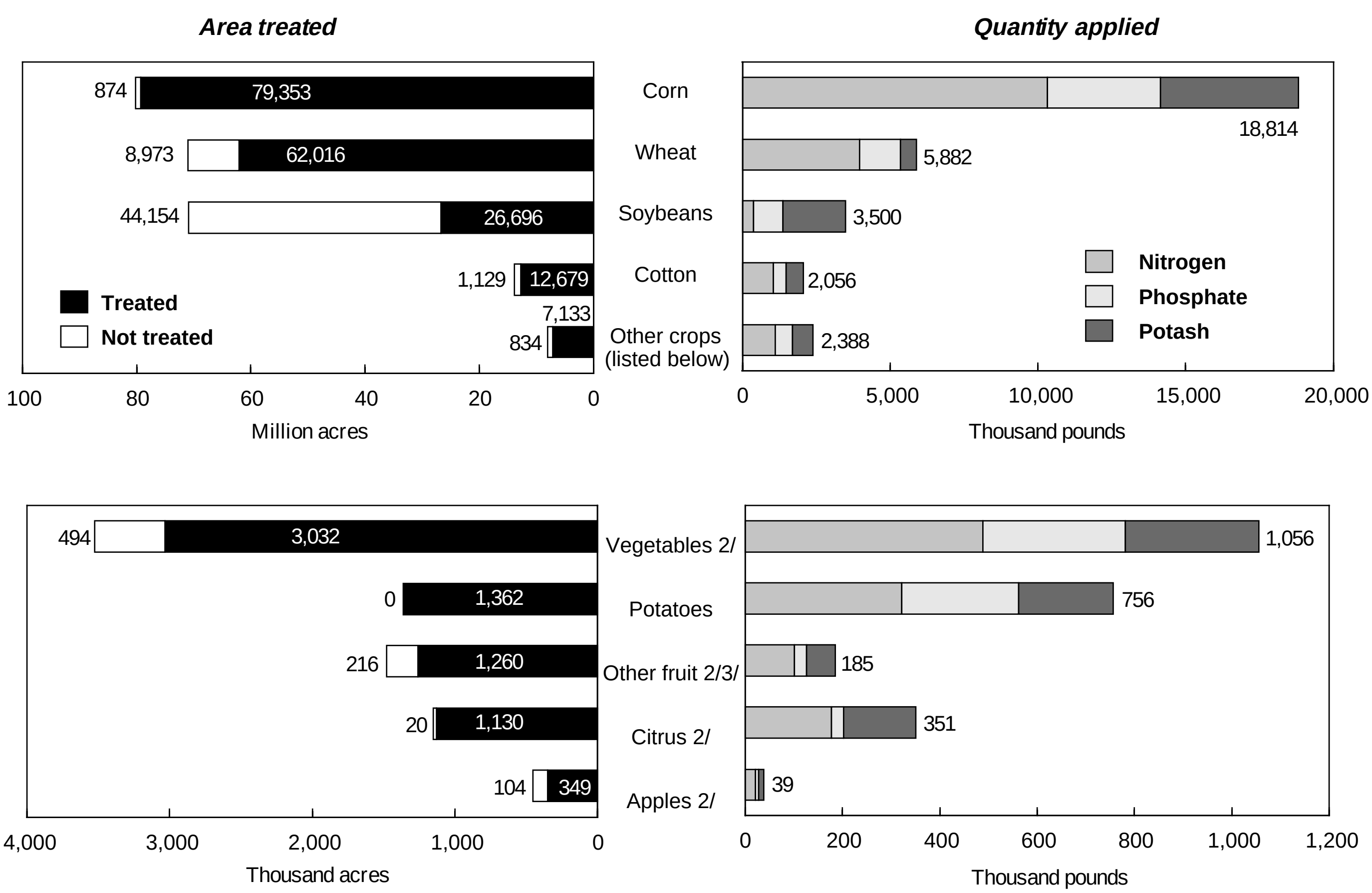
1/ Constructed to represent 244 million acres of 1997 U.S. cropland planted to corn, soybeans, wheat, cotton, potatoes, vegetables, and fruit. See appendix table B1.

Fertilizer Use Greatest for Corn

Corn, which accounted for one-third of all acres surveyed, was the leading crop in plant nutrient use (fig. 2A2). Almost all corn acres were treated. Fertilizer applied to corn accounted for 61 percent of all nitrogen, 53 percent of all phosphate, and 54 percent of all potash applied to the surveyed crops. Like corn, most of the acreage planted to wheat, cotton, potatoes, fruits, and vegetables was also treated with fertilizer, but due to their smaller acreage, fertilizer consumption by these other crops was less. Wheat, cotton, potatoes, and other crops are often grown in rotation with corn and can benefit from the residual fertilizer nutrients from corn. [See the Crop Rotation section, Chapter IV, for information about the difference in fertilizer use from crop rotations.] Less than 40 percent of the soybean acreage received any commercial fertilizer. Soybeans, like other legumes, process atmospheric nitrogen to meet most nitrogen needs. Most specialty crops (potatoes, vegetables, and fruits) received fertilizer at relatively high rates, but accounted for less than 10 percent of the total commercial fertilizer tonnage, due to the small acreage.

Figure 2A2

Fertilizer use greatest for corn 1/



1/ Constructed to represent 244 million acres of 1997 U.S. cropland planted to corn, soybeans, wheat, cotton, potatoes, vegetables, and fruit. See appendix table B1.

2/ Treated area includes only the area treated with nitrogen.

3/ Includes most other deciduous fruits and berries (except apples and citrus).

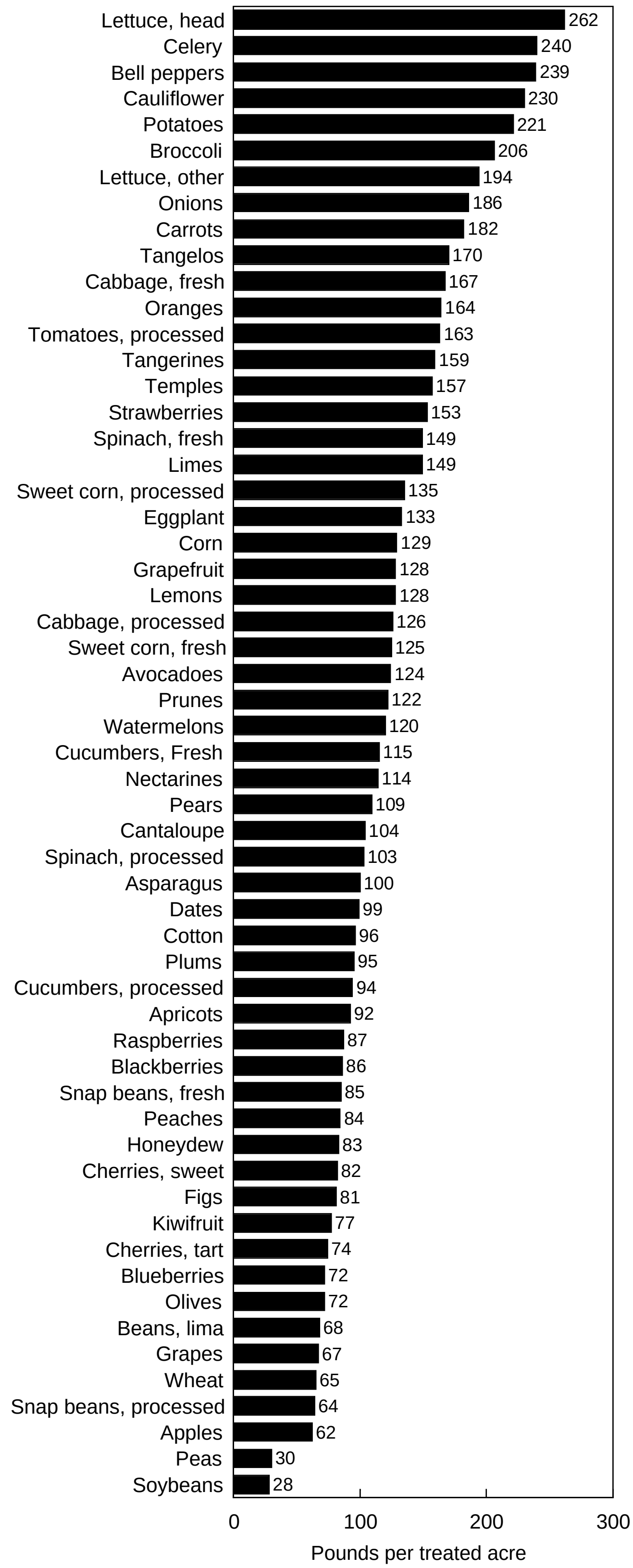
Source: USDA, ERS and NASS, 1996c.

Nutrient Application Rates Highest on Vegetables

Fertilizer needs of crops vary widely (figs. 2A3, 2A4, and 2A5). Average nitrogen and phosphate application rates were generally highest for nonlegume vegetable crops and potatoes and lowest for noncitrus fruit and legume crops. For the field crops, nitrogen and phosphate application rates were highest for corn and lowest for soybeans. Although commercial fertilizer was not applied to most soybeans, when it was applied, potash was the ingredient applied most often and generally at rates higher than for other field crops.

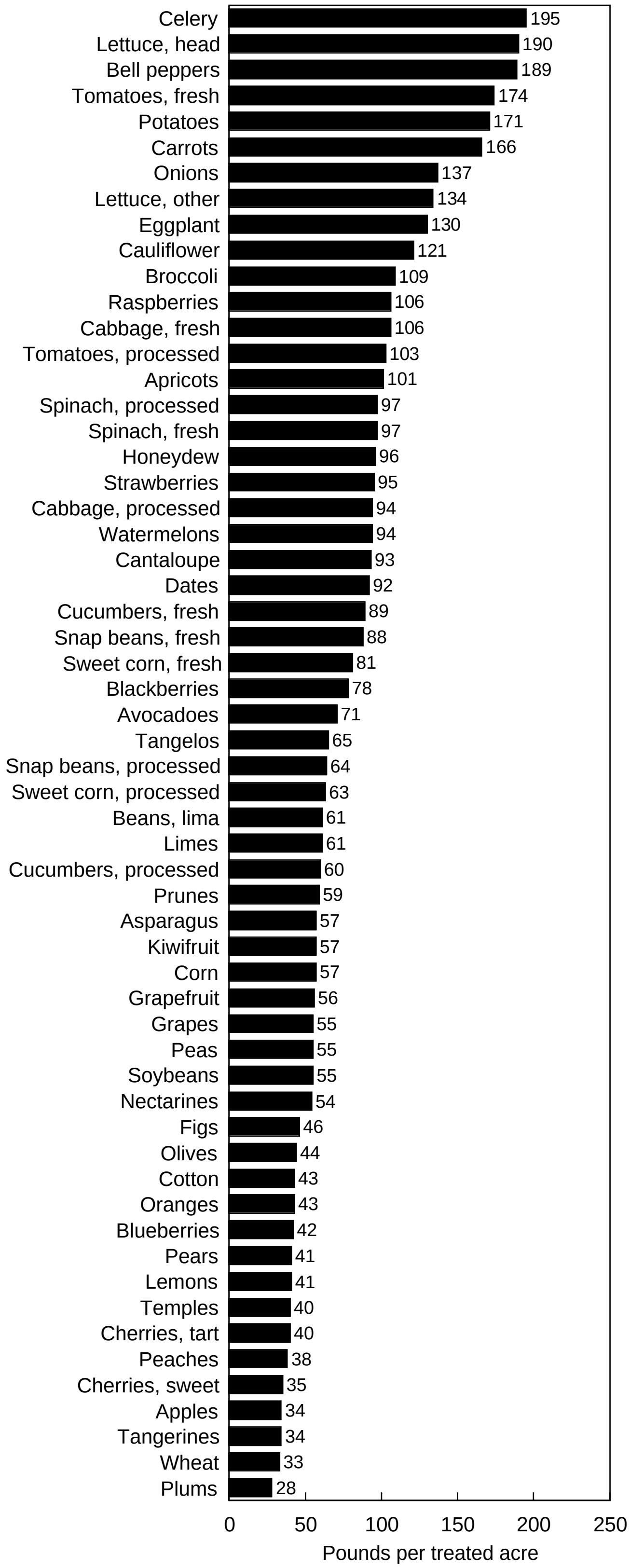
Figure 2A3

Nitrogen application rates for selected crops



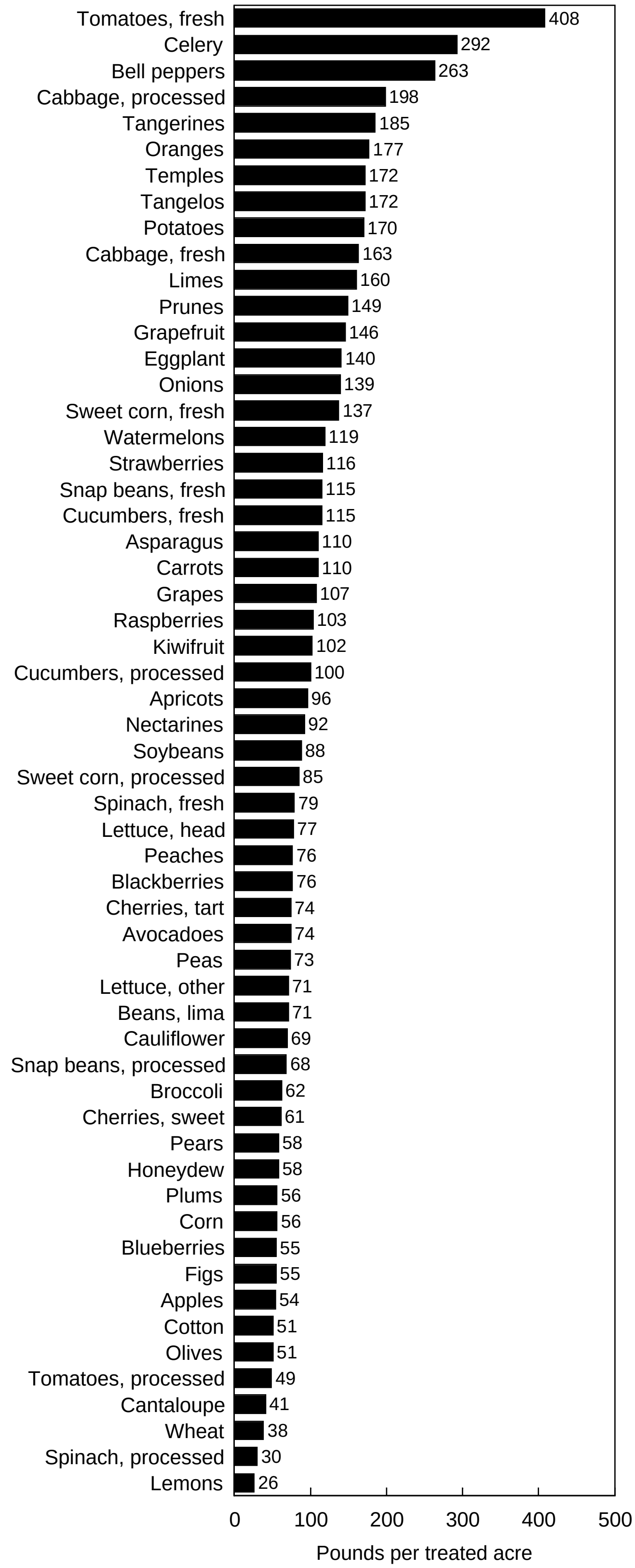
Sources: USDA, NASS and ERS, 1996b, 1996a, and 1995a.

Figure 2A4
Phosphate application rates for selected crops



Sources: USDA, NASS and ERS, 1996a, 1996b, and 1995a.

Figure 2A5
Potash application rates for selected crops



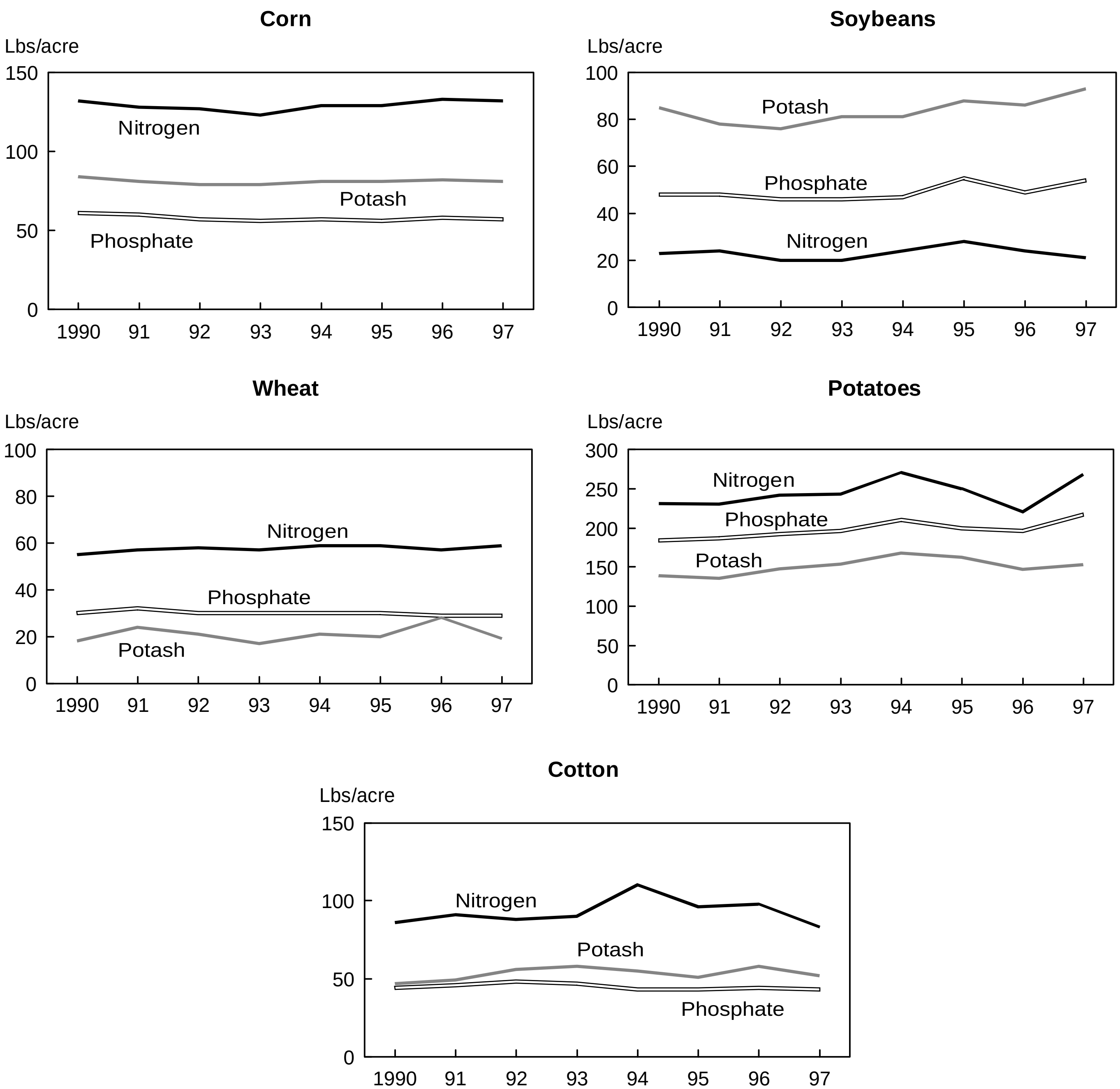
Sources: USDA, NASS and ERS, 1996a, 1996b, and 1995a.

Crop Nutrient Application Rates Remain Stable, 1990-97

Between 1990 and 1997, nutrient application rates remained relatively stable for field crops (fig. 2A6). Annual changes in fertilizer prices, commodity prices, expected yields, weather, and participation in Federal farm programs are factors that can affect fertilizer use decisions. Nitrogen application rates on corn dropped slightly between 1990 and 1993, but were up in the following years. For cotton, nitrogen rates were up between 1990 and 1994, but decreased in 1994-97. For soybeans, wheat, and potatoes, the trend was generally up between 1990 and 1997.

Figure 2A6

Crop nutrient application rates remain stable during 1990-97



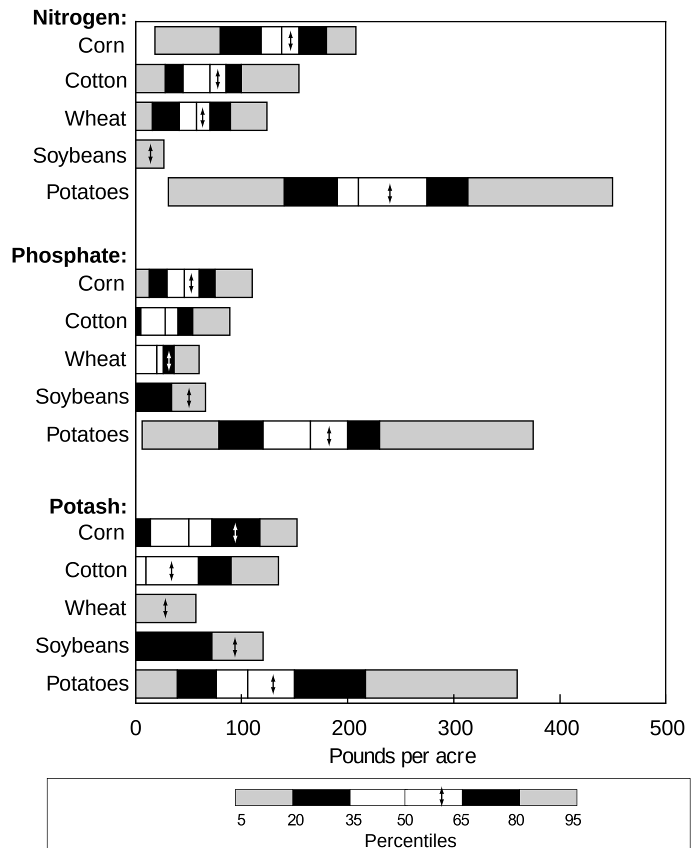
Sources: USDA, NASS and ERS, 1998b.
See appendix table B2 for States represented.

Variation in Nutrient Application Rates Highest Across Potato Fields

Besides the variation in application rates between crops, there was also wide variation in the application rates between fields of the same crop (fig. 2A7). Soil characteristics, yield expectations, previous crops, cultural practices such as irrigation, weather, and other factors can cause fertilizer rates to vary among fields. While some fields received no fertilizer, other fields were intensively treated. For example, the 5 percent of the potato area having the lowest application rates (5th percentile) received 31 pounds or less of nitrogen per acre, while the 5 percent of the area having the highest application rates (95th percentile) received 450 pounds or more of nitrogen per acre. For corn, the highest 5 percent received 208 pounds or more per acre of nitrogen and 110 pounds or more of phosphate. At the median (50th percentile), half of the acres receive more than that rate and half receive less. The mean is the average rate for all acres treated, but excludes untreated acres. Because some acres are not treated and because the rate on the the treated acres does not necessarily follow a normal statistical distribution, the mean rate is often higher than the median rate.

Figure 2A7

Nutrient application rates vary between fields



Each bar represents the range in application rates for the 5th percentile (area with no pesticide applied or lowest rates) to the 95th percentile (area with the highest rates). The bar segments represent ranges in application rates at 15-percentile intervals. At the 50th percentile (median), half of the area received less than the identified rate and half received more. The double arrow indicates the average (mean) rate for the treated area.

Source: USDA, NASS and ERS, 1996b

Nutrient Management Practices

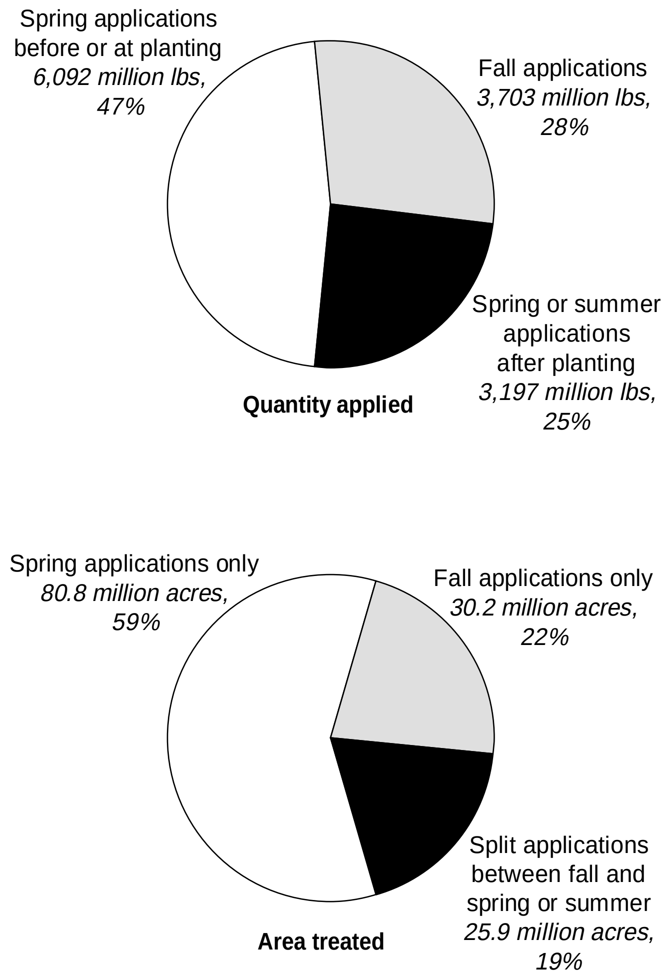
Most Nitrogen Fertilizer Applied Before or At Planting

Timing fertilizer applications to the plant's biological needs helps to reduce nutrient losses from leaching, runoff, or volatilization [Aldrich, 1984] (fig. 2B1). Nitrogen, in a form that can be used by plants, is mobile and can quickly be lost through leaching and runoff. The longer the nutrients are in the soil before they can be used by the crop, the more likely that they may be lost. Applications made during the growing season when the nutrient is most needed by the plant can reduce some of these losses. However, because of the cost of additional treatments and other factors, many farmers chose to apply their nutrients before or at planting time. Delaying fertilizer application until later in the growing season poses an additional risk that wet fields or other conditions may prevent timely treatment and result in yield losses. To free labor for the peak spring planting periods, some farmers apply their nutrients in the fall or at other off-peak times.

About three-fourths of all nitrogen used on the surveyed field crops (corn, soybeans, wheat, cotton, and potatoes) was applied before or at the time the crop was planted. An estimated 28 percent of the total nitrogen was applied in the fall, including that applied to winter wheat at or before planting. Winter wheat accounts for about one-third of the fall applications while the remainder was applied to crops planted the following spring. Nitrogen applications made after planting, which better coincides with plant needs, accounted for about one-fourth of the total quantity. About 22 percent of the area treated with nitrogen was treated with only fall applications. Fifty-nine percent of the area received all of the nitrogen treatments in the spring or later in the growing season. Split treatments, with part of the nitrogen applied in the fall and part the following spring or summer, occurred on about 19 percent of the area.

Figure 2B1

Most nitrogen fertilizer applied before or at planting



Represents fertilizer applied to 194 million acres of corn, soybeans, wheat, cotton, and potatoes.

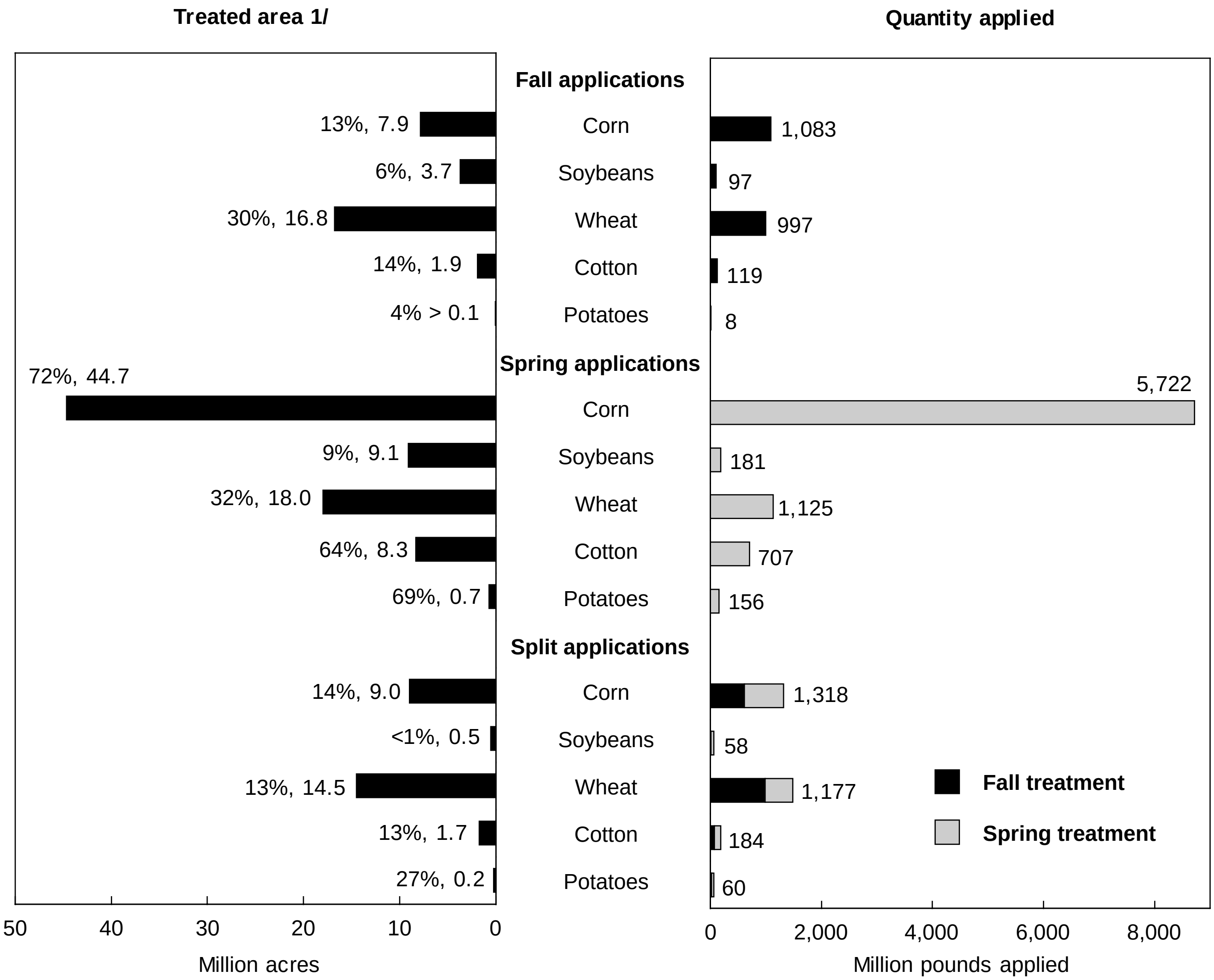
Source: USDA, NASS and ERS, 1996c.

Fall Nitrogen Applications Common for Corn and Wheat

Except for winter wheat, other crops received most of their nitrogen applications in the spring (fig. 2B2). For winter wheat or other fall-planted crops, split applications between fall and spring can better time the treatment with plant needs. For corn and other spring-planted crops in northern regions, nitrogen can normally be applied late in the fall without loss of nitrogen so long as the soil remains cold. About 27 percent of the corn area received fall nitrogen fertilizer applications and for about 13 percent of the area no other nitrogen was applied. Nitrogen applications were split between the fall and following spring or summer on 14 percent of the corn area.

Figure 2B2

Fall nitrogen applications used mostly for corn and wheat, 1997



1/ The first value at the end of each bar is the percentage of area treated, and the second value is million acres treated.

Source: USDA, ERS and NASS, 1996c.

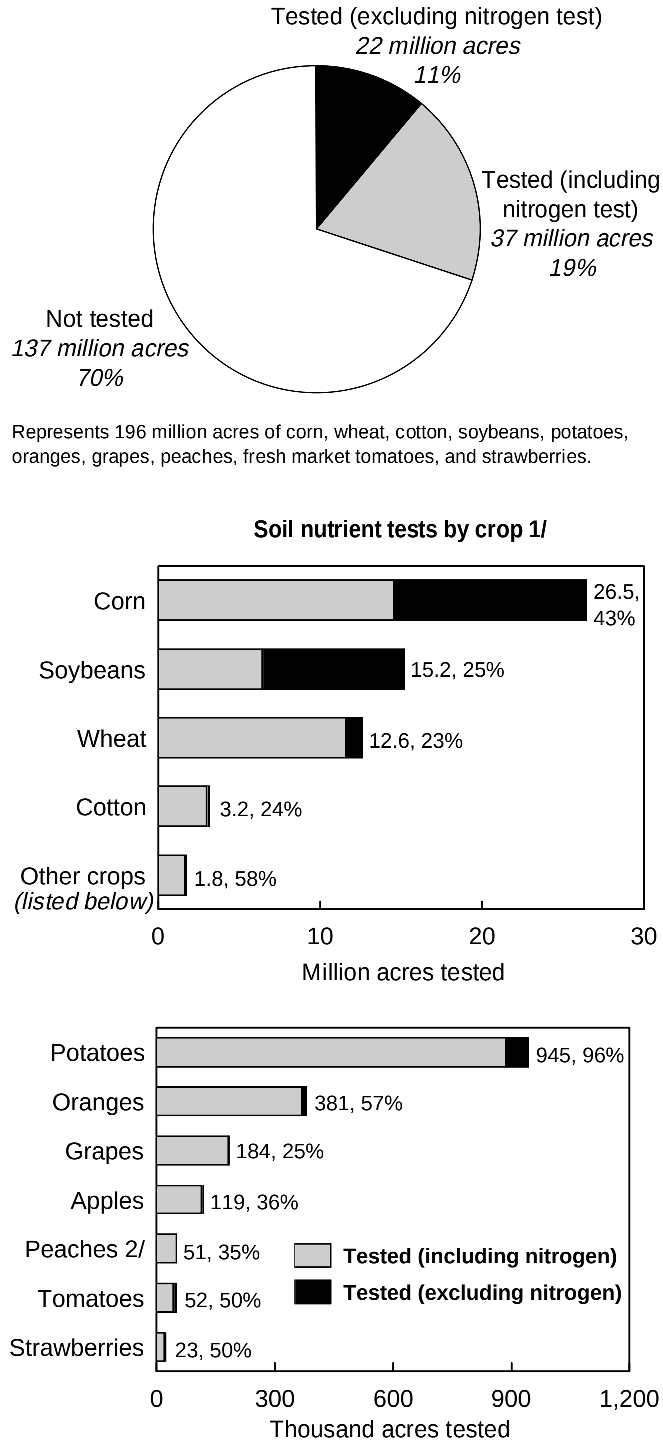
Annual Soil Nutrient Test Not Widely Used

Soil tests help farmers monitor soil nutrient levels in their fields to make more informed fertilizer application decisions (fig. 2C1). Analysis of soil samples in laboratories can help scientists and farmers more precisely develop fertilizer treatment plans that are cost effective and that do not result in excess nutrient levels. Laboratory tests of soil samples often include analysis of soil pH, organic matter content, amount of phosphate, potash, nitrate, and micronutrients along with recommendations for fertilizer treatments. The amount of nutrient actually available to plants depends on many factors and changes over time as some nutrients are lost or temporarily tied up in the soil.

Less than a third of the represented crop acreage in the surveys had soil nutrient testing, at least on an annual basis. Soil nutrient testing was more often reported on crops that require large quantities of commercial fertilizer, such as potatoes and vegetables, than for crops that require less fertilizer, such as soybeans. About two-thirds of the area reporting soil tests also reported that the tests included one for nitrogen.

Figure 2C 1

Annual soil nutrient tests used on 30 percent of surveyed acres, 1994-95



1/ The first value at the end of each bar is total area tested, and the second value is the percent of the planted area tested.
2/ Information regarding nitrogen tests was unavailable.

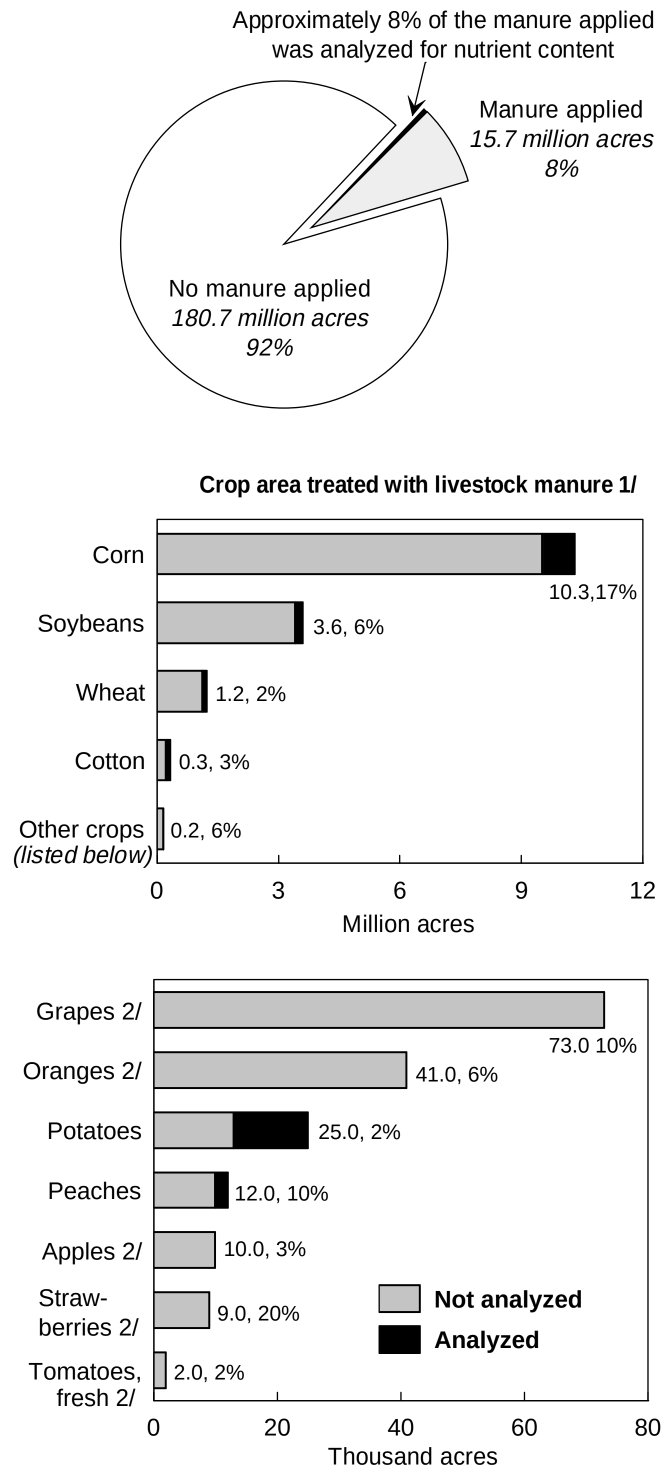
Source: USDA, NASS and ERS, 1994, 1995c, 1995d.

Acres Treated with Livestock Manure

Livestock manure is a source of plant nutrients, but it can also contribute to water quality problems (fig. 2C2). The nutrient content of manure can differ significantly depending on the livestock species and the storage and application methods. For more accurate crediting of nutrient content, farmers can pay for a laboratory analysis of the manure's nutrient content. Only about 8 percent of the area surveyed had any manure applied and very little of the manure was analyzed for its nutrient content. Most of the area treated with manure was planted to corn. The manure discussed here excludes any prepared and sold as a commercial fertilizer.

Figure 2C2

Few acres treated with livestock manure and analyzed for nutrient content



1/ The first value at the end of each bar is total area tested and the second value is the percent of crop area treated.
2/ Information was not available on manure analysis for nutrient content.

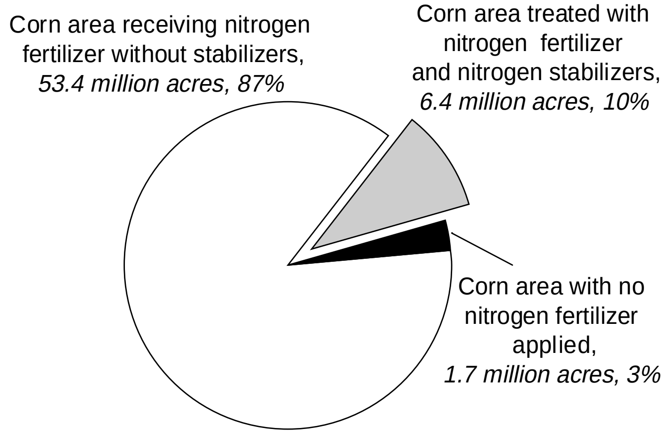
Source: USDA, NASS and ERS, 1994, 1995d, 1996d.

Use of Nitrogen Stabilizers for Corn

Without a stabilizing material, many nitrogen fertilizers quickly dissolve in water and move easily through the soil (fig. 2D1). Stabilizing materials have been developed that temporarily immobilize the fertilizer material and help prevent it from leaching below the crop root zone or being lost in runoff. The nutrient is then more slowly released during the growing season as the plant develops and requires the nitrogen. The use of nitrogen stabilizers allows earlier application of nitrogen and reduces potential losses. The stabilizers were most commonly used on corn and in areas subject to potential losses from high precipitation or irrigation. About 6 million acres (10 percent) of the surveyed corn area in 1997 used a nitrogen stabilizer. Extremely wet soils in 1993 delayed normal fertilizer applications, and use of nitrogen stabilizers was much lower that year.

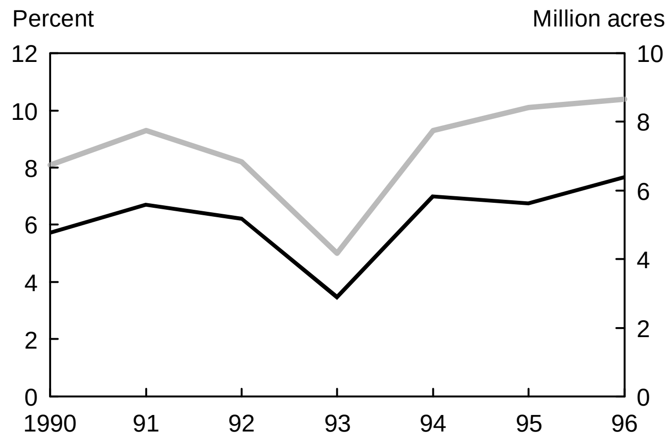
Figure 2D1

Limited use of nitrogen stabilizers for corn in 1996



Represents 61.5 million acres of corn in IL, IN, IA, MI, MN, MO, NE, OH, SD, and WI in 1996.

Corn area receiving nitrogen stabilizers, 1990-96



Source: USDA, NASS and ERS, 1995c, 1996c.

Chapter III

Pest Management Practices in Crop Production

Throughout history farmers have relied mostly on physical and cultural practices to manage and control the pests that damaged their crops [Smith, Apple, and Bottrell, 1976]. Weeds were controlled with tillage implements, mowing, site selection, planting seeds free of weedseeds, and often even with the use of hands and hand tools. Attempts to reduce losses from insects and disease also included practices such as crop rotations, planting trap crops, adjusting planting dates, and seed selection. Prior to the 1940's, the use of chemicals was limited to a few inorganic chemicals and some natural or organic materials. These controls were for a limited spectrum of pests and often were ineffective. The development of synthetic pesticides following World War II, along with improvements in seed genetics, mechanization, and other production practices, brought about many changes in the way farmers manage pests. Before the development of synthetic chemical pesticides, weed control was primarily limited to mechanical practices. The purpose of this chapter is to report estimates of various kinds of chemical, cultural, and biological practices that are now used to combat the damages caused by pests.

Agricultural pesticide expenditures have grown from $44 million in 1940 to over $8 billion in 1997, a 15-fold increase in constant dollars [Aspelin, 1999]. Many studies on the productivity of pesticides give economic justification for increased farm use, but the studies do not account for possible health costs or environmental damages. Studies of agricultural productivity report marginal returns to pesticide use in the range of $1 to $3 for each dollar spent on pesticides [Headly, 1968; Padgitt, 1969; Carlson, 1977; Duffy and Hanthorn, 1984; Fernandez-Cornejo and Jans, 1995]. Estimates of marginal returns varied between pesticide types, crops, and regions. Miranowski found higher returns for corn insecticides ($2.02) than corn herbicides ($1.23). Campbell (1976) estimates a $12 return per dollar of apple insecticides while Lee and Langham (1973) reported marginal returns of less than $1 on citrus. Some evidence has been reported that the model specification of some of the earlier studies tends to overestimate the marginal productivity of pesticides [Lichtenberg and Zilberman, 1986]. Teague and Brorsen (1995) estimated declines in the marginal returns from pesticides between 1949 and 1991, but marginal returns were still above marginal costs. Estimates of marginal productivity are also an indirect measure of the forgone production that might occur should farmers be required to constrain pesticide use to protect human health or the environment.

A pesticide, according to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) [7 USC 136] is "... any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any insects, rodents, nematodes, fungi, or weeds, or any other forms of life declared to be pests; and any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant." Types or classes of pesticides used in this report are:

- **Fungicides** control plant diseases and molds that either kill plants by invading plant tissues or cause rotting and other damage to the crop both before and after harvesting.
- **Herbicides** control weeds that compete for water, nutrients, and sunlight and reduce crop yields. Herbicides that are applied before weeds emerge are *preemergence herbicides*. Preemergence herbicides have been the foundation of row crop weed control for the past 30 years. Herbicides applied after weeds emerge are *postemergence herbicides*. Postemergence herbicides normally have less residual activity and do not persist in the environment as long as preemergence herbicides. Treatments applied prior to any tillage or planting to kill existing vegetation are referred to as "burndown" applications. Burndown applications are often a part of no-till systems.
- **Insecticides** control insects that damage crops. For this report, pesticides used to control mites and nematodes are classified as insecticides. Products used as soil fumigants, with a broad range of target pests including insects, mites, and nematodes, are not classified as insecticides in this report.
- **Other Pesticides** include soil fumigants, growth regulators, desiccants, and other pesticide materials not otherwise classified. Sulfuric acid, when used as a desiccant on potatoes, is included in this class, but petroleum oils used as adjuvants are excluded.

A Restricted-Use Pesticide is a pesticide product whose use requires special handling because of the toxicity of the product's active ingredients. Restricted-use pesticides may be applied only by trained, certified applicators or persons under their direct supervision. All labeled uses of an active ingredient may not be restricted. In some cases, only certain formulations, concentrations, or uses are restricted. Private and commercial applicators are required to keep records of applications of restricted-use pesticides [Subtitle H, 1990 Federal Agricultural Conservation and Trade Act].

The USDA surveys of pesticide use document recent changes in the quantity of pesticides and selected pesticide ingredients applied as well as differences in pesticide use between crops, geographic areas, and cultural and other pest-management practices [USDA, NASS and ERS, 1996c]. The commodity acreage represented in the USDA surveys accounts for approximately 60 percent of the U.S. cropland planted to crops. Pesticide use and pest management practices on the remaining cropland, pasture, range, forest, or other agricultural activities, including livestock, are not included. Estimates of total agricultural pesticide use, as well as nonagricultural uses, are reported by the Environmental Protection Agency [Aspelin, 1999]. [See appendix A for a description of USDA pesticide surveys and the commodities and States represented.] Besides pesticide use, the USDA survey data provide estimates of farmers' use of biological and cultural pest prevention practices, scouting and other pest-monitoring activities, and the information sources used to make pest-management decisions.

Pesticide Use

The estimates of pesticide use reported in this section are based on annual surveys since 1990 for five field crops (corn, soybeans, wheat, cotton, and fall potatoes) and biennial surveys that include 24 fruit and 21 vegetable crops. (See appendix A in this report for specific crops and States included in the surveys.) These States and surveyed commodities accounted for about 60 percent of the U.S. cropland planted to crops and about 75 percent of all agricultural pesticides. In all, more than 250 different pesticide active ingredients were reported on these agricultural crops and classified as herbicides, insecticides, fungicides, or other pesticides. Aggregate pesticide use is reported by the weight of the active ingredients and the number of acres treated one or more times. The intensity of pesticide use is reported by application rates (pounds of active ingredient per treated acre) and number of acre-treatments per acre (total number of different pesticide ingredients applied and number of repeat applications of the same ingredient).

Weed Control Accounts for Most Pesticide Use

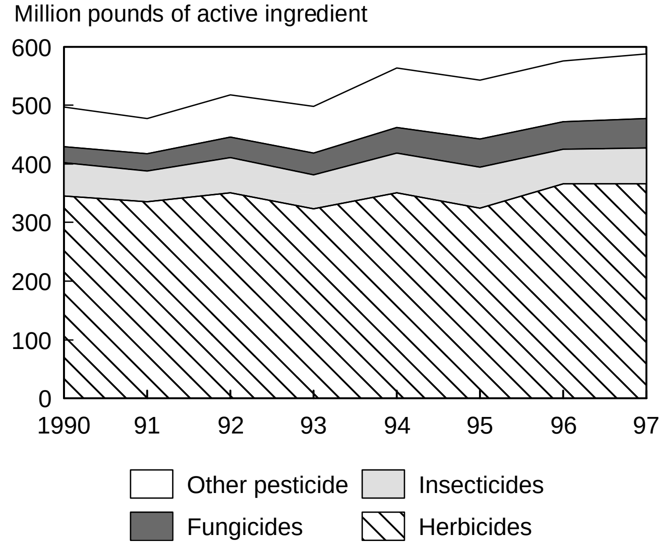
Herbicide ingredients accounted for 62 percent of the 588 million pounds of pesticides applied to the surveyed crops in 1997 (fig. 3A1). About 210 million acres or 86 percent of the surveyed crop area in 1997 received some herbicide treatments. Pesticides in the "other pesticides" category were the second largest in terms of pounds but were applied to only 6 percent of the area. Some ingredients in the "other" category are applied at several hundred pounds per acre compared with herbicides, insecticides, and fungicides, which are normally applied at only a few pounds or even a few ounces per acre. About 18 percent of the crop acres were treated with insecticides. The use of fungicides was primarily limited to potatoes, vegetables, and fruits and represented the smallest use in both total acres treated and total pounds applied.

Total quantities of pesticide use increased about 18 percent between 1990 and 1997 on the surveyed crops, but fluctuated annually with changes in crop acres and other factors. Although the total use increased, the trends varied among pesticide types. Most of the increase in pesticide use occurred in "other pesticides" and largely was a result of a change in products rather than any change in the number of acres treated. There was little change in the pounds of herbicides used between 1990 and 1997, but the share of acres treated edged up while average application rates declined. The use of both insecticides and fungicides increased, with most of the insecticide increase on cotton and the fungicide increase on potatoes and other vegetables.

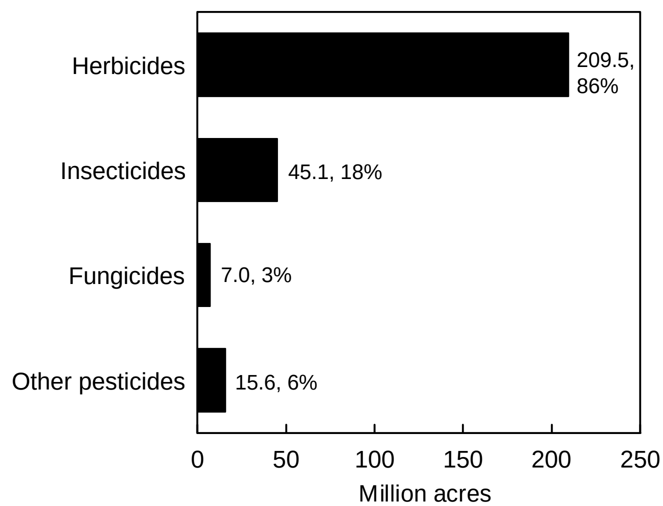
Figure 3A1

Weed control accounts for most pesticide use

Quantity of pesticide active ingredients applied to selected crops 1/



Total acres treated one or more times with a pesticide ingredient 2/



1/ The constructed estimates of pesticide quanitity and treated area represent 244 million acres of corn, soybeans, wheat, cotton, potatoes, other vegetables, and fruit. See appendix table B5.

2/ The first value at the end of the bar is acreage treated, and the second value is the percentage of the total crop area treated.

Sources: Lin, Padgitt, Bull, Delvo, Shank, and Taylor, 1995; USDA, NASS and ERS, 1994, 1995d, 1996c, and 1996d.

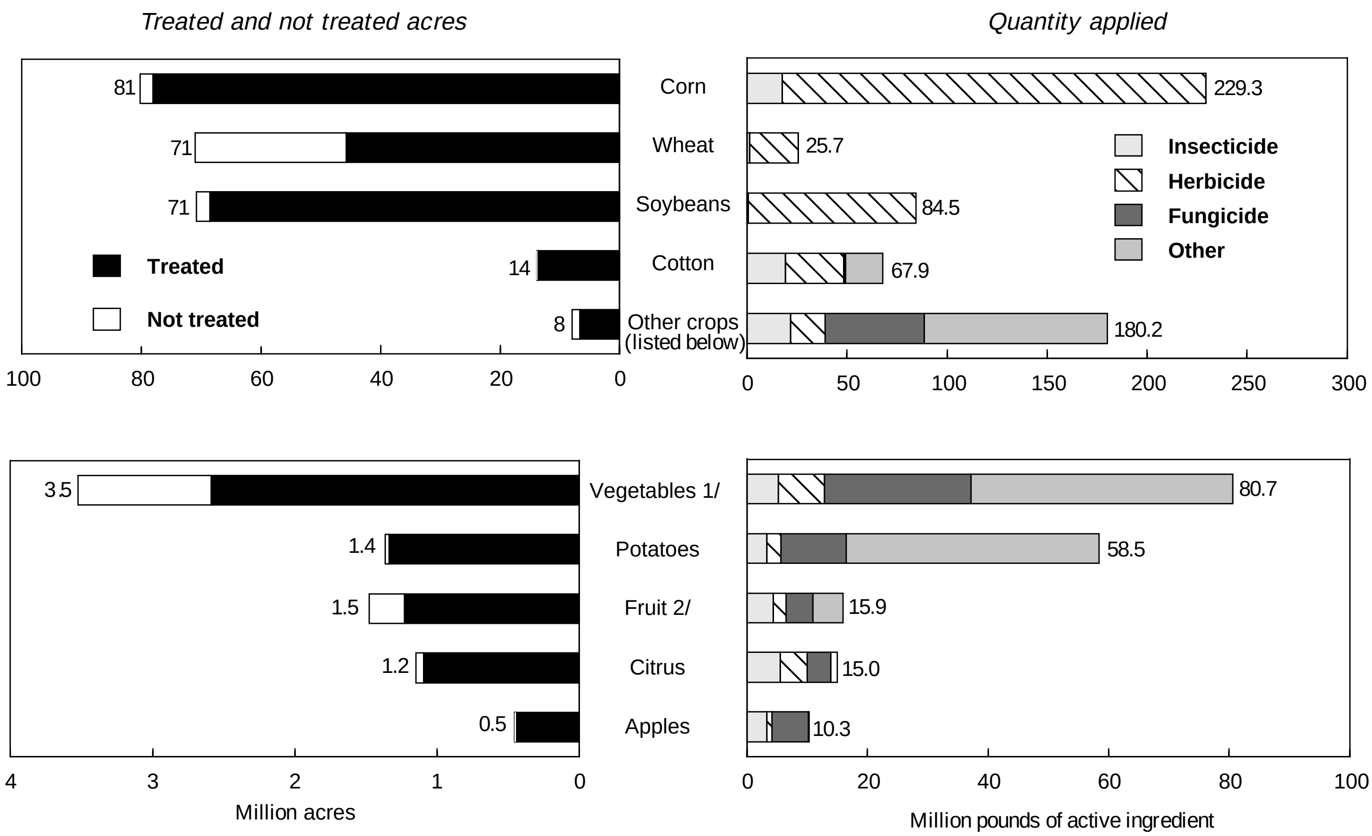
Corn Received Largest Quantities of Pesticides

Most crops included in the USDA surveys received some pesticide treatments, but the seasonal rate of application and types of pesticides applied differed among crops (fig. 3A2). Corn had the largest crop acreage in 1997 with 81 million acres planted and exceeded all other surveyed crops in terms of quantity of pesticides applied and acreage treated. Nearly all corn acres were treated with some pesticides, and herbicides accounted for most of the use. Although wheat acreage is only slightly less than that of corn, significantly less pesticide was applied to wheat. Many winter wheat acres received no pesticide treatments, and the intensity of treatments on the treated acres was much less than for corn. Soybean acres were treated mostly for weeds and were the second largest users of herbicides.

Although cotton acreage was much smaller than that of corn, wheat, or soybeans, the seasonal rate of aggregate applications was higher. Cotton was the largest user of insecticides and accounted for 32 percent of the total quantity of insecticides. Potatoes, with only 1.4 million acres planted in 1997, were the second largest users of pesticides among the surveyed crops. Nearly 75 percent of all potato pesticides were classified as “other pesticides”—mostly soil fumigants and vine killers. Most fruit acres received several treatments per year for insects and diseases, but because of their relatively small acreage and low application rates, fruit accounted for only 7 percent of the total pesticide use.

Figure 3A2

Largest quantities of pesticides used for corn production, 1997



1/ The constructed estimates represent 244 million acres. See appendix table B6 for specific crops and area. The pesticide use for vegetables is based on the 1994 use rates. The estimates for pesticide use for fruits are based on 1995 use rates, and the estimates for field crops are based on 1997 use rates.
2/ Includes fresh and processed vegetables and strawberries from the 1994 crop year.

Source: USDA, ERS and NASS, 1995a, 1996b, and 1998b.

Variation in Pesticide Application Rates Across Fields

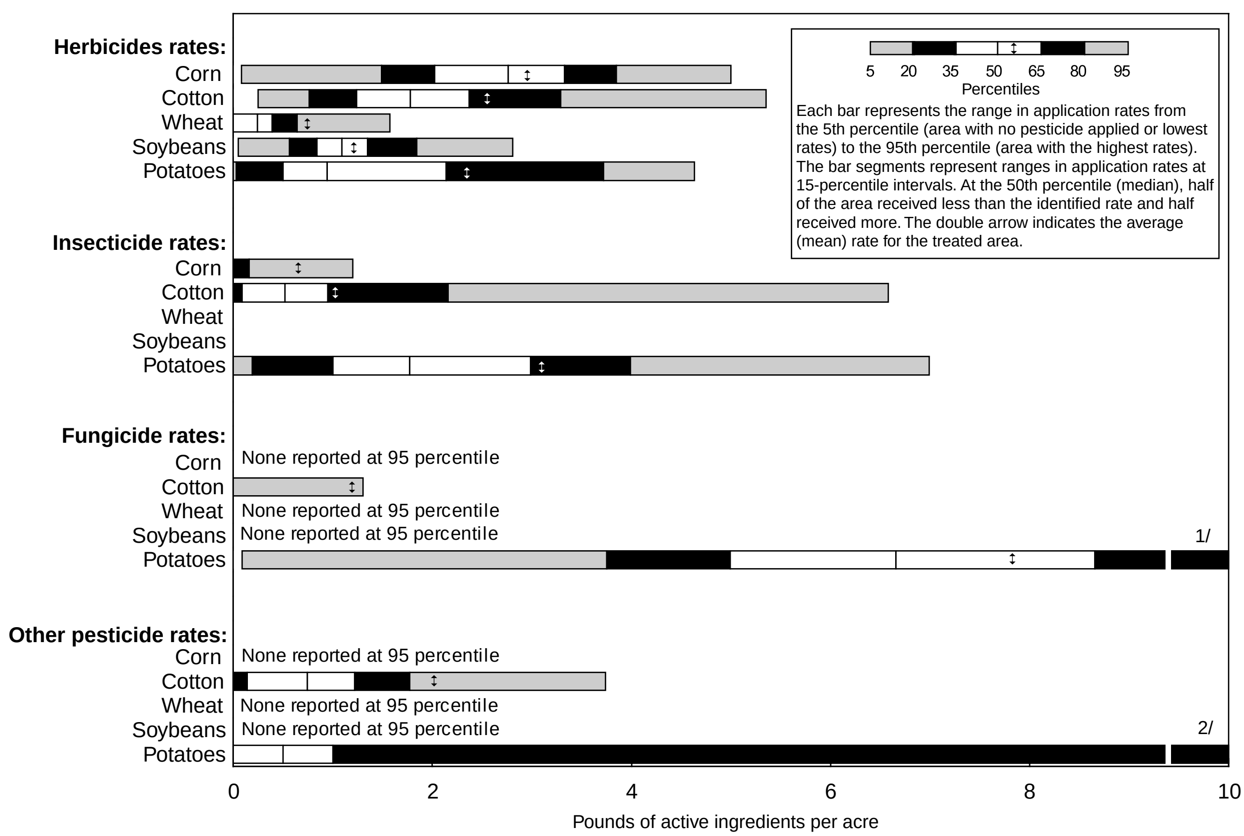
The intensity of pesticide applications varies widely not only between crops and pesticide types but also between fields of the same crop (fig. 3A3). Many factors contribute to differences in pesticide application rates between fields. The target pest species, infestation levels, weather, use of cultural practices, application methods and timing, and prices can all affect the selection and the amount of pesticide material applied [Lin, 1995]. Differences in the potency and persistence of ingredients are additional factors affecting the quantity applied. Some pesticide ingredients are applied at several pounds per acre, but alternative pesticides that provide similar kinds of pest control are applied at only a few ounces per acre. Some ingredients, especially insecticides and fungicides, require several treatments during the growing season because they soon lose their effectiveness when exposed to weather and other environmental forces. These factors and the length of the growing season can all affect the accumulated quantities applied and total number of acre-treatments.

The most intensively treated land can account for a disproportionately large share of pesticide use on any crop. For corn herbicides, the application rates ranged from zero at the 5th acreage percentile to 5 pounds per acre at the 95th acreage percentile. At the median (50th acreage percentile), half of the corn acreage received 2.8 pounds or more per acre while the other half received less than 2.8 pounds per acre.

Although the majority of potato acres received less than 2.5 pounds of herbicide or insecticide ingredients, some fields received higher rates of fungicide and other pesticide ingredients. Twenty percent (80th acreage percentile and higher) of the potatoes received at least 12 pounds of fungicides and at least 140 pounds of “other” pesticides. At the 95th acreage percentile, the rates exceeded 16 pounds for fungicides and 300 pounds for “other” pesticides. Treatments accounting for such high levels of use include several repeat application of fungicides, the use of sulfuric acid as a vine killer, or treatment with a soil fumigant. A single treatment with sulfuric acid or a soil fumigant can be at a rate of several hundred pounds per acre.

Figure 3A3

Pesticide application rates vary among fields, 1997



1/ This bar extends to 11 pounds per acre at the 80th acreage percentile and 17 pounds per acre at the 95th.

2/ This bar extends to 155 pounds at the 80th acreage percentile and over 400 pounds at the 95th, reflecting the use of sulfuric acid as a potato vine killer. The mean rate for other pesticides was 104 pounds per treated acre.

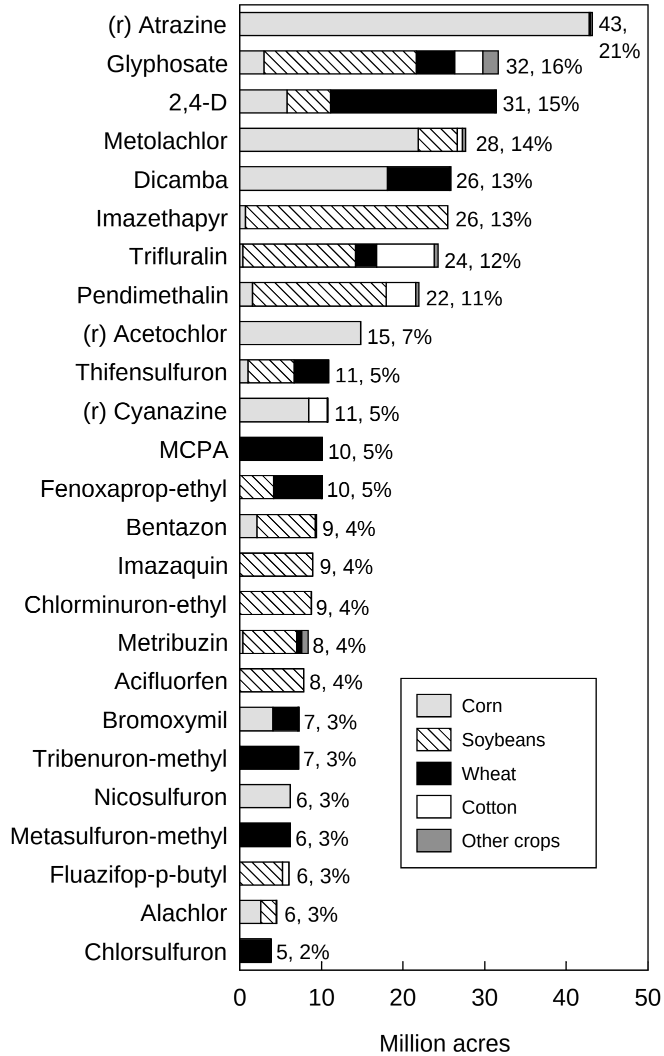
Source: USDA, ERS and NASS, 1996c.

Atrazine was the Leading Herbicide Ingredient

Although many herbicide ingredients are used in agriculture, a relative few account for most of the use (total pounds or acres treated, fig. 3A4a). Only 23 herbicide ingredients were applied to more than 5 million (3 percent) of the 188 million acres surveyed. Atrazine, 2,4-D, dicamba, and metolachlor were among the five leading herbicides, and all have been widely used for more than 30 years. These ingredients are applied both as a single ingredient or in combination with other ingredients to improve their efficacy and cost effectiveness. Atrazine is almost exclusively used on corn and grain sorghum, while dicamba and 2,4-D are also used on wheat and other crops. Glyphosate was the second most used herbicide in acres treated. It is frequently used on orchards and vineyards and widely used with no-till systems on corn, soybeans, and wheat. Imazethapyr, first registered for use in the late 1980's, is the leading ingredient used on soybeans. Trifluralin, another ingredient available 30 years ago, is the leading herbicide used on cotton and also is widely used on soybeans and vegetables. Three of the 25 leading herbicide ingredients are labeled as "restricted-use" pesticides—atrazine, cyanazine, and acetachlor. (All formulations of an ingredient, however, may not be labeled for restricted use). Restricted-use products are only to be applied by applicators who are trained and certified.

Figure 3A4a

Atrazine was the leading herbicide applied to the surveyed area, 1996-97 1/



1/ The letter "r" in the parentheses identifies ingredients that are restricted-use products. Not all formulations of the ingredient may be restricted. The first value at the end of each bar is the area treated, and the second value is the percent of total surveyed area receiving the ingredient.

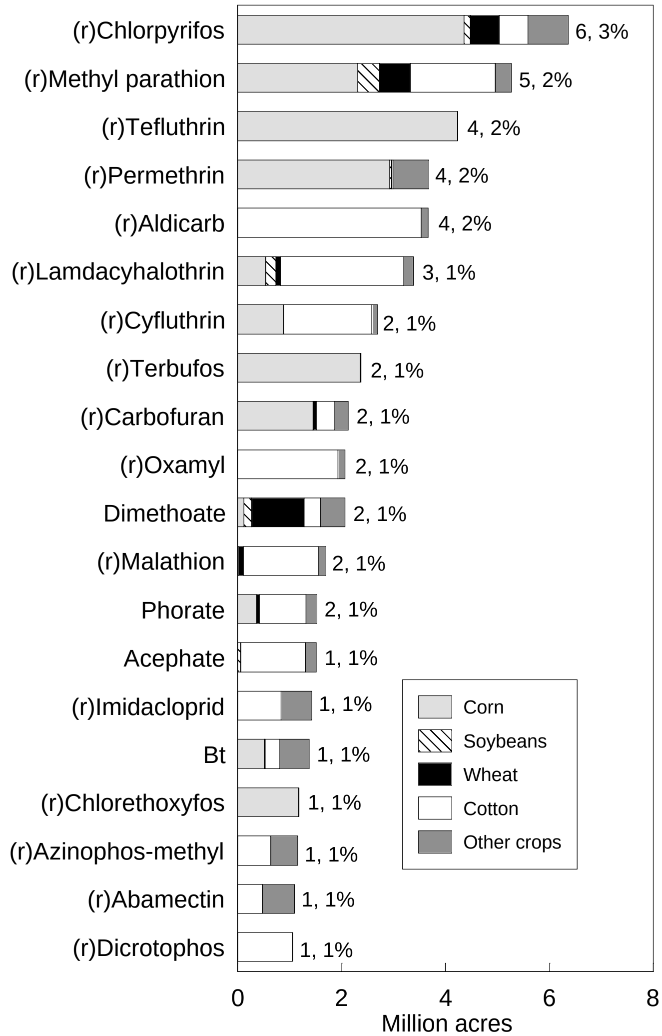
Sources: USDA, NASS and ERS, 1998a, 1998b, and 1997a.

Chlorpyrifos was the Leading Insecticide Ingredient

More than 60 different insecticide ingredients were reported used on the surveyed crops, but only a few accounted for most of the acres treated (fig. 3A4b). Only eight ingredients were applied to more than 2 million of the 188 million acres surveyed. Chlorpyrifos and methyl parathion, the two most widely used insecticidal ingredients, were applied to several different crops, with corn and cotton accounting for the largest treated area. Unlike herbicides, most of the leading insecticide ingredients are labeled as "restricted-use" pesticides and require application by licensed applicators. Chlorpyrifos and methyl parathion are among the organophosphate compounds which have been assigned top priority by the Environmental Protection Agency for tolerance re-assessment using the 1996 Food Quality Protection Act guidelines [EPA, 1998]. (See box, p.26, on the use of organophosphate pesticides.)

Figure 3A4b

Chlorpyrifos was the leading insecticide applied to surveyed area, 1996-97 1/



1/ Represents 188 million acres of field crops, fruits, and vegetables. See appendix table B.5.
The letter "r" in the parentheses identifies ingredients that are restricted-use products. Not all formulations of the ingredient may be restricted.
The first value at the end of each bar is the area treated and the second value is the percent of total surveyed area receiving the ingredient.

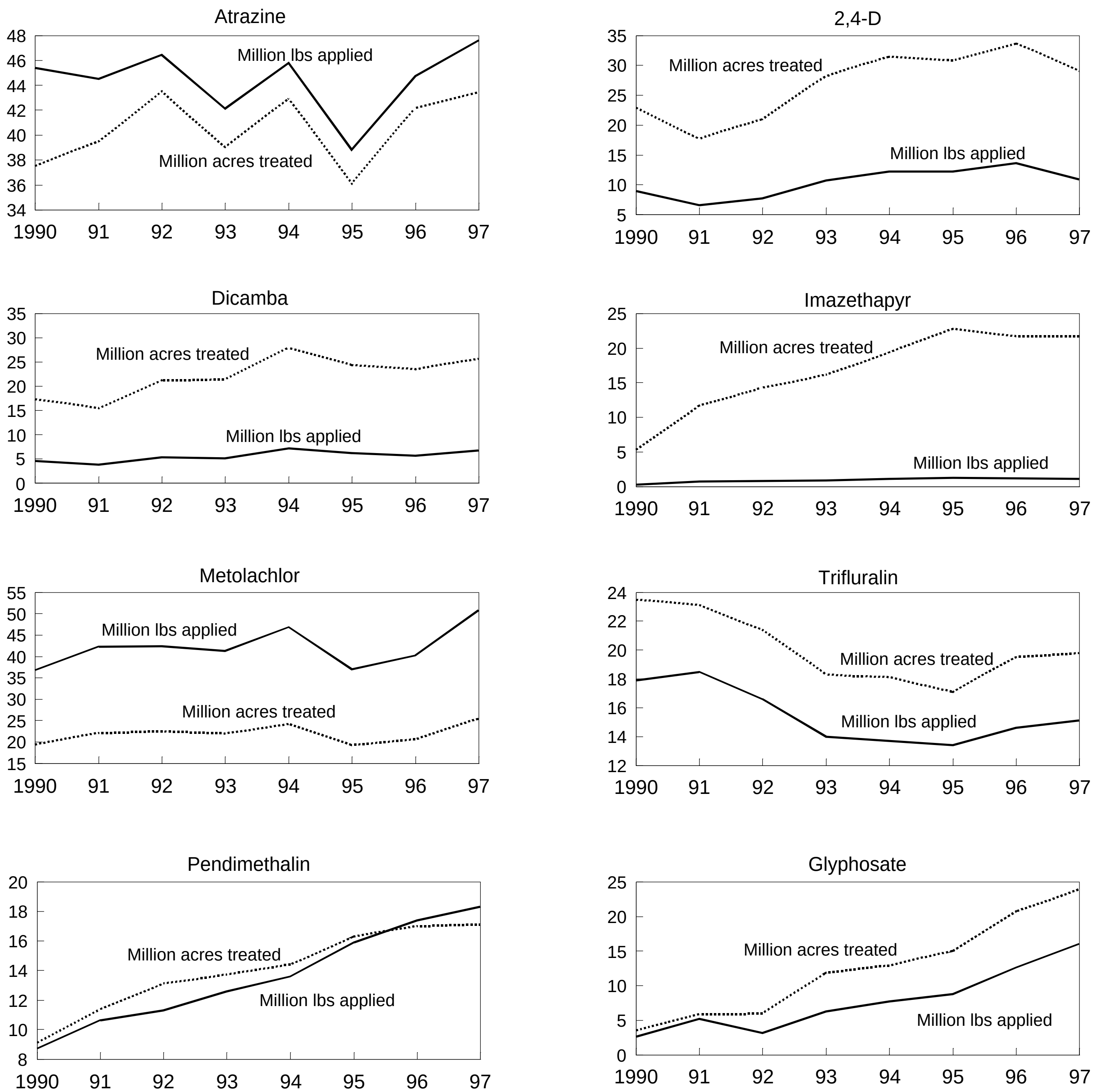
Sources: USDA, NASS and ERS, 1998a, 1998b, and 1997a.

Change in Herbicide Ingredients and New Herbicides Adopted between 1990 and 1997

Because the combination of pesticide ingredients used is constantly changing with the adoption of newer products and abandonment of older products, the trend in aggregate use masks most changes in the use of individual ingredients (figs. 3A4c). The development and use of new ingredients that are less toxic to humans and wildlife species, that quickly degrade to natural and safer compounds, and that are less likely to move into the atmosphere or water supplies can offer health and environmental benefits just as would any downward trend in aggregate quantity. Changes in the use of several leading herbicide ingredients are illustrated in this chart.

Figure 3A4c

Change in herbicide ingredients' use, 1990-97

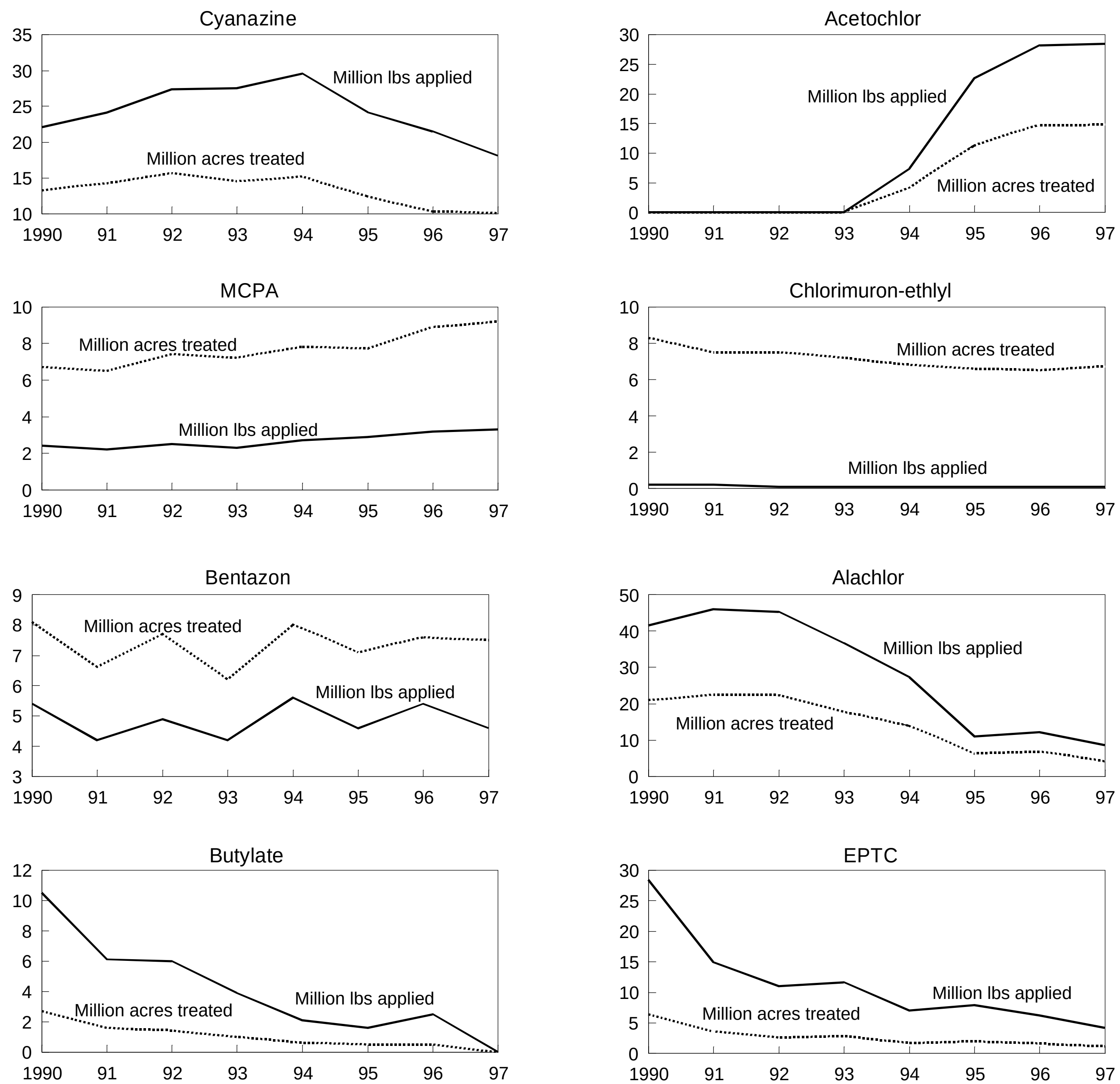


Source: USDA, NASS and ERS, 1996c and 1995c.

Acetochlor is a herbicide that was granted conditional registration by EPA in 1994 for use on corn. Its use climbed from 7 percent to 24 percent of the corn acreage between 1994 and 1997, while acreage treated with alachlor, a product that provides similar kinds of weed control on corn, dropped from 25 percent to 7 percent of the acreage. Acreage treated with glyphosate and imazethapyr more than quadrupled during the 5 years. Glyphosate use increased with the adoption of soybean seeds resistant to the herbicide. Imazethapyr is a relatively new ingredient used for soybeans and apparently a cost-effective substitute for older ingredients, like trifluralin. The area treated with atrazine fluctuated between 64 and 69 percent of the planted corn acreage between 1990 and 1997 which is not significantly different from the 68 percent reported in a 1976 survey [Eichers, Andrilenas, and Anderson, 1978]. While the share of acres treated with atrazine has been stable, total quantities have declined some from reductions in application rates.

Figure 3A4c--Continued

Change in herbicide ingredients' use, 1990-97



Source: USDA, NASS and ERS, 1996c and 1995c.

Organophosphate Pesticides are used in the Production of Many Agricultural Crops

The Food Quality Protection Act of 1996 [PL 104-170] stipulates that risk assessments for pesticide use consider the aggregate exposure from all sources, including food, drinking water, and household uses and that an extra tenfold safety margin be made for food items common in the diets of infants and children (apples, peaches, pears, potatoes, carrots, sweet corn, green beans, peas, and tomatoes). Organophosphate pesticides have been identified by the U.S. Environmental Protection Agency to be the first family of pesticides to be reviewed under the new guidelines [EPA, 1998]. Some current uses of organophosphate pesticides on crops could be prohibited under these new assessment procedures.

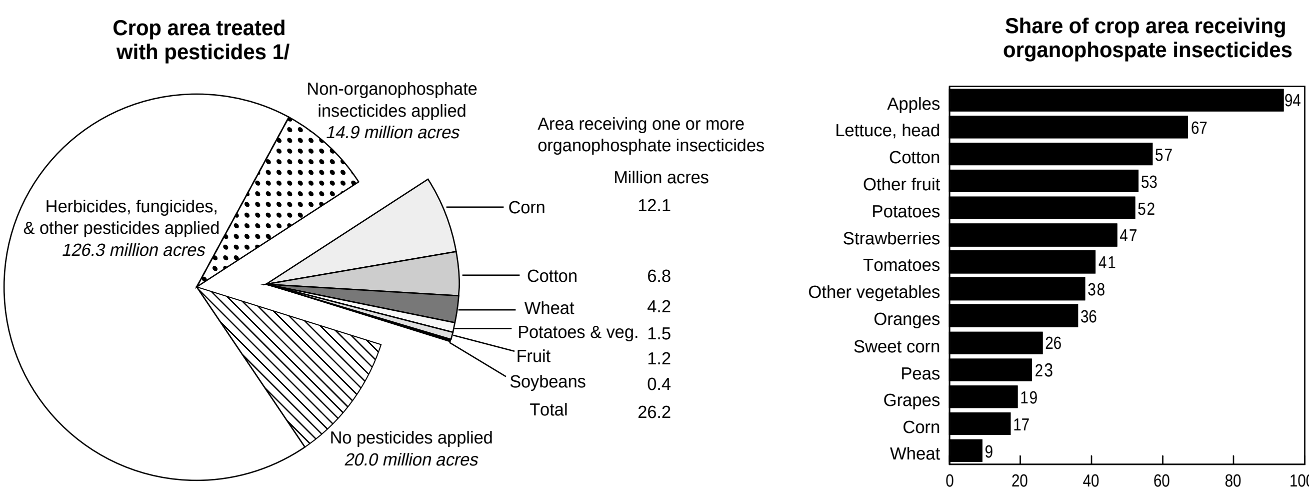
Organophosphate pesticides can affect the enzyme (acetylcholinesterase) which controls the nervous system. Organophosphate pesticides can be absorbed by inhalation, skin absorption, and ingestion, and certain organophosphates are prone to storage in fat tissues [EXTOXNET, web site]. The most common symptoms from overexposure are headaches, nausea, and dizziness, but they can cause sensory and behavior disturbances, lack of coordination, and depressed motor functions, and at high concentrations organophosphates can cause respiratory and pulmonary failure. The long-term effects of these chemicals, especially when the exposure is during early growth and developmental periods, are not fully known. Concern about those long-term effects is one reason for their re-assessment priority.

Farmers have used organophosphate pesticides for many years to reduce pest damages on many different crops. These pesticides can kill a broad spectrum of insect pests and have a longer persistence than some alternatives. A large share of the fruit and vegetable acreage is treated with organophosphate insecticides, but the major field crops of corn, cotton, and wheat account for most of the cropland area treated with these pesticides. Organophosphates were applied to over half the acreage of apples, peaches, pears, and potatoes, all of which are identified as most common in the diets of infants and children.

USDA's Agricultural Marketing Service collects data on pesticide residues in food, including fresh and processed fruits and vegetables [USDA, Agricultural Marketing Service, 1998]. In 1996, 4,856 fruit and vegetable samples were analyzed for residues of 78 different pesticide ingredients, including organophosphates that are most widely used in fruit and vegetable production. About 12 percent of the samples represented imported produce. Organophosphate pesticide residues were detected on many of the samples, but only three samples exceeded the established tolerance level for the commodity. Presumptive violations occurred on 90 samples where no tolerance has been set, but an organophosphate residue was detected.

Figure A

Organophosphate pesticides were applied to 14% of major field crops, potatoes, fruits, and vegetables, 1995-96



1/ Represents 188 million surveyed acres

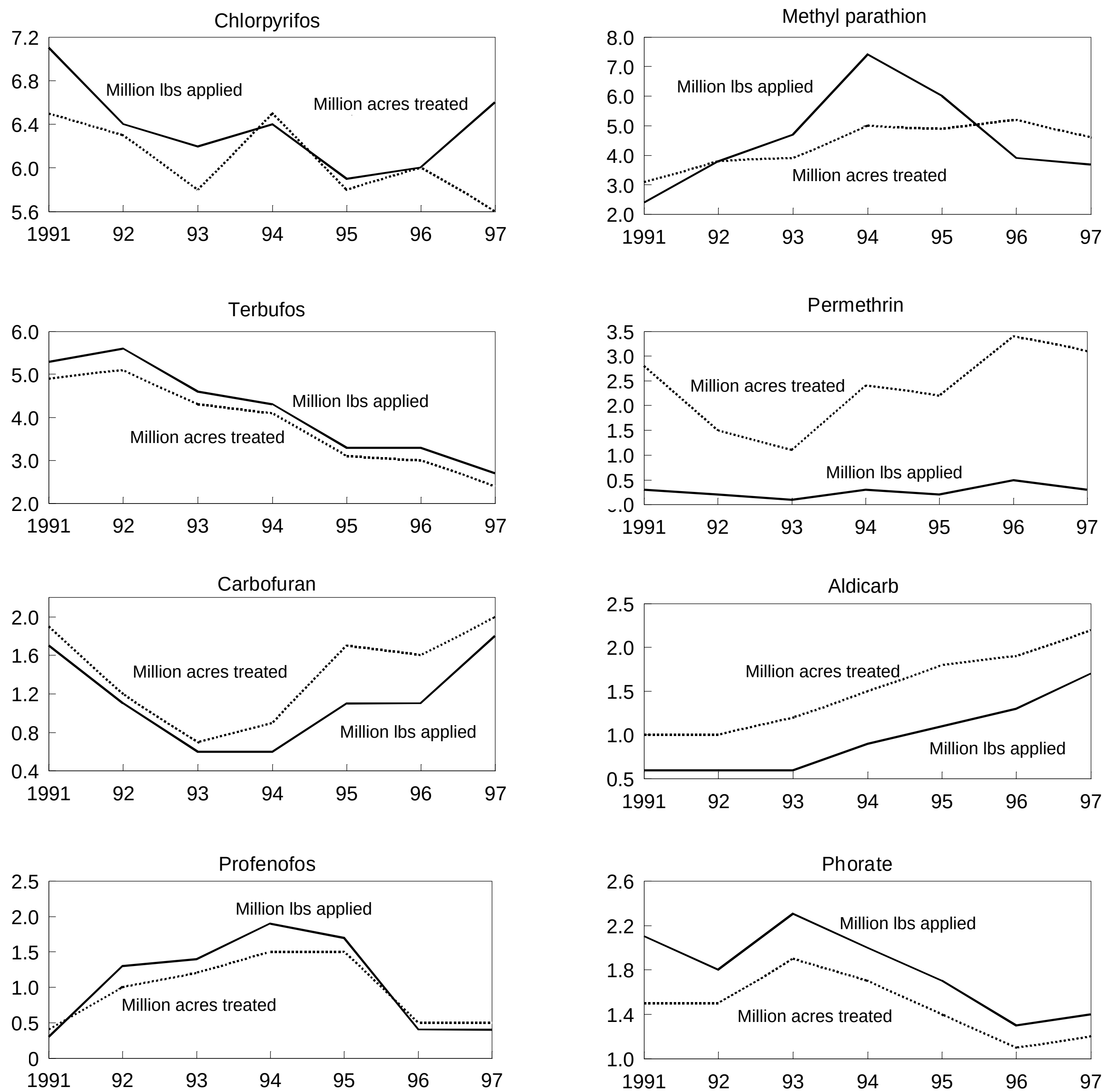
Sources, NASS, and ERS, 1996c, 1995d, and 1996d.

Change in Insecticide Ingredients, 1991-97

The use of some insecticide ingredients increased while others decreased or remained relatively unchanged between 1991 and 1997 (fig. 3A4d). Among the leading ingredients that decreased in use (chlorpyrifos, terbufos, and phorate) were those most commonly used to treat corn pests while those that increased (methyl parathion and aldicarb) were widely used to treat cotton pests. The use of methyl parathion more than doubled between 1991 and 1997.

Figure 3A4d

Change in insecticide ingredients' use, 1991-97



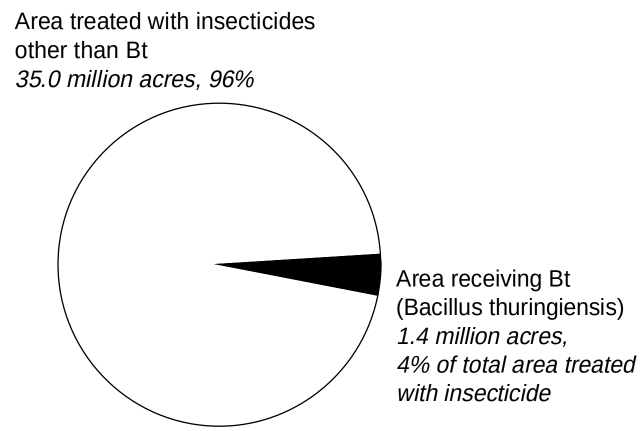
Source: USDA, NASS and ERS, 1996c and 1995c.

Bt (Bacillus Thuringiensis) Widely Applied on Vegetable Crops

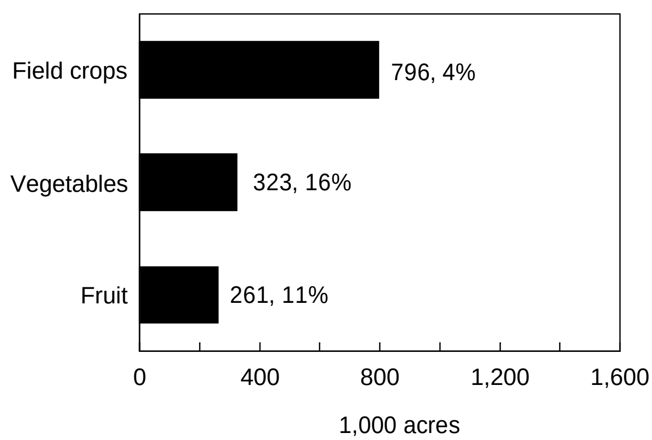
Bacillus thuringiensis or Bt is a microbial pesticide that can kill certain insect pests (fig. 3A4e). It is the most widely used microbial pesticide and is used to treat Colorado potato beetle, cotton budworm, and several other insects on fruit and vegetable crops [Meister, 1996]. Because Bt is a natural bacterial organism, it offers several health and environmental safety advantages over synthetic pesticides, but may not be as cost effective as conventional insecticides. Bt was used on only 4 percent of the total surveyed crop acreage treated with an insecticide, but it was used on more than 25 percent of the acreage of several vegetables (cabbage, celery, cucumbers, eggplant, head lettuce, peppers, processed spinach, fresh market tomatoes, strawberries, and raspberries). Corn and cotton, however, account for most of the area treated with Bt. Besides the pesticide ingredient, bioengineered seeds with Bt have been developed and are now being marketed for cotton, corn, and potatoes.

Figure 3A4e

Bt applied to 4 percent of area treated with insecticides, 1996-97 1/



Crops treated with Bt 2/



1/ Represents 36.4 million acres treated with an insecticide out of the 244 million acres that were represented by the surveys.
2/ The first value at the end of the bar is the area treated with Bt, and the second value is the percent of insecticide-treated area that was treated with Bt.

Sources: USDA, NASS and ERS, 1996b, 1997a, and 1997b.

Pesticide Use Trends by Pesticide Type: Total Quantities, Treated Area, Acre-Treatments, and Application Rates

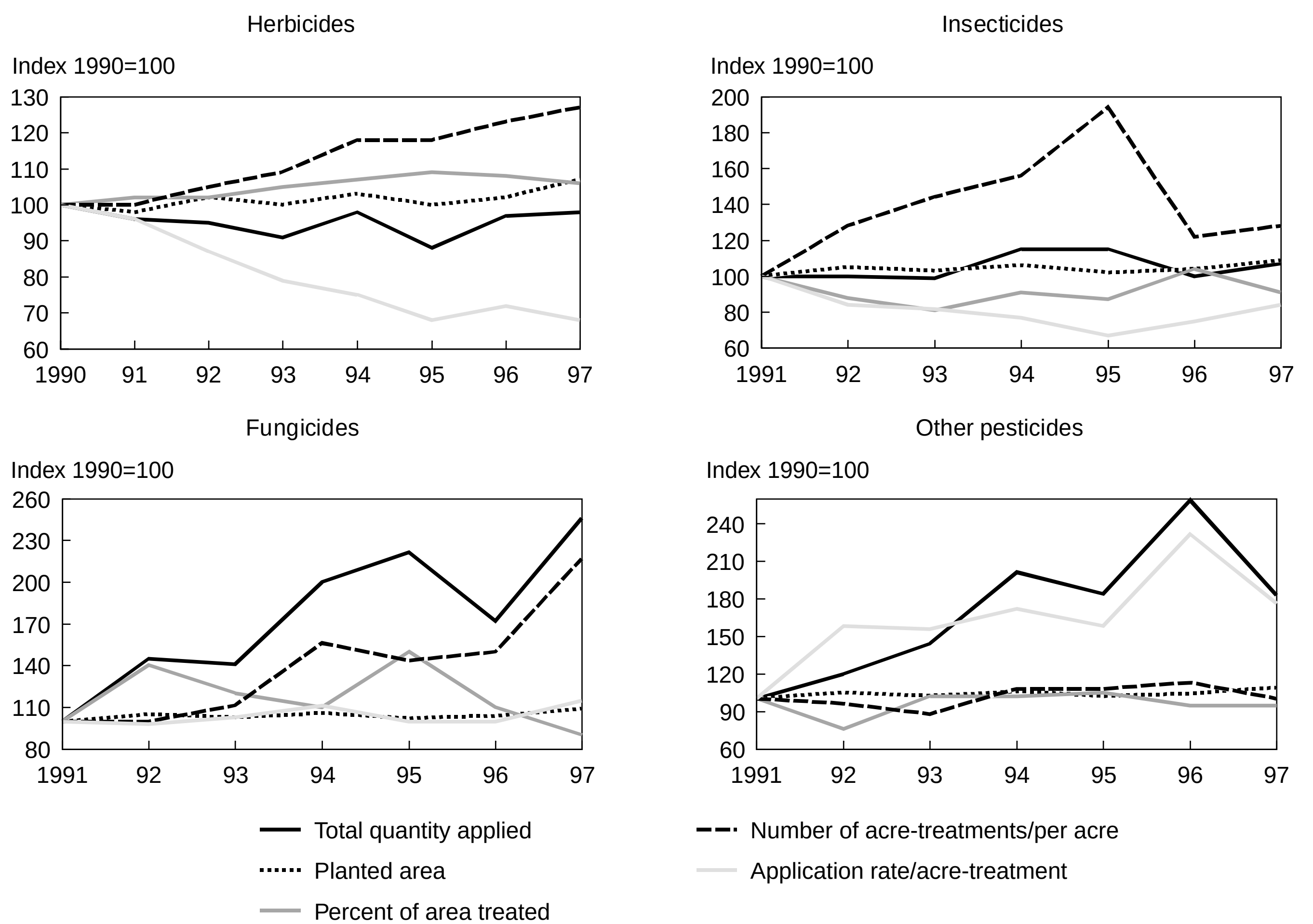
The trends in pesticide use were quite different for each pesticide type (fig. 3A5). The change in intensity of pesticide use can be divided into three components: (1) share of area receiving any pesticide treatments, (2) number of ingredient treatments per treated acre (acre-treatments), and (3) application rate per acre-treatment. The total quantity of pesticide used over a full production season is the product of these three intensity measurements and planted acreage. Because planted acreage remained relatively stable for the major field crops between 1990 and 1997, most of the changes in pesticide use were the result of various changes in intensity.

The share of acres treated gradually increased for herbicides and fungicides, but remained relatively unchanged for insecticides and other pesticides. The largest changes in the intensity of pesticide use occurred with the average number of acre-treatments and the application rates. For herbicides, the number of acre-treatments per acre increased while the application rates decreased. The net result was a slight decline in total herbicide use between 1990 and 1997. These trends in herbicide use can partially be attributed to a shift to ingredients applied at ultra-low rates and the increased use of several narrow-spectrum ingredients rather than a single broad-spectrum ingredient.

The trends for insecticides were somewhat similar but the net result was a slight upward trend for the total quantities of insecticides. For fungicides, the change was from an increase in both the share of acres treated and the number of acre-treatments. Fungicide application rates per treatment did not change substantially. The large increase in the use of "other pesticide" types was largely a result of increased application rates. The increase in application rates between 1991 and 1997 primarily results from a shift to sulfuric acid to kill potato vines prior to harvest. When used, sulfuric acid is applied at several hundred pounds per acre and can substitute for other desiccants applied at only a few pounds or ounces per acre.

Figure 3A5

Pesticide use trends by pesticide type, 1990-97



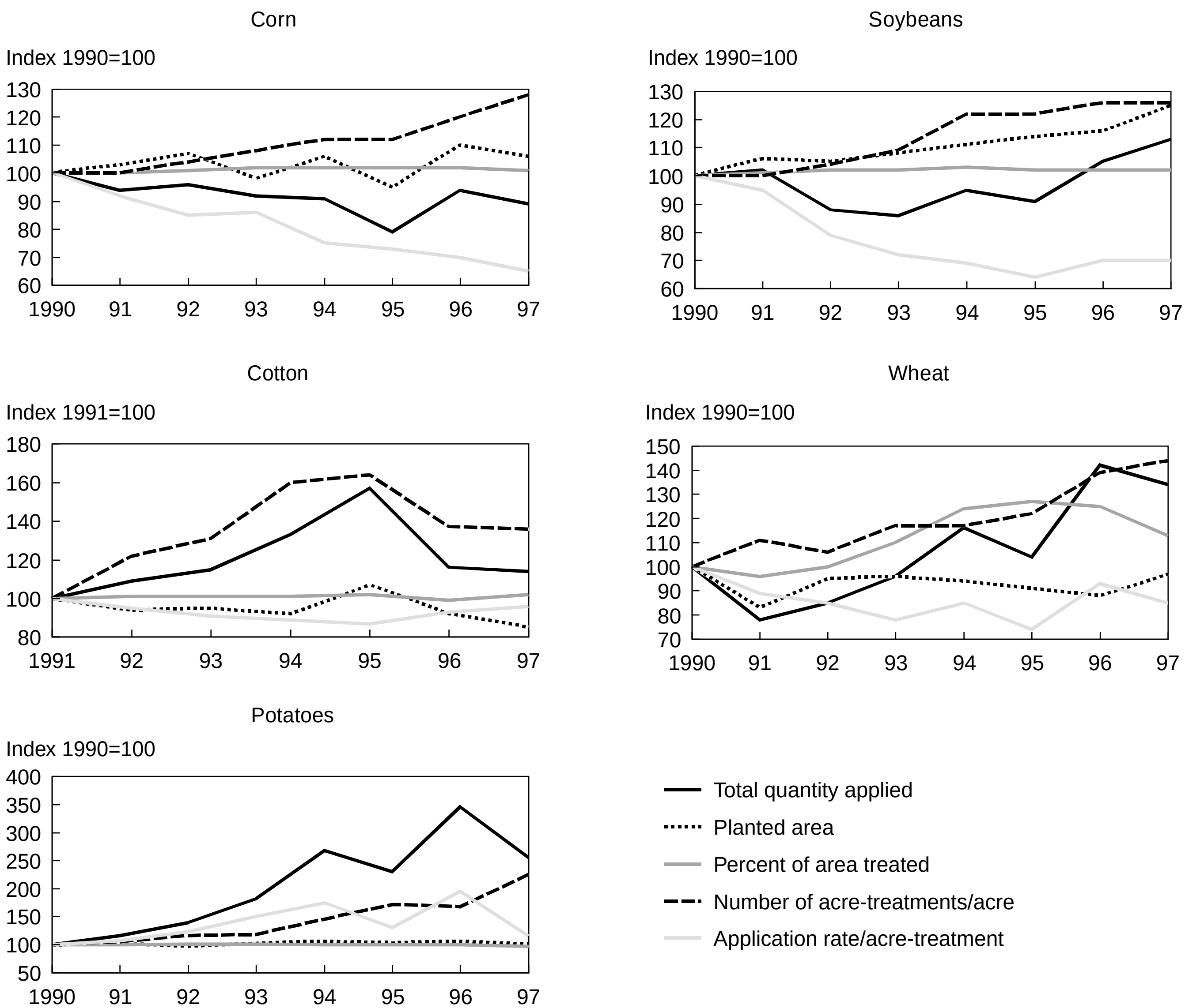
Source: USDA, NASS and ERS, 1995c and 1996c.

Pesticide Use Trends by Crop: Total Quantities, Treated Area, Acre-Treatments, and Application Rates

Changes in the intensity of pesticide use were also quite different among the surveyed crops (fig. 3A6). For corn and soybeans, the number of acre-treatments increased between 1990 and 1997, while the application rates decreased. Although slightly larger shares of both crops were treated, most of the increases in acre-treatments result from more acres treated with a combination of two or more ingredients rather than with a single ingredient. The decline in application rates came from the adoption of ultra-low application rate ingredients and from reductions in the rates of some individual ingredients, e.g., atrazine on corn. The net result from these changes was a slight decline in the total quantity of pesticides applied to both corn and soybeans. For wheat, similar trends in acre-treatments and application rates occurred, but the share of acres treated with pesticides increased. Pesticide use on wheat increased from 59 percent of the planted area in 1990 to 75 percent in 1995, then dropped back to 66 percent in 1997. For cotton and potatoes, the changes were mostly increases in the number of acre-treatments on the treated area. For cotton, the increase was due to additional treatments for insect control; for potatoes, it was for disease control.

Figure 3A6

Pesticide use trends by crop, 1990-97



Source: USDA, NASS and ERS, 1995c and 1996c.

Primary Target Insects

Research to develop biological pest control products, pest eradication programs, and integrated pest management have the potential to reduce pesticide treatments for several specific pests (fig. 3B). Many of these products and programs have been directed toward specific insects that account for the major share of the total pesticide treatments. The boll weevil and bollworm together were the primary target species for about two-thirds of all insecticide acre-treatments applied to cotton in 1994. The boll weevil eradication program has succeeded in eliminating the pest on nearly 3 million acres in North and South Carolina, Georgia, Florida, Arizona, and California [APHIS, 1998].

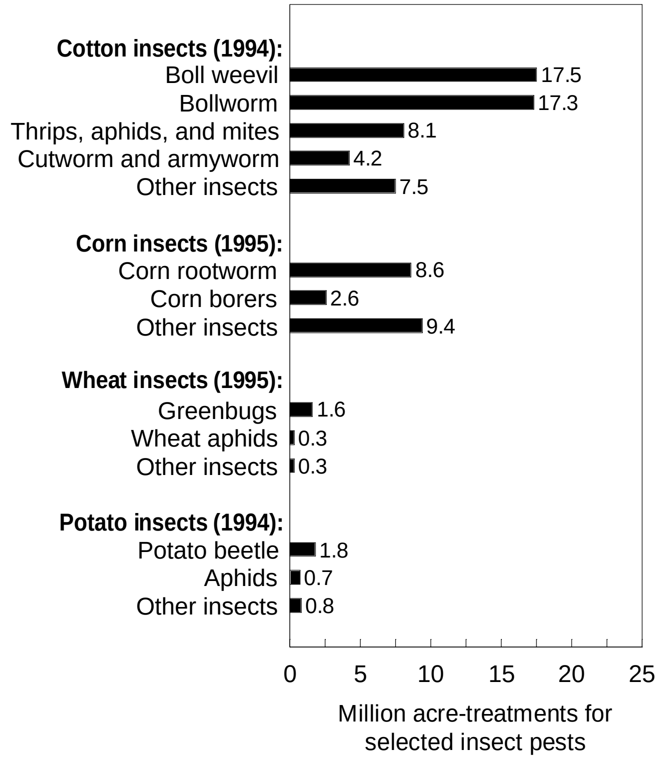
The emerging technology of Bt-transgenic seeds also holds a promise for reduced pesticide needs on corn, cotton, and possibly other crops. These transgenic crops produce a protein toxin in the plants that has been successful in controlling cotton bollworms, corn borers, and some other insect pests in these and other crops. Bollworms were the primary target species for 17.5 million (32 percent) insecticide acre-treatments on cotton in 1994, and the corn borer was the target pest for 2.6 million acre-treatments (13 percent) of all corn treatments in 1995. The Bt-transgenic corn and cotton seeds were first marketed for widespread use in 1996 and have the potential to reduce the amount of pesticide used for these target pests.

Most insecticide acre-treatments on corn are for corn rootworm control. Corn rootworm can usually be controlled by planting another crop in rotation with corn that does not serve as a host to the pest. Corn rootworm treatments are most common in the Plains regions and other areas where a nonhost crop is often less profitable than continuous corn. Corn rootworms have developed resistant species to several conventional insecticides in the past and since 1993 there is evidence that some rootworm species survive in corn-soybean rotations.

Most insecticide acre-treatments on wheat are for greenbugs and on potatoes for potato beetles. Both pests have developed biotypes resistant to several kinds of insecticide products prompting farmers to seek integrated pest management practices to reduce reliance on chemical control methods.

Figure 3B

Cotton boll weevil and bollworm and corn rootworm were primary target insects, 1994-95



Sources: USDA, NASS and ERS, 1995c.

Pest Monitoring Practices

Most definitions and applications of integrated pest management include pest-monitoring activities as a major element. Information about the presence and infestation levels of different pest species or beneficial organisms is essential for making sound economic decisions concerning the use of pest prevention or intervention practices. Treatment decisions that are based on economic decision rules or thresholds require specific measurements of pest infestation. An economic threshold, in general, is the pest infestation level at which the expected crop damages exceed the cost of treatment necessary to prevent those damages [Headly, 1972]. Economic thresholds have been developed for major insect pests using research that accounts for (1) the crop yield damage caused by pests at a known level of infestation, (2) the revenue loss from pest damage, and (3) the treatment costs. When this information is available, farmers can monitor pests in a field and apply the threshold pest number to decide whether a treatment is needed.

Even though scientifically developed thresholds are not available for all crop-pest situations, pest monitoring is still a valuable practice for making informed decisions. Some pests quickly reproduce to damaging infestation levels and just their presence can warrant preventive or intervention treatments. Knowledge of particular pest species, of changes in infestation levels, or of developmental stages also helps farmers select the appropriate pesticide ingredients, time of application, or treatment method. Monitoring for the purpose of making timely and appropriate treatments can prevent future spreading of the pest, development of pesticide-resistant species, or harm to beneficial organisms.

Professional Scouting Most Common on Cotton and Specialty Crops

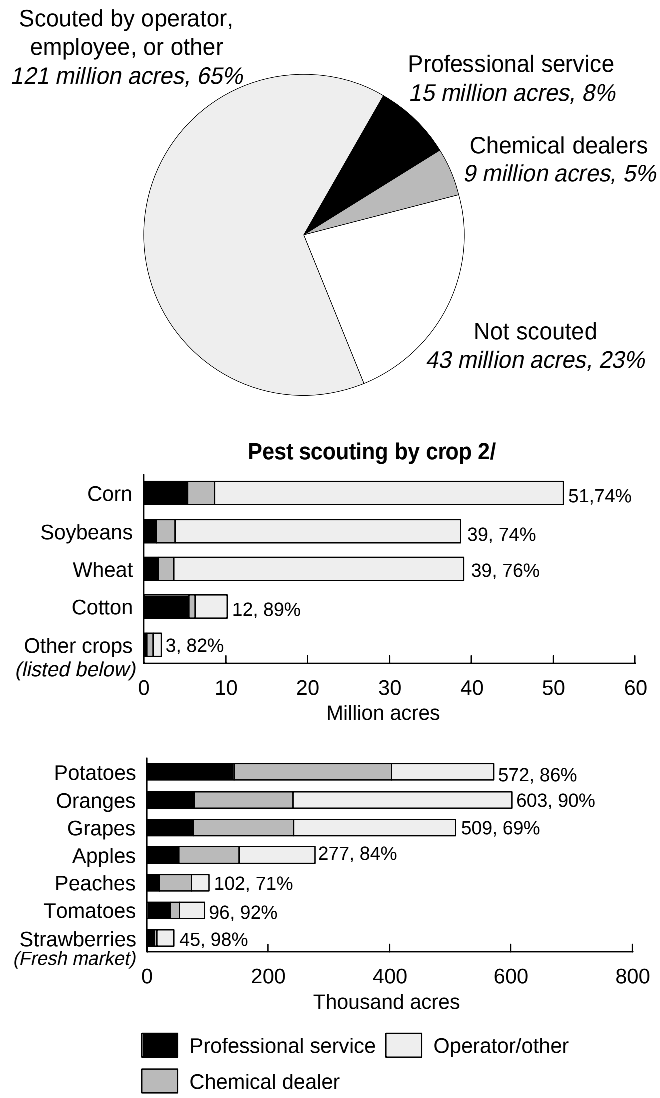
Scouting fields for insects, weeds, and diseases is a common form of pest monitoring (fig. 3C1). In general the process involves examining several small sections of a field or different plants to identify the presence of a pest species, to measure their population or infestation, or assess their developmental stage. The rigor by which the scouting process is applied can vary widely between regions, crops, and pest species. Some weed species can be monitored by rather casual observations while small insects, mites, or disease organisms require close examination or dissection of plant tissues.

USDA's Cropping Practices and Chemical Use Surveys in 1994 and 1995 collected general information about pest scouting on several crops [USDA, NASS and ERS, 1994; USDA, NASS and ERS, 1995c; USDA, NASS and ERS, 1995d]. Producers were asked if their fields were scouted for weeds, insects, or diseases and who did the scouting.

For most crops, either the operator, family member, or farm employee was most often reported as the person doing the

Figure 3C1

Professional scouting most common on cotton and specialty crops, 1994-95 1/



1/ Represents 188 million acres of surveyed crops.
2/ The first value at the end of each bar is the total acreage scouted and the second value is the percentage of crop area scouted.
Source: USDA, NASS and ERS, 1995c, 1995d, and 1994.

scouting. Approximately 8 percent of the surveyed crop area was scouted by a professional scouting service or crop consultant. An additional 8 percent was scouted by representatives of chemical dealers. Some scouting was also done by representatives of food processors or others.

Professional scouting services, crop consultants, representatives of chemical dealers and processors, or other professionals scouted over half of the cotton, potato, peach, and tomato acres.

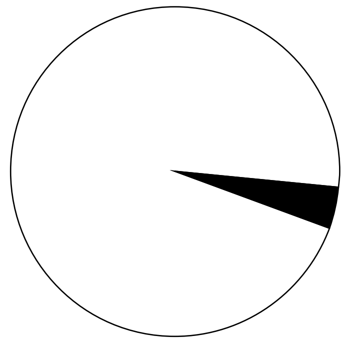
Soil and Tissue Testing for the Presence of Pests Most Common on Specialty Crops

Soil and tissue testing are sometimes used to determine the presence or population of pests that cannot be effectively monitored by scouting or casual observations (fig. 3C2). Early detection and treatment during dormant or early developmental stages are often the most cost-effective way to treat several kinds of pests. Soil or tissue testing can detect the presence of egg masses, weed seeds, or other micro-organisms, and the information can be used to determine if the pests are likely to cause economic losses if left uncontrolled.

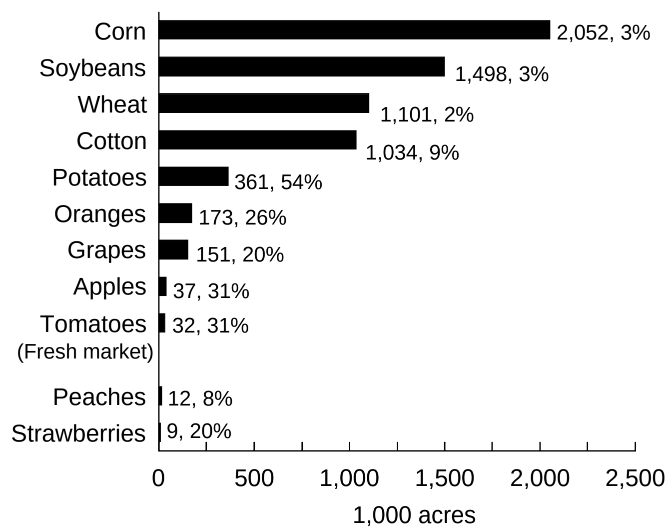
Soil or tissue testing was applied to about 4 percent of the surveyed crop acres. While most of the tested acres were major field crops, the practice was used on a larger share of potatoes, vegetables, and fruit crops. Soil and tissue testing were reported on over half of the potato acres in the four surveyed States. Soil tests in soybeans are often for cyst nematodes while those for corn are for corn rootworm.

Figure 3C2

Soil and tissue testing for the presence of pests most common on specialty crops, 1994-95 1/



Soil and tissue testing for the presence of pests, by crop 2/



1/ Represents 188 million acres of surveyed crops.

2/ The first value at the end of the bar is the acreage tested, and the second value is the percentage of crop area tested.

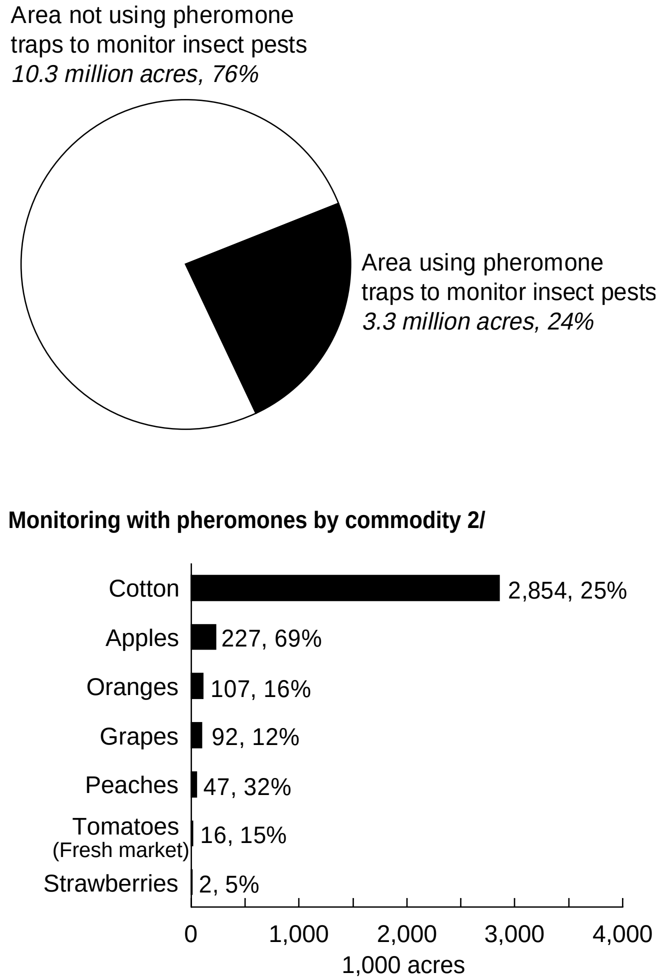
Sources: USDA, NASS and ERS, 1994, 1995c, and 1995d.

Monitoring Insect Pests with Pheromones

Pheromones are semio-chemicals (behavior-modifying chemicals) produced by pests and emitted to attract a mate (fig. 3C3). Pheromones have been synthetically produced for some insects and are used to lure specific insect pests into traps for the purpose of monitoring infestation levels and their developmental stages. Pheromones can also be used to control insect populations by disruption of mating. (See p. 39.) The number of insects found in traps over a period of time can be compared with thresholds to determine whether a treatment is needed. Also, the developmental stage of trapped insects is useful to determine appropriate timing of pest treatments. Such traps are widely used to monitor pests on cotton and in fruit orchards. Pheromone traps were reported to have been used on over two-thirds of the apple acres.

Figure 3C3

Monitoring insect pests with pheromones, 1994-95 1/



1/ Represents 13.6 million acres of cotton, apples, oranges, grapes, peaches, tomatoes, and strawberries.

2/ The first value at the end of the bar is the acreage monitored, and the second value is the percentage of crop area monitored.

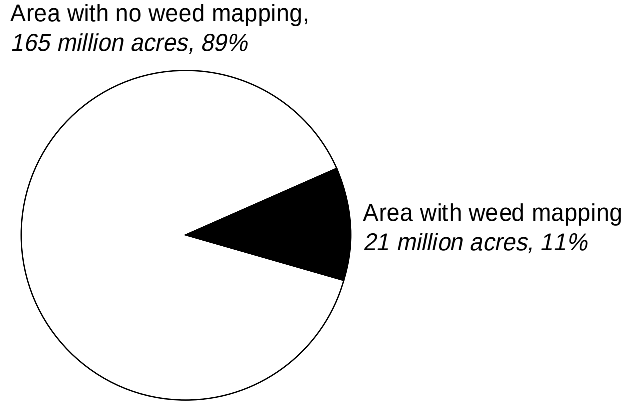
Sources: USDA, NASS and ERS, 1994, 1995c, and 1995d.

Weed Mapping to Aid Herbicide Treatment Decisions

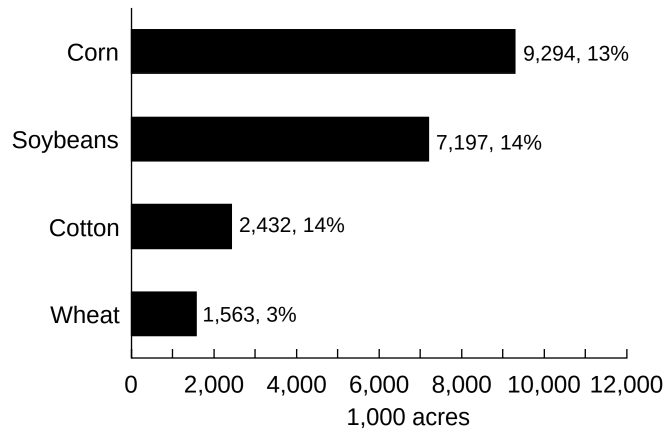
The use of preemergence herbicides, which are applied early in the growing season to kill weeds as they germinate, is the most common form of weed treatment on field crops. Field mapping is a practice that identifies the location, species, and infestation of weeds in fields for the purpose of making decisions about future preventive treatments. Mapping weeds helps producers select appropriate herbicide ingredients and application rates and also helps detect the presence of any herbicide-resistant species. Precision farming, a technology that varies pesticide treatments according to changing field conditions, also requires mapping information to program equipment or to apply spot treatments within the field. The practice was reported on about 11 percent of the area (fig. 3C4).

Figure 3C4

Weed mapping to aid herbicide treatment decisions, 1994-95 1/



Weed mapping on field crops 2/



1/ Represents 186 million acres of corn, soybeans, wheat, and cotton.
2/ The first value at the end of each bar is the acreage mapped, and the second value is the percentage of crop area mapped.

Sources: USDA, NASS and ERS, 1995c.

Practices to Reduce Pest Infestations

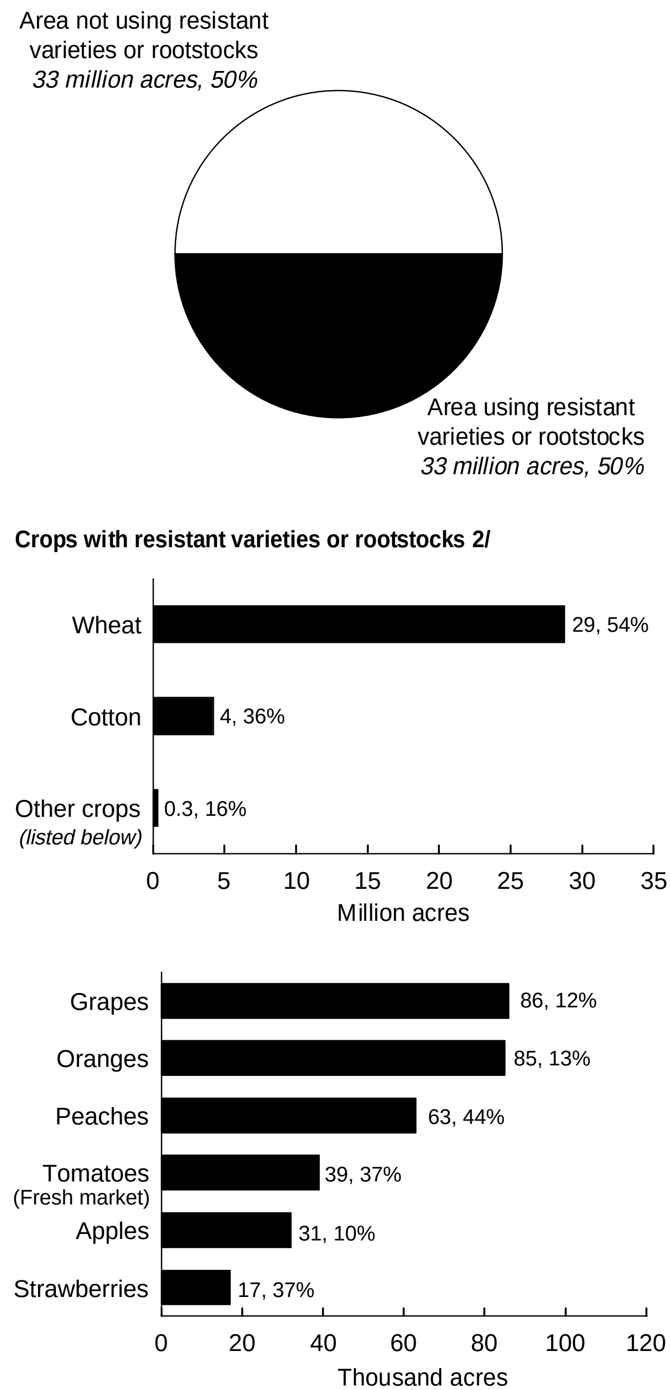
Growers use several practices to reduce pest infestations and to eliminate or reduce the need for pesticides. They include several cultural and biological practices that are often components of integrated pest management.

Planting Pest-Resistant Varieties or Rootstocks

Planting pest-resistant varieties of crops or using pest-resistant rootstock in fruit orchards is an available alternative to control certain crop diseases and pests (fig. 3D1). Plant breeding programs have been successful in developing more disease-resistant varieties of wheat, corn, cotton, potatoes, and apples. The cost to growers is generally less than costs associated with using pesticides. Resistant varieties were used on a large share of the wheat (54 percent) and peach (44 percent) acreage.

Figure 3D1

Planting pest-resistant varieties or rootstocks, 1994-95 1/



1/ Represents 67 million acres of wheat, cotton, oranges, apples, grapes, peaches, tomatoes, and strawberries.
2/ The first value at the end of each bar is the acreage planted with pest-resistant varieties or rootstock, and the second value is the percentage of crop area with this characteristic.

Source: USDA, NASS and ERS, 1994, 1995c, and 1995d.

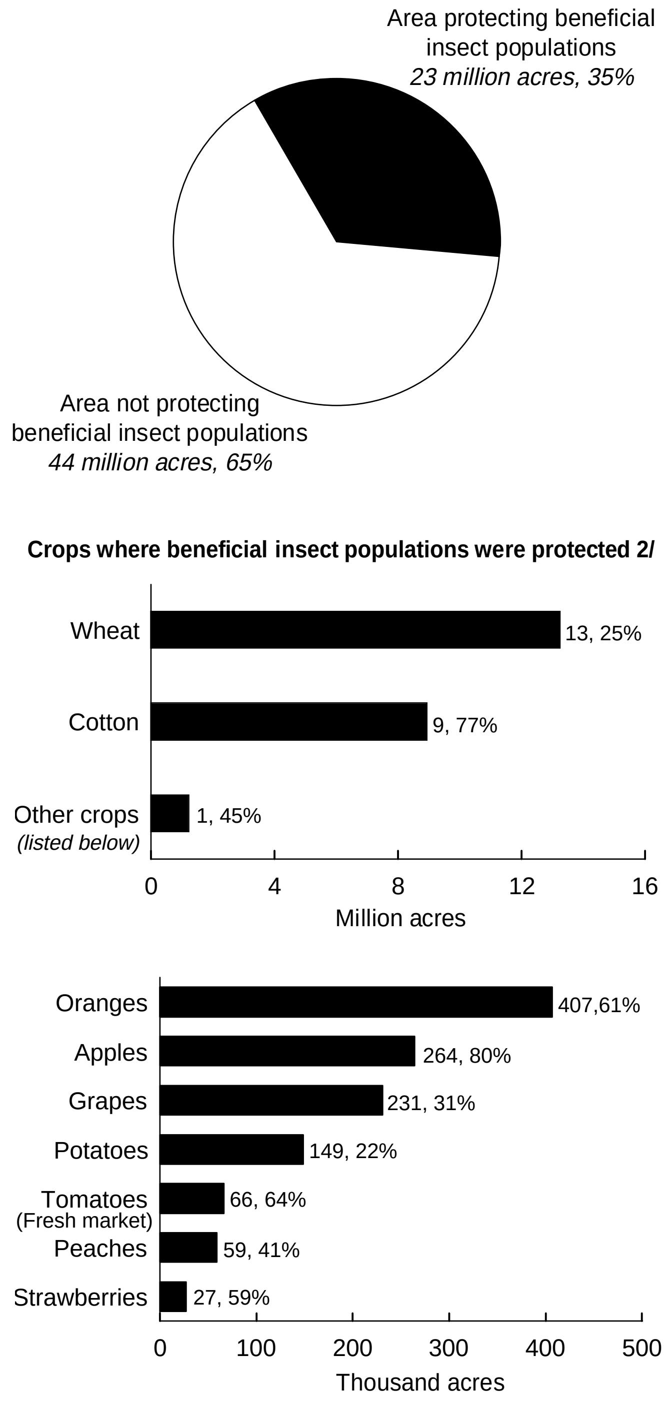
Protecting Beneficial Insect Populations

Beneficial insects are those that are natural predators of other pests. They may already be present in the crop fields or they may be purchased and released. Examples include lady beetles and green lacewings for treating fruit mites and naturally occurring parasites that are harmful to alfalfa weevils and cereal leaf beetles. This biological method provides successful control for some crop-pest situations and reduces the need for pesticide intervention.

Beneficial insect populations were protected on approximately one-third of the surveyed acreage (fig. 3D2). Special precautions to protect beneficial insects were most common on commodities that have high use of insecticides—cotton, fruits, and vegetables.

Figure 3D2

Protecting beneficial insect populations, 1994-95 1/



1/ Represents 67 million acres.
2/ The first value at the end of each bar is the acreage receiving protection, and the second value is the percentage of crop area receiving protection.

Source: USDA, NASS and ERS, 1994, 1995c, and 1995d.

Purchasing and Releasing Beneficial Insects

When not naturally present, beneficial insects are sometimes purchased and released into crop fields for the purpose of suppressing pests and averting crop damage (fig. 3D3). For some crop-pest situations, beneficials can control pests without pesticide applications. When the level of infestation is too high, producers may first destroy pests with a pesticide and then introduce beneficials following the pesticide treatments to control subsequent generations.

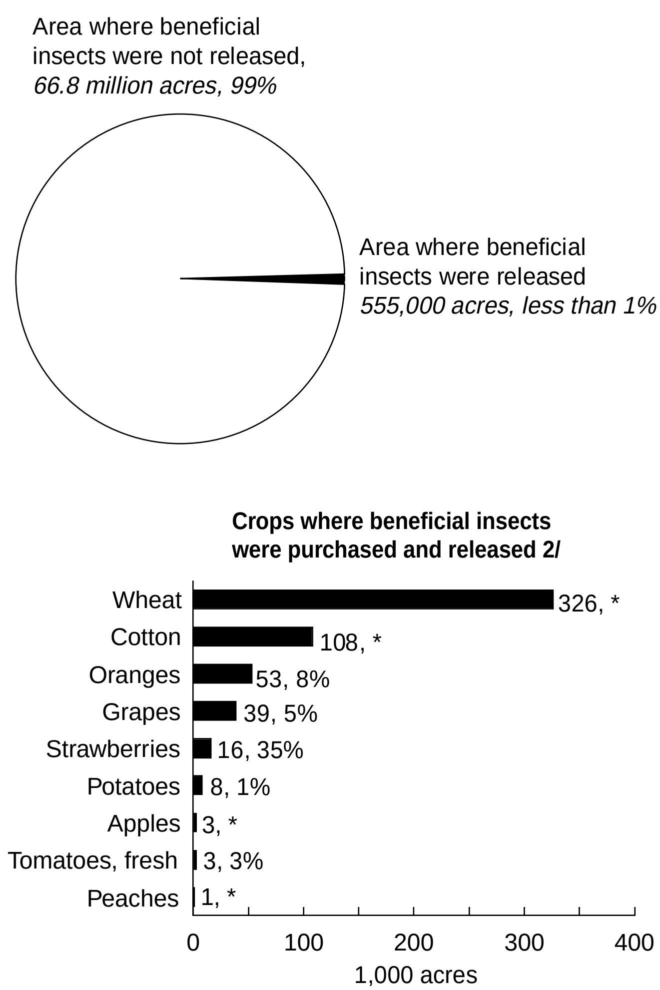
Less than 1 percent of the surveyed crops were affected by the release of beneficial insects in the field or surrounding area. The practice was most common on strawberries.

Adjusting Planting Dates to Avoid Pests

Pest populations mature and reach peak concentrations at specific times. Adjusting planting dates can help avoid pest populations being in the fields at critical times to cause crop damage (fig. 3D4). A notable example is the Hessian-fly safe dates for planting winter wheat. Delaying wheat planting until after these "safe" dates assures less damage by insects than earlier plantings. Planting dates are also planned to avoid weather conditions that are conducive to plant diseases. Pest avoidance was considered in planting decisions on approximately one-third of the surveyed acres.

Figure 3D3

Purchasing and releasing beneficial insects, 1994-95 1/

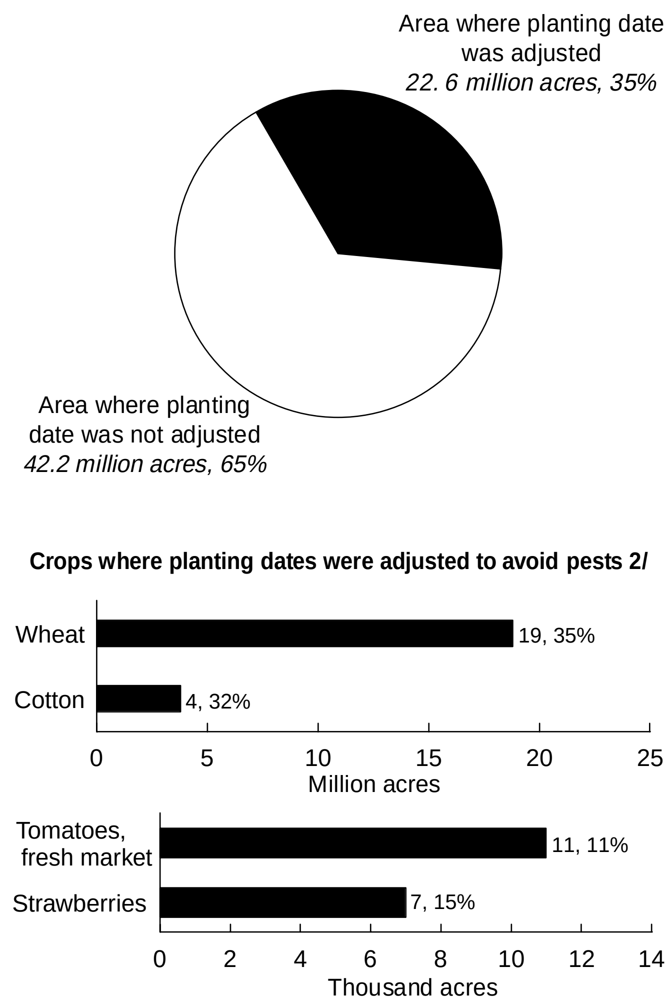


1/ Represents 67 million acres of surveyed crops.
2/ The first value at the end of each bar represents the acreage using beneficial insects and the second value is the percentage of crop area using them. An " * " indicates that beneficial insects were used on less than 1 percent of area.

Sources: USDA, NASS and ERS, 1994, 1995c and 1995d.

Figure 3D4

Adjusting planting dates to avoid pests, 1994-95 1/



1/ Represents 65 million acres.
2/ The first value at the end bar is the acreage where planting date was adjusted to avoid pests and the second value is the percentage of crop area for which the planting date was adjusted.

Sources: USDA, NASS and ERS, 1994, 1995c, and 1995d.

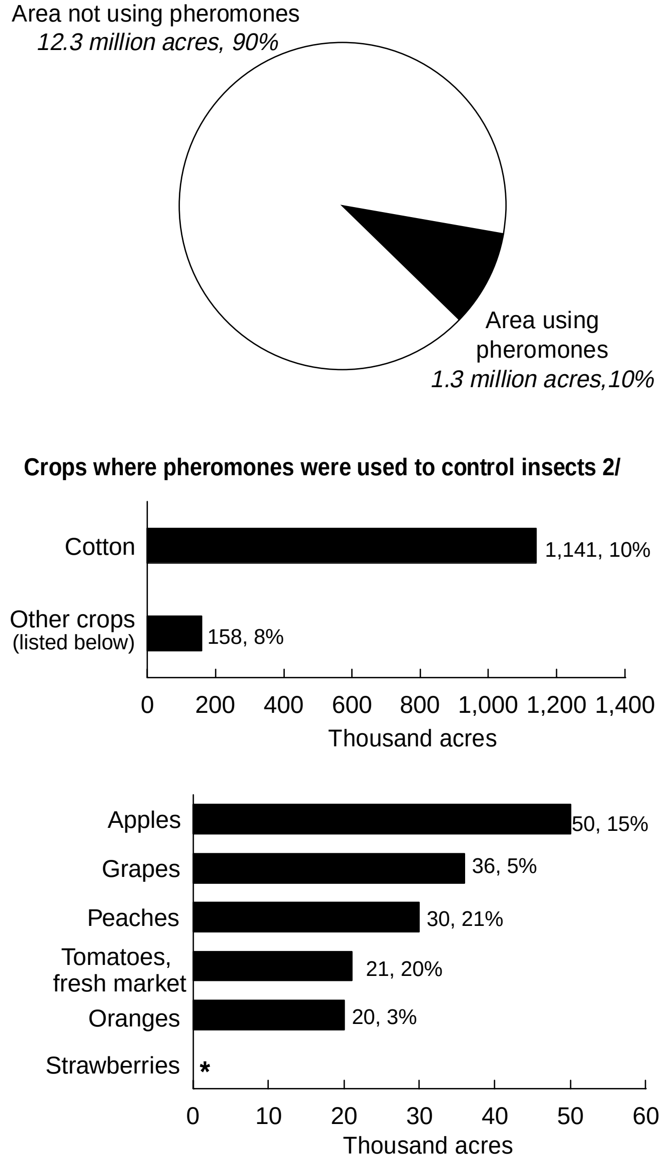
Controlling Insect Pests with Pheromones

Besides monitoring, pheromones are also used as a stimulus to disrupt the mating process, thus controlling and suppressing the pest population (fig. 3D5). Kits that slowly release the pheromone into the air are placed throughout crop fields. Usually males of the particular insect species are lured by the pheromone and few are able to find females and mate successfully. Synthetic pheromones continue to be developed for additional species and are now available for several common insect pests including pink bollworm, oriental fruit moth, and codling moth. Some benefits of using pheromones are long-term reduction in pest population for the treated areas, little or no mammalian toxicity, and compatibility with cultural practices and natural control agents.

Pheromones were used for controlling pest populations on 10 percent of the surveyed area. Pheromones often cost more than insecticide treatments. Also, the treatment does not provide 100-percent control as some females are still able to mate successfully and others can migrate into surrounding areas to lay eggs.

Figure 3D5

Controlling insect pests with pheromones, 1994-95 1/



1/ Represents 13.6 million acres of cotton, fruits, and vegetables.
2/ The first value at the end of each bar is the acreage using pheromones, and the second value is the percentage of crop area using pheromones.
*=Less than 1 percent.

Sources: USDA, NASS and ERS, 1994, 1995c, and 1995d.

Treating Seeds with Pesticides

Treating seeds with pesticides protects the seeds from diseases or pests while in storage as well as preventing losses from pests after planting (fig. 3D6). Seed-borne diseases, like septoria seedling blight in wheat, can be avoided by seed treatments. Seed treatments or seed coating can also prevent damage from soil insects before the seed germinates.

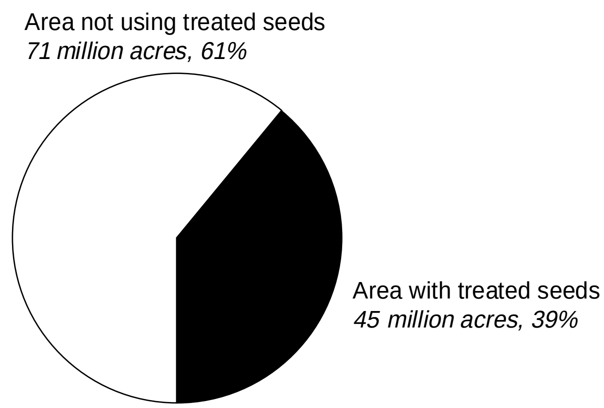
For the major field crops surveyed—wheat, soybeans, cotton, and potatoes—39 percent of total acres used treated seeds. Most noted were cotton (81 percent) and potatoes (80 percent). Treated seedcorn was not included in the survey as nearly all hybrid seedcorn receives pesticide treatments.

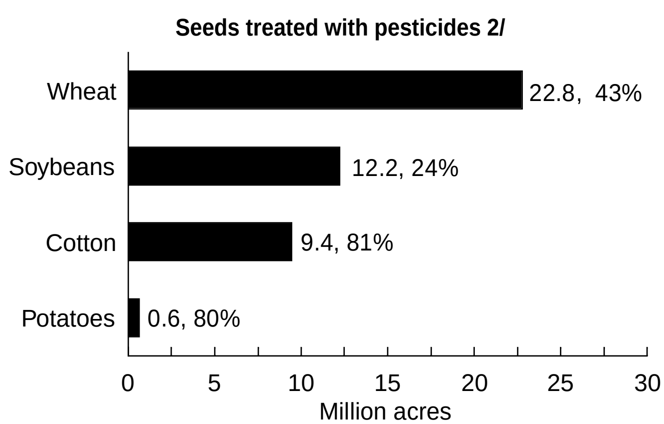
Planting Herbicide-Resistant Seedcorn

Recently, seeds have been developed that allow treatment with herbicides that previously damaged the crop (fig. 3D7). Specifically, seedcorn is now marketed with resistance or tolerance to imidazoline herbicides. Imidazoline herbicides inhibit the synthesis of certain amino acids as the mode of action (ALS inhibitors) and can be alternated with herbicides, such as triazines, that have a different mode of action to reduce the development of resistant weed species. Also, the broader choice of herbicides offers greater flexibility for controlling difficult weed species. For no-till systems that may eliminate the need for soil-incorporated herbicides, the new seeds offer a post-emergence treatment for grassy weeds. Soybeans are also being developed and marketed that are resistant to additional herbicides, including glyphosate (sold as Roundup Ready).

Figure 3D6

Treating seeds with pesticides, 1995 1/



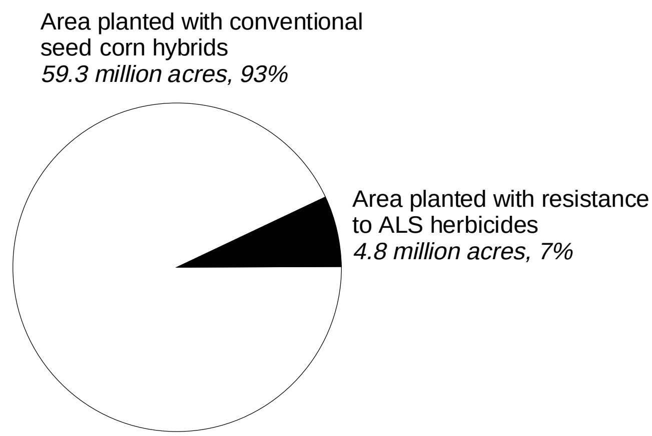


1/ Represents 116 million acres.
2/ The first value at the end of each bar is the acreage with seed treatments, and the second value is the percentage of crop area with seed treatments.

Sources: USDA, NASS and ERS, 1995c.

Figure 3D7

Corn planted with resistance to ALS-inhibitor herbicides, 1995



Sources: USDA, NASS and ERS, 1995c.

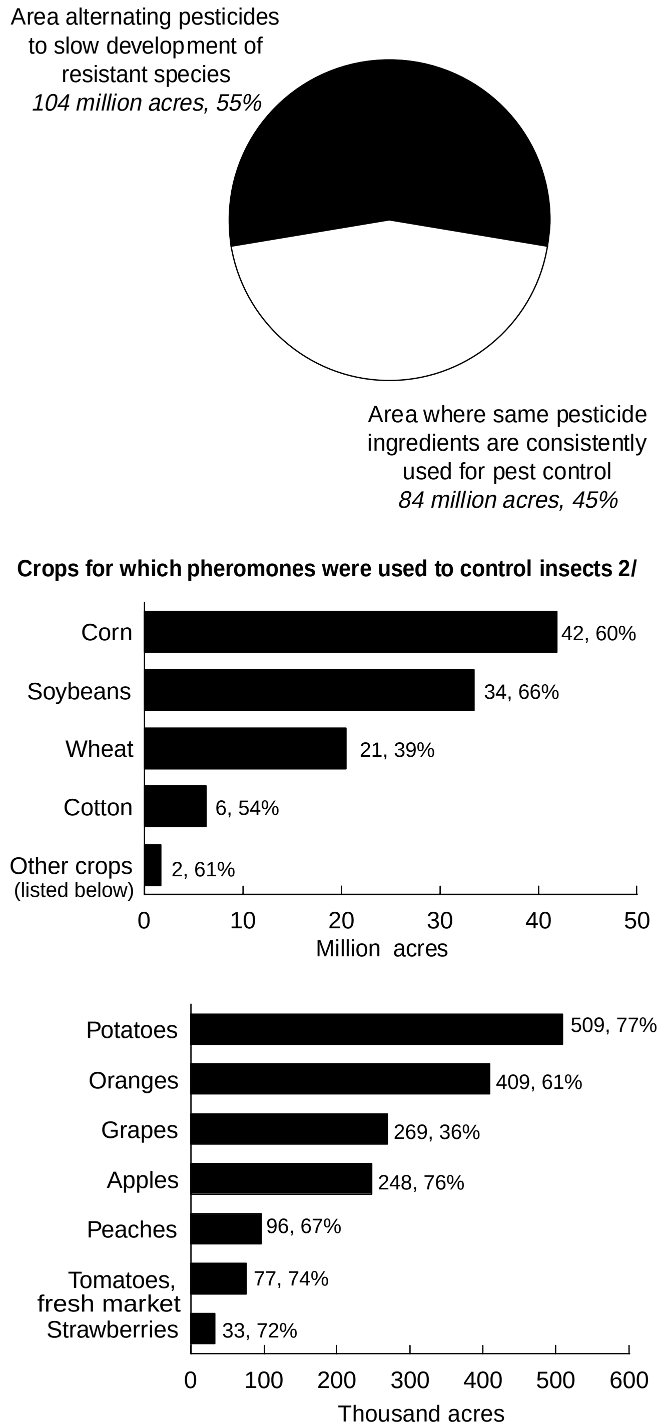
Alternating Pesticides to Slow Development of Resistant Species

Pest populations can develop resistance to a particular pesticide or pesticide family over time. A few individuals from a pest population can inherit genetic characteristics that withstand the pesticide. These surviving species are the genetic pool for future generations, which are also likely to have the resistant trait. Repeated applications with the same pesticide can result in a population dominated by resistant species that require alternative means of control. Resistance has been identified as a problem in treating many crop pests, but has been most notable for insect pests of cotton and potatoes. Accounting for yield losses, alternative treatments, and environmental damages, pesticide-resistance costs have been estimated at more than $1 billion (Meister, 1995).

Rotating pesticides from year to year is a practice that slows the development of resistant strains of insects or weeds (fig. 3D8). Approximately half of the surveyed acres were treated by alternating pesticides for the purpose of slowing resistance. Of the field crops surveyed, potatoes and soybeans were the crops that most used this practice. Of the fruit and vegetable crops, apples, fresh tomatoes, and strawberries were highest users.

Figure 3D8

Alternating pesticides to slow development of resistant species, 1994-95 1/



1/ Represents 188 million acres of surveyed crops.
2/ The first value at the end of each bar is the acreage on which pesticides were alternated, and the second value is the percentage of crop area on which pesticides were alternated.

Sources: USDA, NASS and ERS, 1994, 1995c, and 1995d.

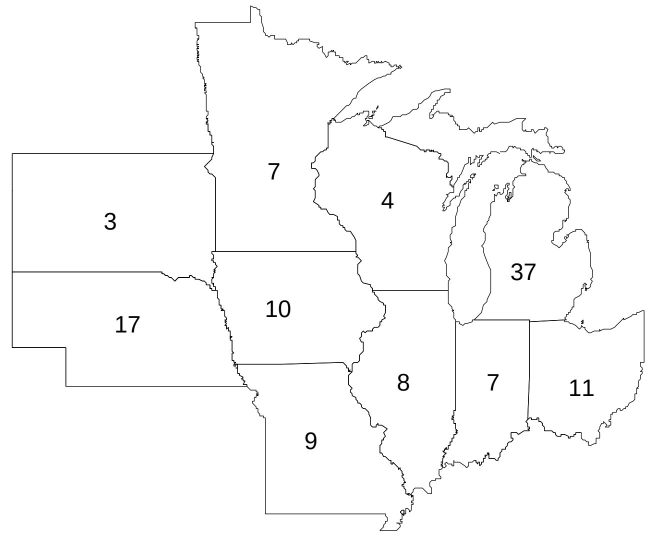
Triazine-Resistant Weeds in Corn, 1996

Repeated applications of triazine herbicides (atrazine, simizine, cyanazine, metribuzin, and others) can result in weeds resistant to the chemical. Weeds that are resistant to triazine herbicides are among the more common resistant biotypes found in corn fields. In 1996, farmers in major production States reported the presence of some triazine-resistant weeds on 10 percent of their planted corn area. The share of area with triazine-resistant weeds ranged from 3 percent in South Dakota to 37 percent in Michigan (fig. 3D8a). Some of the practices used by farmers to retard the development of resistance to triazines or other herbicides include alternating herbicides with different modes of action, crop rotations, and field cultivations.

Figure 3D8a

Triazine-resistant weeds in corn acreage, 1996

Percentage of planted corn area with triazine-resistant weeds



Sources: USDA, NASS and ERS, 1996c.

Pesticide Application Decision Factors

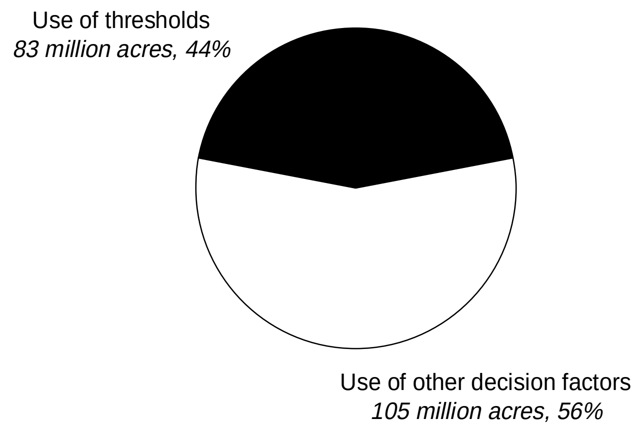
Several factors are used by growers to determine whether or not to apply pesticides. Economic thresholds, contract requirements, preventive schedules, previous infestation levels, and information sources such as agricultural magazines and journals are examples. The surveys asked farmers about the decision strategy used to determine whether or not to apply a pesticide.

Use of Thresholds as a Decision Factor to Apply Insecticides

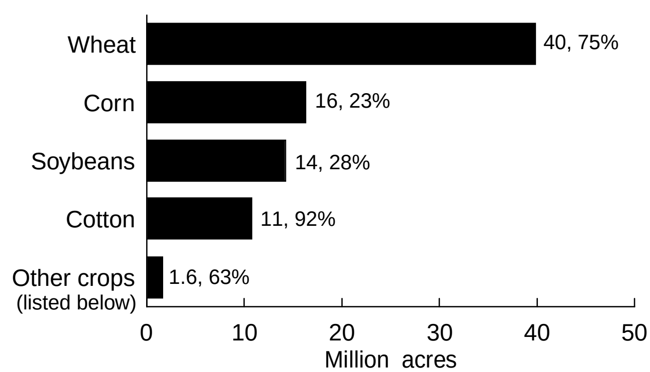
Growers use different methods to determine when pest infestations reach or are expected to reach levels that require treatment (fig. 3E1). Some use professional scouts to measure the infestation in their fields and apply pesticides only when the infestation reaches the threshold as prescribed by the Extension Service or other research-based sources. Farm operators or their employees may al47so do the scouting and similarly apply research-based thresholds. Analytically derived thresholds are not available for all crop-pest combinations or may not apply to all situations. Based on their own experience and knowledge, farmers may have their own "experience-based" thresholds that help them decide whether or not to apply pesticides. The surveys asked farmers if their decision strategy was based on threshold levels, either provided by an outside source or determined by the farm operator. Most insecticide treatments for cotton, wheat, and specialty crops were based on some threshold concept. Thresholds were less widely used for corn insecticides. Insecticide treatments on corn are often for soil insect pests that are difficult to monitor, and decisions are often based on previous problems and crop sequence.

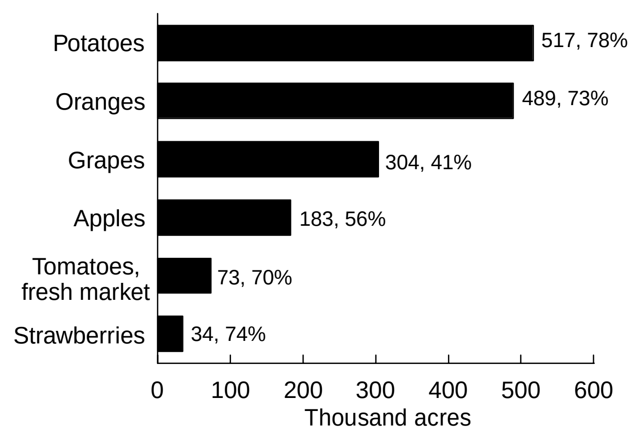
Figure 3E1

Use of economic thresholds as a decision factor to apply insecticides, 1994-95 1/



Crops for which economic thresholds were used as a decision factor to apply insecticides 2/





1/ Represents 188 million acres of surveyed crops.
2/ The first value at the end of each bar is the acreage on which economic thresholds were applied, and the second value is the percentage of crop area on which they were applied.

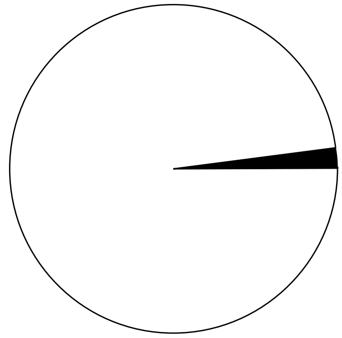
Sources: USDA, NASS and ERS, 1994, 1995c, and 1995d.

Sale Contracts That Require Treatments with Prescribed Pesticides

To maintain consistent product quality or for food safety reasons, some buyers restrict or prescribe the use of certain kinds of pesticides (fig. 3E2). Such buyers may include, among others, processors of infant foods, distributors of certified organic produce, or processors and retailers who use environmental labels. Processors who desire a uniform product quality or appearance may also stipulate the type and timing of pesticide treatments.

Figure 3E2

Sale contracts that required treatment with prescribed pesticides, 1995 1/



1/ Represents 1.74 million acres of oranges, apples, and grapes.

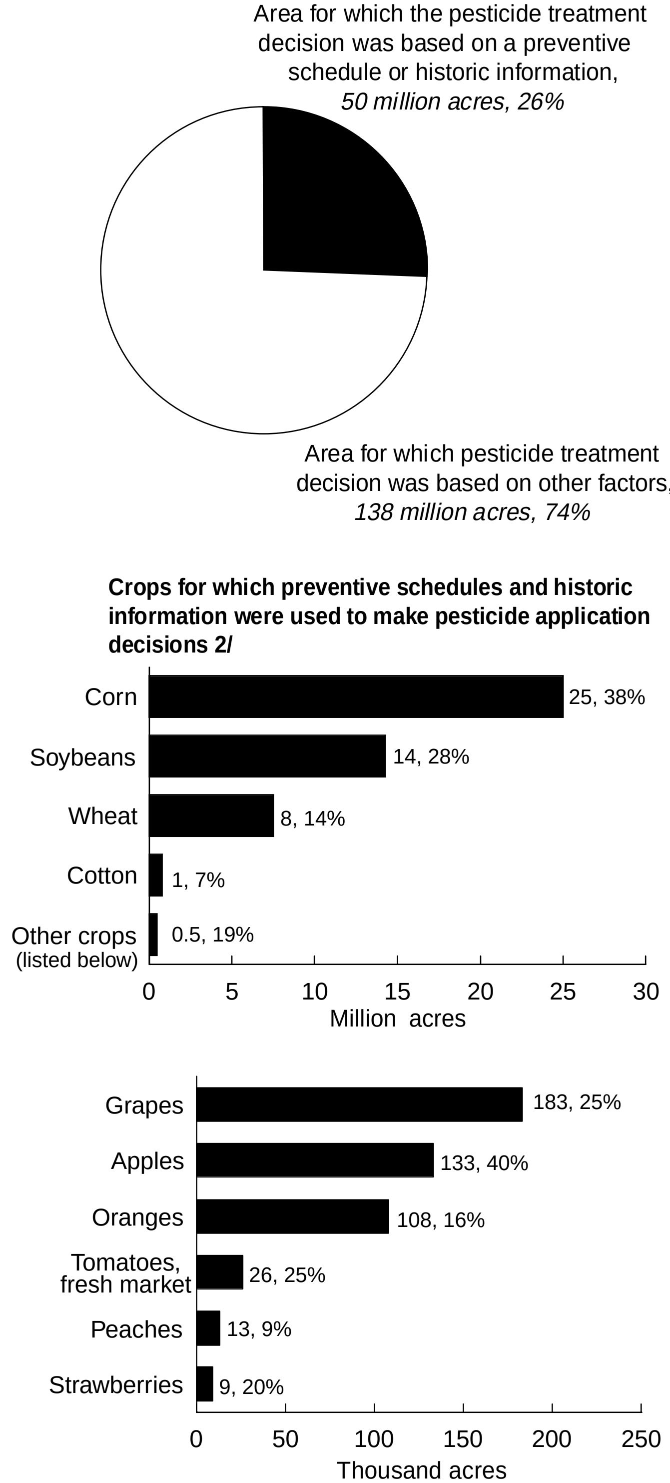
Sources: USDA, NASS and ERS, 1995d.

Use of Preventive Schedules or Historic Information for Pesticide Application Decisions

Producers who do not scout or use thresholds to make their decisions about whether treatments are necessary often rely on preventive schedules and historic information about the pest (fig. 3E3). Where pest infestations vary widely between years, the use of such preventive schedules can result in unnecessary treatments when threshold levels do not occur. Regularly scheduled pesticide applications were most common on apples—40 percent of area—where large economic damages can occur with very low infestations of pests that affect fruit quality.

Figure 3E3

Use of preventive schedule and historic information for pesticide application decisions, 1994-95 1/



1/ Represents 188 million acres of surveyed crops.
2/ The first value at the end of each bar is the acreage on which preventive schedules were used, and the second value is the percentage of crop area using preventive schedules to make pesticide application decisions.

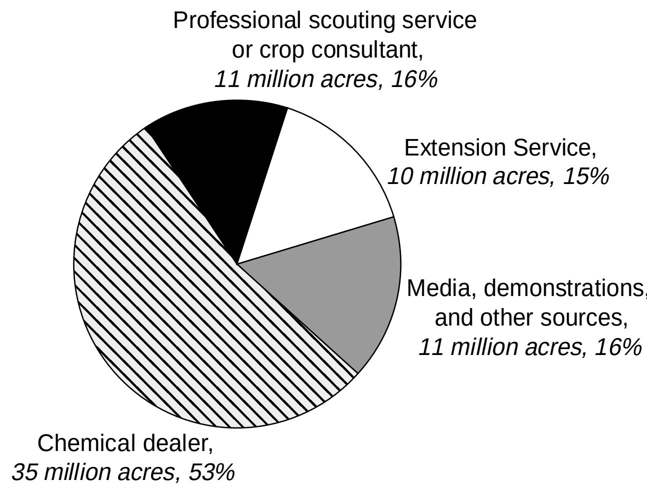
Sources: USDA, NASS and ERS, 1994, 1995c, and 1995d.

Information Sources for Making Pest Management Decisions

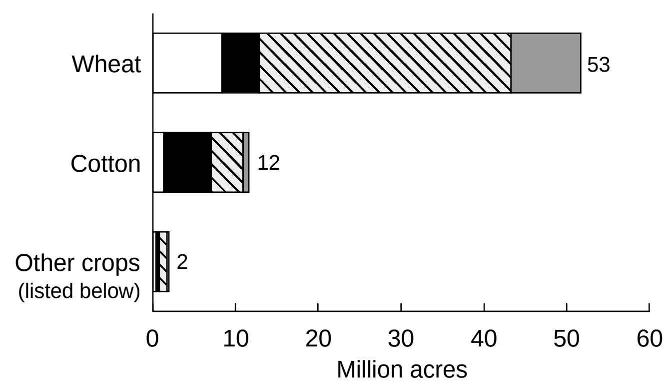
Growers obtain pest control information from a variety of sources including extension advisors, extension publications, chemical dealers, and scouting services (fig. 3E4). The source of producers' pest management information, as well as its currency and accuracy, can be important in implementing new pest management policies. Providers of professional pest management information, such as paid crop consultants, may recommend treatment options that have an established record for effectiveness, while chemical dealers may desire to expand sales of their newer or more profitable product lines.

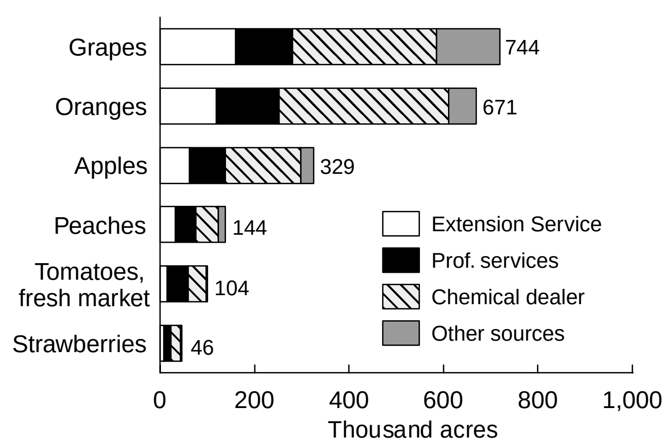
Figure 3E4

Information sources for making pest management decisions, 1994-95 1/



Information sources for making pest management decisions, by crop 2/





1/ Represents 67 million acres of surveyed crops.
2/ The value at the end of each bar is the crop acreage relying on different information sources for pest management decisions.

Sources: USDA, NASS and ERS, 1994, 1995c, and 1995d.

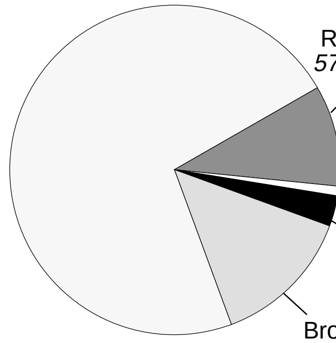
Pesticide Application Methods

Different pesticide application practices can affect the treatment efficacy, reduce the quantity of pesticide applied, or have different potential health and environmental risks (fig. 3F1). Alternative treatment methods require different kinds of equipment and have different labor and equipment costs. To reduce risks, Federal and State laws, regulations, and permit systems dictate many safety precautions to be used when applying pesticides, as well as for storing, transporting, and disposing of unused pesticide materials. Additional safety precautions include restricting entry to the fields for a number of days following applications, forbidding applications within a certain number of days before harvest, specifying maximum application rates, requiring protective clothing, respirators, and special equipment, and specifying the crop development stages when applications can be made. Although these safety standards eliminate most risk to health and the environment, the quantity of material applied and the risk can vary by method of application.

Application methods can affect the amount of pesticide that moves off cropland either by atmospheric drift, leaching, or runoff. Pesticide applications made by aircraft or ground equipment that creates a mist, fog, or dust require special precautions to prevent drift by wind to nontarget areas or to prevent skin contact and inhalation. Pesticides incorporated or placed directly into the soil have a greater probability of leaching to ground water, while those applied to the surface are subject to both runoff and leaching. Pesticides applied to foliage have risk of atmospheric loss as well as risk to the health of applicators or farmworkers who enter the field following applications. Reduced coverage practices are sometimes used in lieu of full broadcast coverage and they usually require a smaller quantity of pesticide materials.

USDA surveys have estimated that ground broadcast applications were the most widely used means of applying all types of pesticides to crops. Nearly three-fourths of all pesticide acre-treatments on the surveyed fruits, vegetables, and field crops used this application method. Another 14 percent of the acre-treatments were broadcast by aircraft. While many broadcast pesticides must be incorporated into the soil to be effective, only a small share of the quantity of pesticides were applied directly to or injected into the soil. Application practices that provided less than 100 percent soil or canopy coverage accounted for about 10 percent of the total acre-treatments. Applying pesticides through irrigation systems (chemigation) is another broadcast method but it accounted for a very small share of the total acre-treatments.

Figure 3F1
Pesticide application methods, 1994-95 1/



1/ Represents 188 million acres of surveyed crops, of which 165 million received at least one pesticide acre-treatment.

Sources: USDA, NASS and ERS, 1994, 1995c, and 1995d.

Reduced-Coverage Application Methods

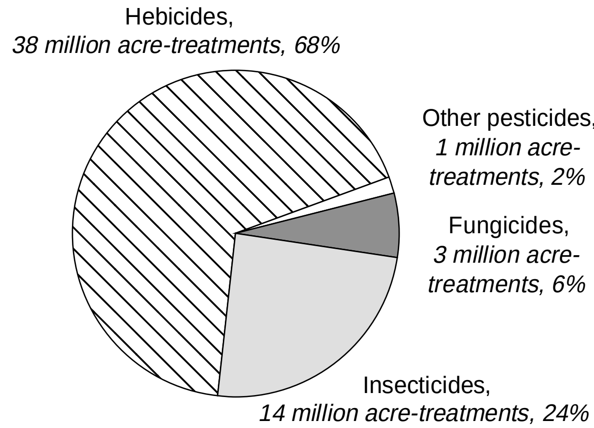
Spot treatments, band application, and alternate-row spraying can reduce pesticide use and costs and still control certain pests (fig. 3F2). Spot treatment, which selectively treats small infested areas in a field, is effective when the pests are concentrated in a particular section of a field or when pests can be treated before spreading or migrating throughout a field. Another form of spot treatment is the selective treatment of each target pest, such as with a wick-type applicator used for shattercane or other tall weeds in soybeans. Banding pesticide application over the rows and not treating the middle of the rows is another reduced coverage practice that can reduce the quantity of pesticide applied. Banded herbicide applications are sometimes used to control weeds between plants within rows, then mechanical cultivations are used to control the weeds between the rows. Banded treatments are also used for certain soil insects that attack planted seeds or plant roots. Alternate-row spraying is a practice sometimes used in orchards. With this practice only one side of the fruit trees is sprayed with each treatment, with the opposite side sprayed with the following treatment. Some pesticide material will drift and provide partial protection to the opposite side of the tree until it receives a full treatment at the next application.

About 10 percent of all pesticide acre-treatments are one of the above types of reduced-coverage practices. Corn, cotton, and soybeans accounted for most of the acre-treatments using these practices, but the reduced-coverage practices accounted for only a small share of the total acre-treatments on these crops (corn, 12 percent; soybeans, 7 percent; cotton, 15 percent). In contrast, most pesticide treatments on fresh market tomatoes (86 percent) and strawberries (66 percent) were a reduced-coverage practice. Alternate-row spraying or other reduced-coverage practices accounted for more than 20 percent of the acre-treatments on apples and peaches. Reduced-coverage applications on field crops were chiefly of herbicides, while reduced-coverage applications on fruits and vegetables were most commonly insecticides and fungicides.

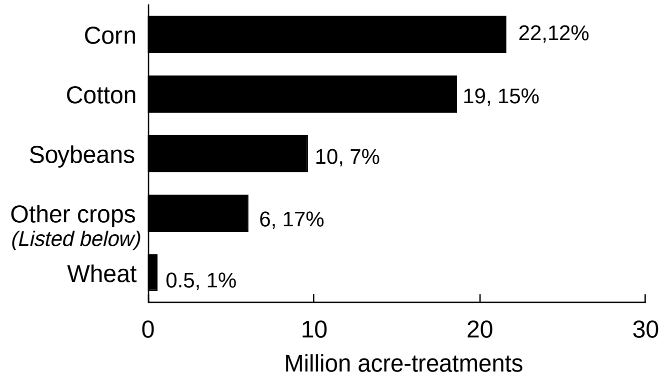
Figure 3F2

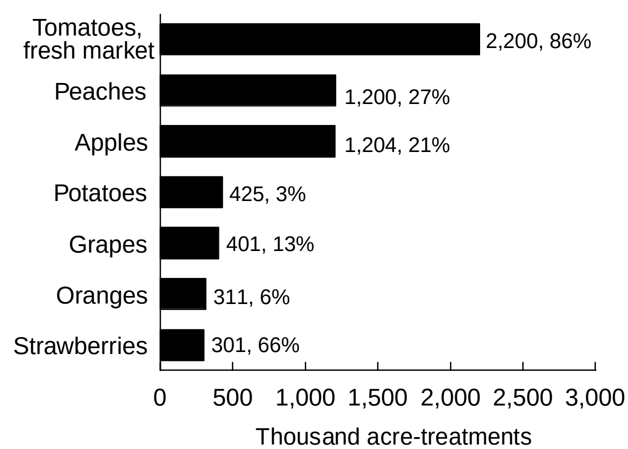
Reduced-coverage application methods (band applications, spot treatments, and alternate row spraying, 1994-95 1/)

Pesticide types applied using reduced-coverage methods



Reduced-coverage applications methods by crop 2/





1/ Represents 56 million acre-treatments using a reduced-coverage application method.
2/ The first value at the end of each bar is the number of acre-treatments, and the second value is the percentage of the total crop acre-treatments.

Sources: USDA, NASS and ERS, 1994, 1995c, and 1995d.

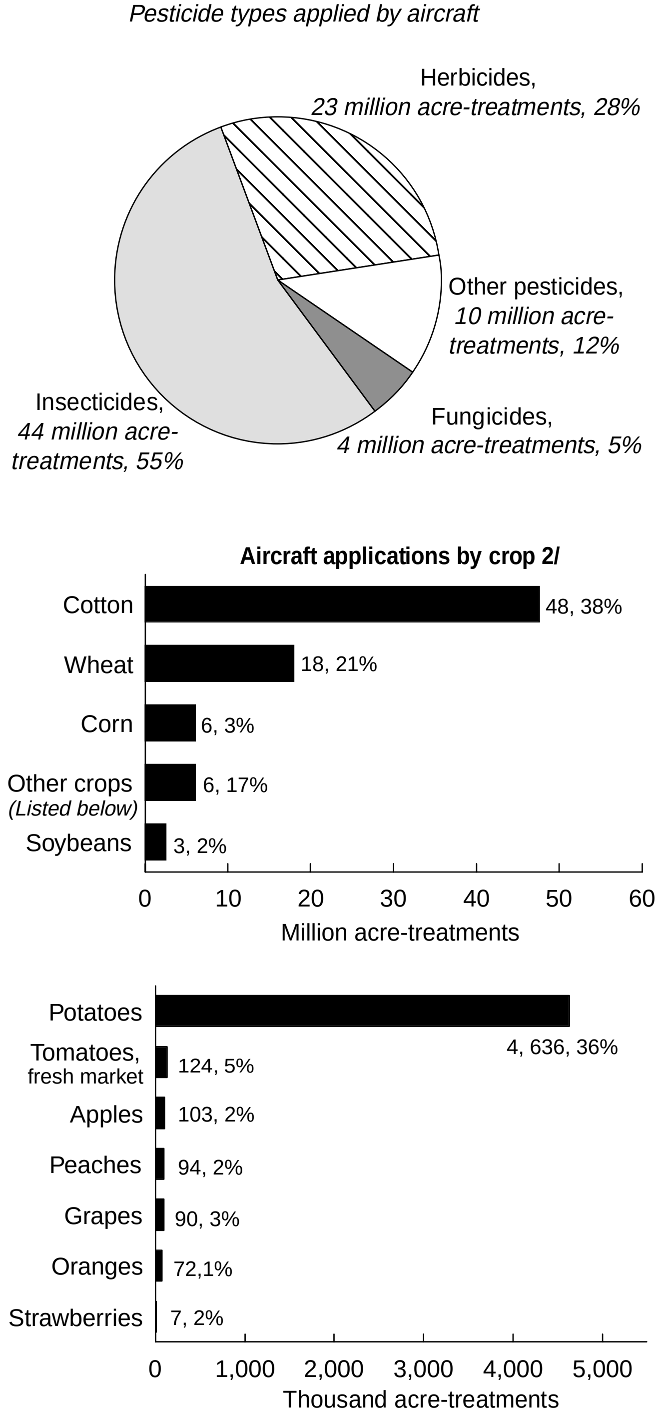
Pesticide Applications by Aircraft

Potential drift or "chemical trespass" is most likely when pesticides are applied as a fine mist, fog, or dust and applied in the presence of wind (fig. 3F3). Pesticides applied by either aircraft or ground broadcast methods can drift to nontarget sites with wind gusts or thermal inversions during and shortly following the application. Some pesticide materials will even continue to volatilize into the atmosphere for several days after application. While wind, particle size, spray pressure, and equipment calibration are important factors and require safety precautions, some application equipment and methods are better at targeting and preventing drift than others.

Pesticide applications made by aircraft usually are less precisely targeted than ground application equipment. Aircraft are often used to apply pesticides when crops reach a growth stage such that ground equipment would harm the crop or when soils are too wet to support ground equipment. Pesticide applications by aircraft were most common on cotton and wheat. About 38 percent of the cotton and 21 percent of the wheat pesticide acre-treatments were applied by aircraft. For cotton, these applications were mostly for insect control, while for wheat they were for weeds.

Figure 3F3

Pesticide applications made by aircraft, 1994-95 1/



1/ Represents 80 million acre-treatments applied by aircraft.
2/ The first value at the end of each bar is the number of acre-treatments applied by aircraft, and the second value is the percentage of total crop acre-treatments applied by aircraft.

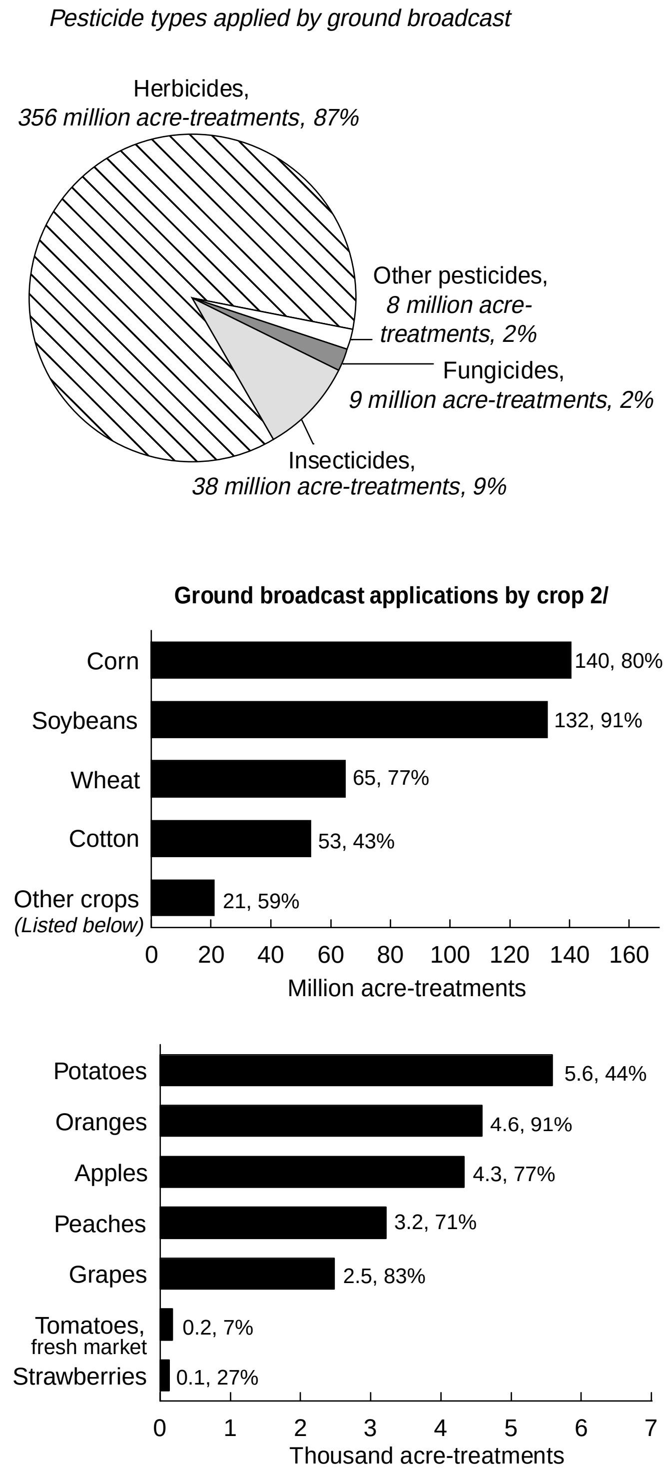
Sources: USDA, NASS and ERS, 1994, 1995c, and 1995d.

Ground Broadcast Applications

Whether applied to the plant canopy or to the soil surface, the use of ground broadcast equipment accounted for most pesticide applications (fig. 3F4). Ground broadcast applications accounted for 87 percent of the herbicide acre-treatments, but less than half of the acre-treatments of all other pesticide classes (insecticides, 9 percent; fungicides, 2 percent; other pesticides, 2 percent). More than 75 percent of all pesticide acre-treatments on wheat, soybeans, corn, and surveyed fruit used a ground broadcast application method, compared with less than 50 percent of cotton and vegetable acre-treatments.

Figure 3F4

Pesticide applications made by ground broadcast methods, 1994-95 1/



1/ Represents 412 million acre-treatments made with ground equipment to either the plant follage or the soil surface.
2/ The first value at the end of each bar is the number of acre-treatments applied by ground broadcast methods, and the second value is the percentage of crop acre-treatments applied by ground methods.

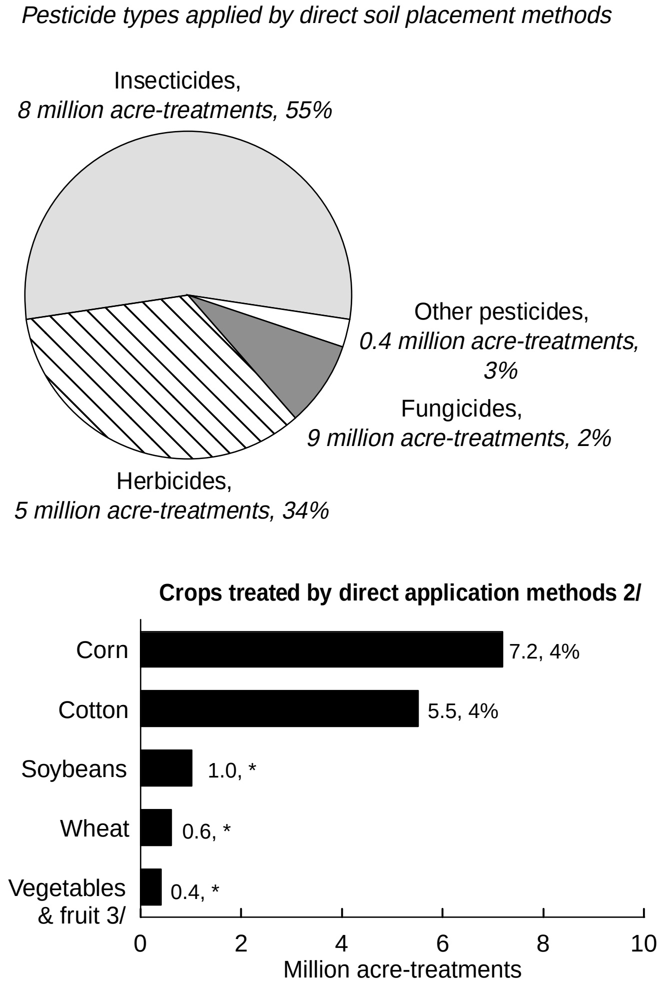
Sources: USDA, NASS and ERS, 1994, 1995c, and 1995d.

Direct Soil Placement Methods

Ground application equipment that applies the pesticide materials directly into the soil by injection or into a furrow made by a planter or tillage equipment can have some safety advantages over surface application methods (fig. 3F5). There is less risk of direct contact by humans or wildlife when the pesticide is placed in the soil, and the soil cover can reduce potential losses to the atmosphere or runoff from precipitation. Some States even exempt direct soil placement methods from obtaining spray permits when applying certain pesticide materials. A common use of direct soil placement is the treatment for corn rootworm in corn and several soil insects in cotton. Soil fumigation for strawberries, fresh market tomatoes, potatoes, and some other crops is another use of the practice, but accounts for a relatively small share of the total acres using direct soil placement methods.

Figure 3F5

Pesticides applied by direct soil placement methods, 1994-95 1/



1/ Represents 14.7 million acre-treatments of pesticides applied directly into the soil.
2/ The first value at the end of the bar is the number of pesticide acre-treatments applied by direct soil placement, and the second value is the percentage of total pesticide acre-treatments that used this application method. An "*" indicates that less than 1 percent used this method.
3/ Includes potatoes, tomatoes, lettuce, strawberries, apples, grapes, peaches, and oranges in surveyed States.

Sources: USDA, NASS and ERS, 1994, 1995c, and 1995d.

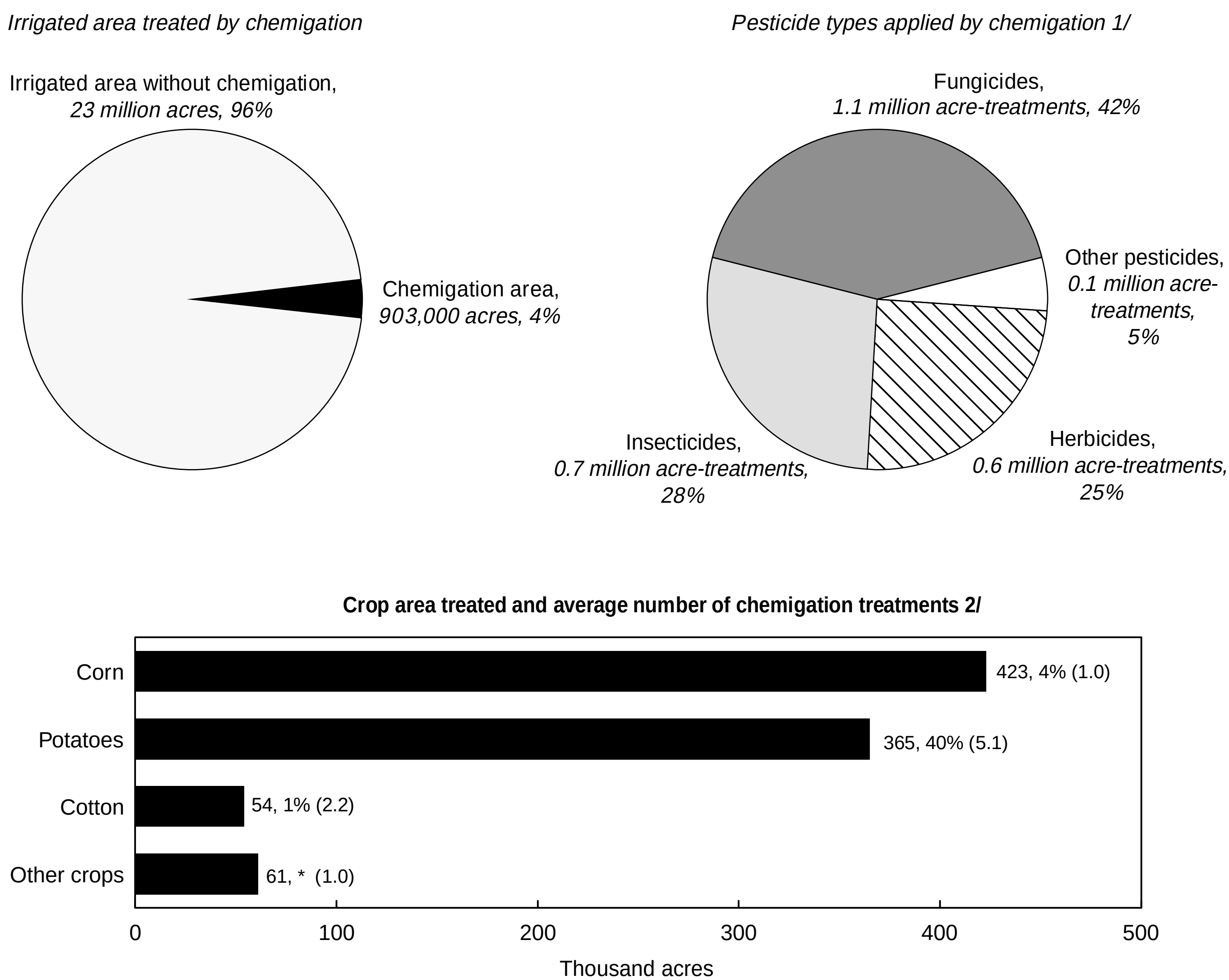
Irrigated Area and Chemigation

Some pesticide materials are applied through sprinkler and drip irrigation systems—a practice called chemigation (fig. 3F6). While a practical and cost-saving application technology for some pesticides, it requires special precautions to prevent water contamination from runoff, leaching, or back-siphoning into wells.

Chemigation was not a widely used practice for applying pesticides to any of the surveyed crops, except for potatoes. Approximately 80 percent of the potatoes were irrigated, and chemigation was used to apply some pesticides on about 40 percent of the irrigated acres (32 percent of total acres). On the potato area treated by chemigation, an average of five different pesticide applications, mostly fungicides, were made during the growing season.

Figure 3F6

Irrigated area and chemigation, 1993-94



1/ Chemigation is the application of pesticides through an irrigation system. Represents 861,000 surveyed acres of irrigated corn, soybeans, cotton, potatoes, apples, oranges, and grapes and applied pesticides by chemigation.

2/ The first value at the end of each bar is the number of acres treated by chemigation; the second value is the percentage of irrigated area treated by chemigation; and the third value is the average number of chemigation acre-treatments applied during the year. An "*" indicates that less than 1 percent used this method.

Sources: USDA, NASS and ERS, 1994, 1995c, and 1995d.

General Crop Management Practices

Crop Rotations

Crop rotations can help control pests, supplement soil nutrients, improve soil tilth, and reduce soil erosion, but producers may have to forgo some income when the rotation includes low-profit crops [NRC, 1989]. Alternatively, producing the highest profit crop on the same land year after year (monoculture) is feasible on many soils with good management of the soil, nutrients, and pests. Besides farm profits, crop rotations may also affect the environment. Environmental effects from crops grown in one year that are erosive or require high levels of chemical input may be mitigated by crops grown in other years in the rotation that are less erosive or use fewer chemicals. For example, soil-conserving crops can be grown in rotation with erosive row crops to keep average soil loss under the tolerance levels. Another way crop rotation affects the environment is when crops grown in a specific sequence have a beneficial effect on the following crop. For example, a legume crop can lower the fertilizer needs for a following crop. Also, the rotation of different crops often breaks the pest reproduction cycle and lowers the need for pesticides.

Federal farm policy changes could encourage greater use of crop rotation. Early Federal Government price support program payments were calculated using a farm base acreage and yield concept that encouraged producers to plant program crops in order to maintain maximum eligibility. The Food, Agriculture, Conservation, and Trade Act of 1990 and the Federal Agricultural Improvement and Reform Act of 1996 provided options to grow alternative crops and could encourage crop rotation when alternative crops are a profitable option to program crops [USDA, ERS, 1996]. The 1990 Act contained a flex-acre provision that allowed farmers to plant up to 15 percent of their contract acreage to certain alternative crops. The 1996 Act basically eliminated all acreage restrictions and allows farmers to respond to market signals without regard to future program eligibility. With these changes, farmers can select alternative rotations and not lose base acreage and eligibility for Federal support payments.

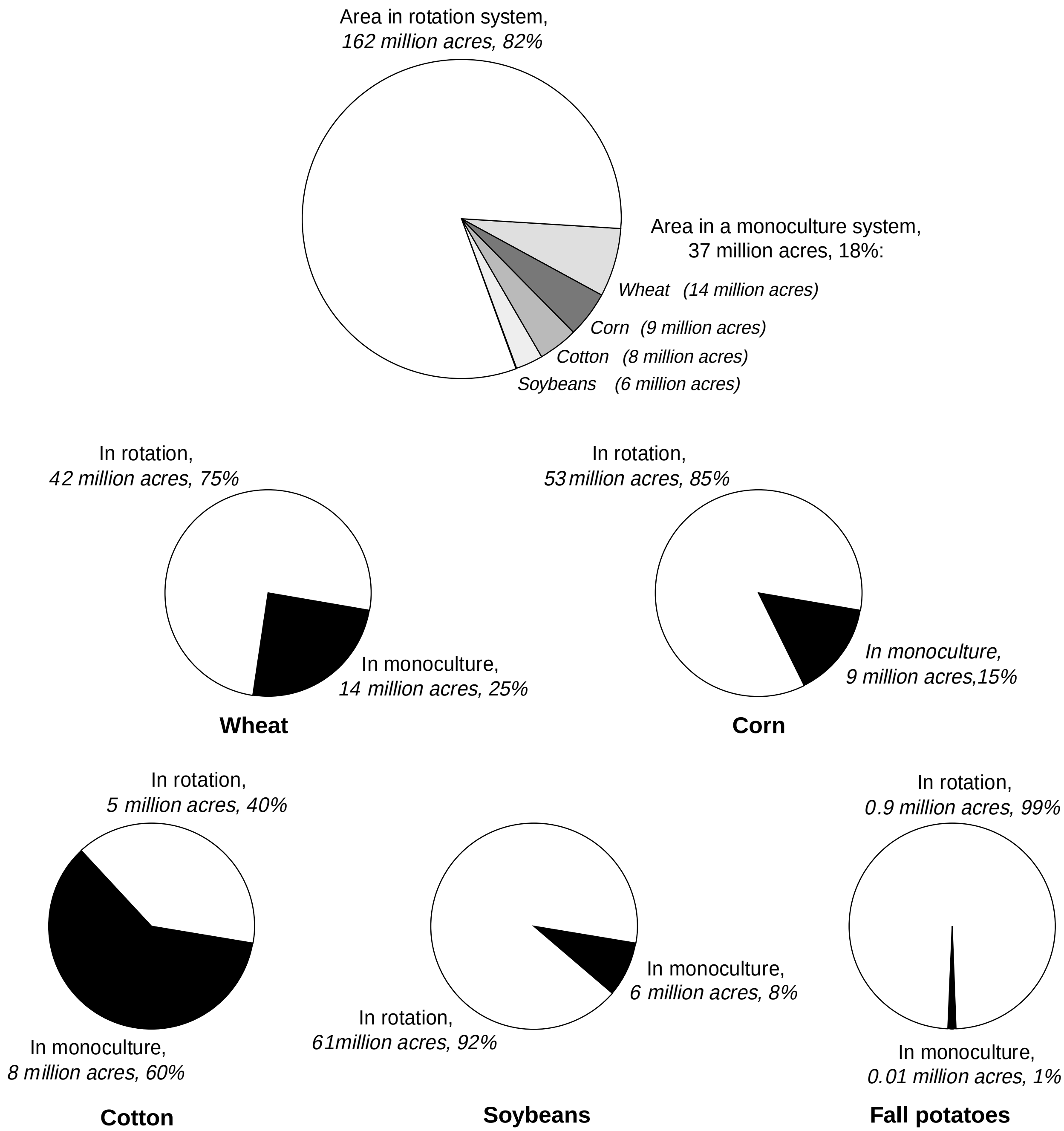
The information about preceding crops from USDA's Agricultural Resource Management Study was used to estimate acreage in alternative rotations or acreage where the same crop was produced for 3 consecutive years (monoculture) [USDA, ERS, 1996c]. Because some rotation systems last more than 3 years, the 3-year crop sequence available from the survey may not accurately reflect longer term rotation systems. Also, the constructed rotations represent only land where the 1997 planted crop was corn, soybeans, wheat, cotton, or potatoes. Additional area may be in some of the constructed rotations if crops other than those previously listed were planted or produced in 1997, for example, hay, other small grains, or other row crops. Estimates of winter cover crops were also constructed from the survey data. Any fall-planted small grain, hay, or meadow crops were assumed to be cover crops. (See box on Cover Crop Benefits, p. 62.)

Most Cotton Grown with Monoculture, but Crop Rotation is Common with Other Field Crops

One-fifth of the total area planted to corn, soybeans, wheat, cotton, and fall potatoes in 1997 were also planted to the same crop in the preceding 2 years (monoculture practice) (fig. 4A). On the remaining area, a rotation with at least one other crop or any idle year occurred in one or both of the 2 preceding years. Monoculture production practices were most widely used for cotton. Wheat and corn, however, accounted for the largest acreage of crops using a monoculture system. Monoculture was least used for soybeans and potatoes.

Figure 4A

Most cotton grown with monoculture, but crop rotation is common with other field crops, 1997 1/



1/ Represents 198 million acres of total U.S. cropland.

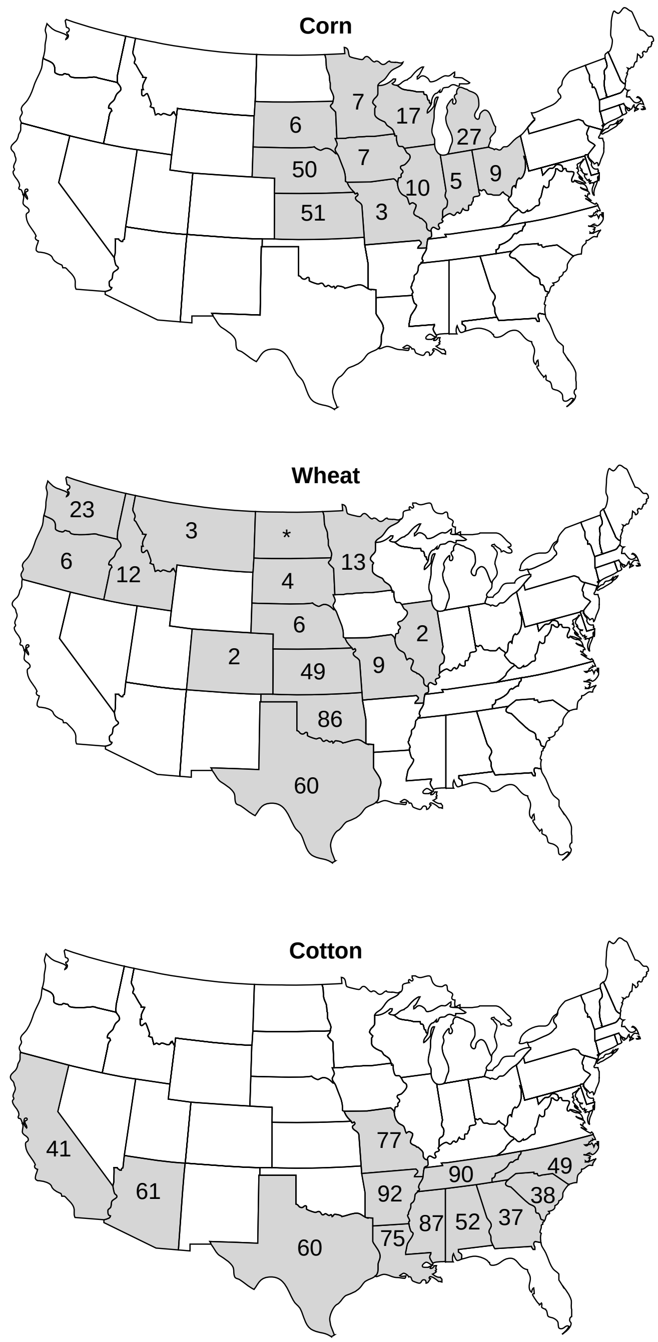
Sources: USDA, NASS and ERS, 1994, 1995c, and 1995d.

Monoculture Practices

Monoculture systems for wheat, corn, and cotton were concentrated in a few regions, mostly because of the uniqueness of soil and water resources (fig. 4B). Continuous wheat was more common in Texas and Oklahoma—States which receive sufficient annual rainfall for wheat but frequently too little rainfall to support row crops without supplemental irrigation. Most cotton produced in the Delta Region was grown with a monoculture practice. Cotton production relies heavily on insecticides to control damaging pests in this region. Continuous corn occurred throughout most of the corn-producing region. However, continuous corn was most common in Kansas and Nebraska—States that extensively use groundwater for irrigating corn.

Figure 4B

Monoculture's share of planted area by crop and State, 1997 1/



* = Less than 1 percent.

1/ Monoculture area includes 9 million acres of corn, 8 million acres of cotton, and 14 million acres of wheat.

Sources: USDA, NASS and ERS, 1996c.

Crop Rotation Benefits

Rotating crops can provide several kinds of economic and environmental benefits [NRC, 1989; Brust and Stinner, 1991; and Heichel, 1987]. Crop rotations are used to increase soil productivity and reduce the need for commercial fertilizers. Legume crops, especially small-seed legumes such as alfalfa, sweet clover, or lespedeza can supply large quantities of nitrogen to the soil over time and significantly reduce commercial nitrogen fertilizer needs for crops that follow [Power, 1987]. Soybeans, dry beans, and other large-seed legume crops provide most of their own nitrogen needs and also reduce commercial fertilizer needs for following crops. In regions with longer growing seasons, winter legume crops are also used to supply nitrogen and other soil nutrients for following crops. The organic matter supplied by previous crops, especially the roots of legumes and sod, supports soil micro-organisms that add other crop nutrients to the soil.

Crop rotation influences the length of time and the degree to which soils are exposed to the erosive forces of wind and water, critical factors affecting soil erosion rates on cropland [USDA, SEA, 1978]. Land planted to corn, soybeans, cotton, and other row crops is more prone to erosion than that planted to small grains, hay or meadow crops, because it lacks vegetative cover, especially during critical erosion periods. Crop rotations that include small grains, hay, or other closely grown crops quickly establish a vegetative cover and root structure that helps protect soils from erosion. When closely grown crops are grown in rotation with row crops, the average erosion rate of the full rotation sequence is reduced. Closely grown crops also provide crop residues that, depending on the residue management system, can help reduce the erosion rate of the following crop. Some soil conservation plans for highly erodible land use conservation crops in rotation with row crops to meet compliance erosion rates.

In semi-arid or other regions where soil moisture is a limiting production factor, rotations are commonly used to conserve soil moisture [Cook, 1986; NRC, 1989]. The practice of fallow is leaving land idle 1 year to accumulate additional moisture for the following crop. Soil management practices designed to increase rainfall infiltration, decrease transpiration, and decrease evaporation of accumulated soil moisture are used. Fallow is most common in wheat production areas in the Plains, Mountain States, and Northwest, but may also be used in other areas having low precipitation or soils with low water-holding capacity. Besides fallow, other crops in a rotation affect soil moisture. Deep-rooted forage crops, such as alfalfa, are often not grown prior to wheat or other crops highly dependent on topsoil moisture. Crops that are harvested early in the summer, such as winter wheat, oats, or rye, allow more soil moisture accumulation after harvest to benefit the following crop.

Crop rotations are effective in controlling many kinds of pests and can reduce the need for intervention with pesticides [NRC, 1989]. Rotations affect pest infestation in many different ways. Perennial grasses and legumes often provide good weed control because they compete with many weed species and when pastured or cut for forage the annual weeds are unable to produce seeds to infest future crops. Fallow tends to encourage weed germination during the idle year when there are many chemical and nonchemical options for their control. Weed infestations are reduced when fall-planted crops such as winter wheat or rye develop a vegetative cover before the spring germination of many weed species. Insect and disease pests, such as corn rootworm, often require the host crop to survive dormant periods. By planting alternate crops, many producers can eliminate or significantly reduce pesticide treatments for corn rootworm. Crop rotation can also be a critical component in reducing species resistant to a pesticide. Planting different crops usually allows the use of pesticides with different control mechanisms, helping to prevent the buildup of resistant pest populations.

Crop rotations that increase the diversity of commodities produced on a farm may reduce the peak labor requirements or income risk. Peak planting and harvesting dates usually differ between crops. A more even distribution of fieldwork through the year gives operators an opportunity to make more efficient use of the available fixed labor supply. Because adverse weather or low product prices usually do not affect all commodities equally, the more diverse outputs from crop rotation help to stabilize and reduce the risk of low income in years with abnormal weather or low market prices for one or more major products.

Corn-Soybean Rotation

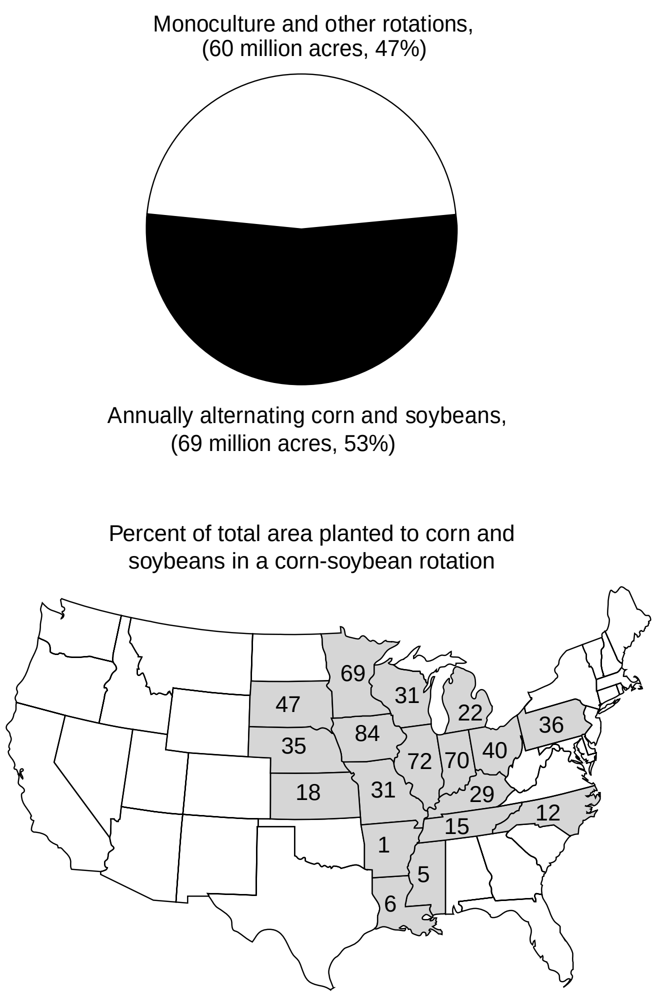
Alternating corn and soybeans is the most common crop rotation and can provide several kinds of environmental and cost-saving benefits (fig. 4C). The corn-soybean rotation accounts for most of the acreage planted to both of these crops in the Corn Belt region. Although the practice is used outside the Corn Belt, other crops are often planted with either corn or soybeans in the other regions. Small grains are commonly grown with corn in areas north and west of the Corn Belt, and cotton, sorghum, or other crops are grown with soybeans in the southern production regions. In Illinois and Iowa, the two largest corn-producing States, the corn-soybean rotation accounted for 72 percent and 84 percent, respectively, of the total corn and soybean acreage in these States.

Fallow-Wheat Rotation

The fallow-wheat rotation is primarily used to conserve soil moisture over a 2-year period for 1 year of production (fig. 4D). The rotation was widely used in the Northwest wheat-growing region and certain parts of the Northern Plains States. In regions with higher annual rainfall and regions where low soil moisture is not a normal production constraint, the wheat-fallow rotation was less common.

Figure 4C

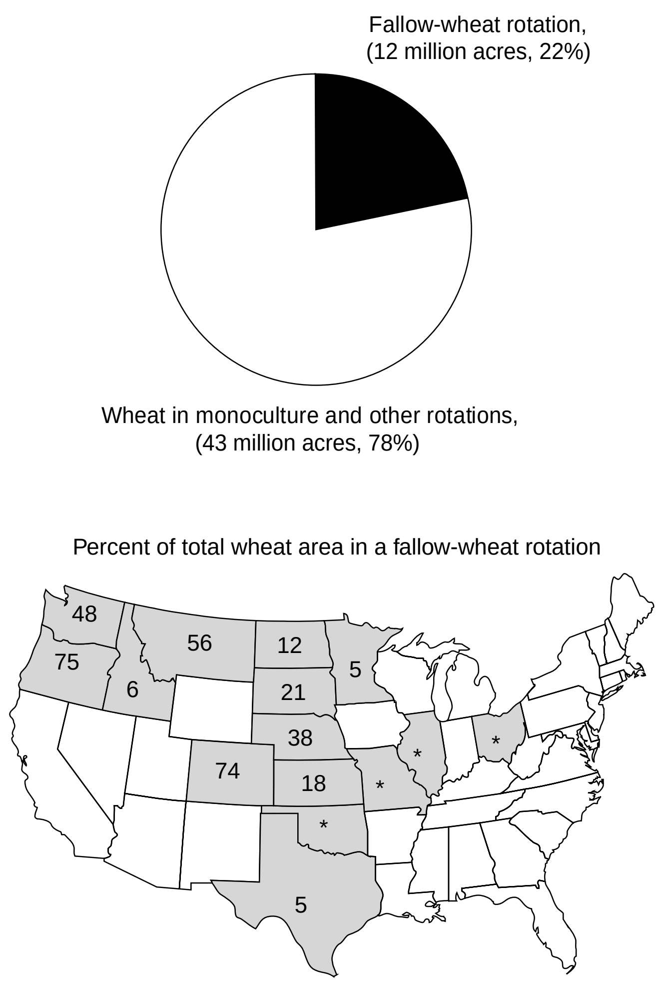
Corn-soybean rotation, 1997 1/



1/ Represents 128 million acres of corn and soybeans planted in 1997.
Source: USDA, NASS and ERS, 1996c.

Figure 4D

Fallow-wheat rotation, 1997 1/



* Less than 1 percent.
1/ Represents 56 million acres of winter, durum, and other spring wheat.
Source: USDA, NASS and ERS, 1996c.

Row Crops and Small Grains in Rotation

Small grains grown in rotation with row crops offer important environmental and conservation benefits over continuous row crops (including row crops grown with a monoculture system) (fig. 4E). Small grains help reduce average annual soil loss and are also helpful in controlling weeds and reducing herbicide needs. Crop rotations that included a combination of small grains and row crops contained many different specific crop sequences. Some of the more common sequences reported in the surveys were corn-wheat-corn, corn-wheat-soybeans, soybeans-rice, corn-oats-corn, potatoes-wheat-potatoes. Growing small grains and row crops in rotation with each other was most common in the Northern Plains. Some crop rotation was used for nearly all potatoes, and the crop in rotation with potatoes was most often a small grain.

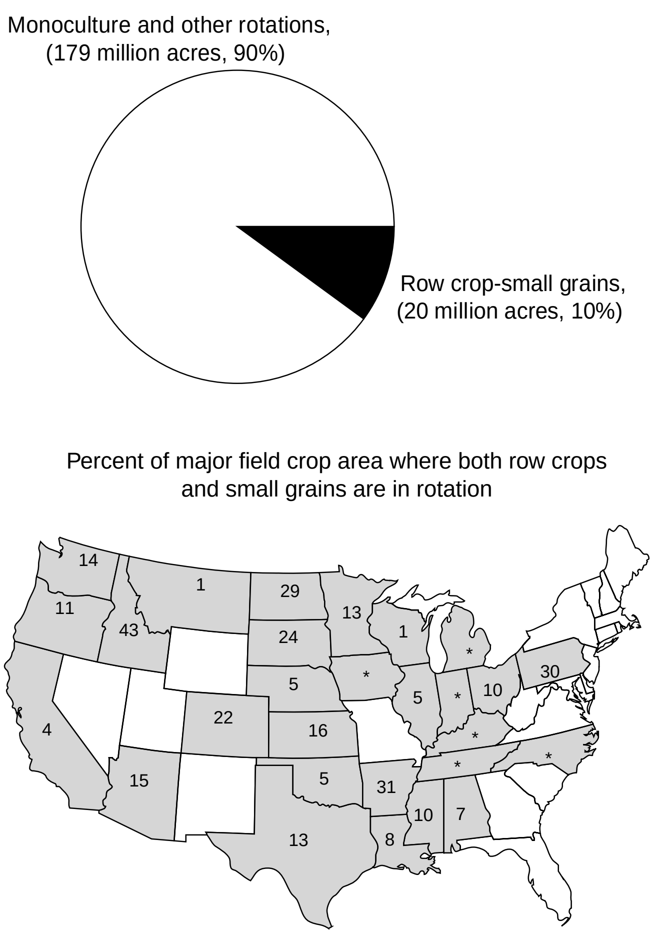
Rotations with Hay or Pasture Crops

Although not widely used, hay and pasture crops in rotation with row crops or small grains can provide many environmental benefits (fig. 4F). Most hay and pasture crops are perennials and have year-round vegetative cover, which provides protection against soil erosion.

Rotations with hay or pasture crops were most common in Wisconsin, California, and Pennsylvania—States with many livestock operations, especially dairy. Without livestock operations or local markets for forages, meadow crops often have a high opportunity cost. The cost for special machinery, labor, transportation, and storage of hay crops can significantly reduce the advantages of including them in rotation with major field crops.

Figure 4E

Row crops and small grains in rotation, 1997 1/

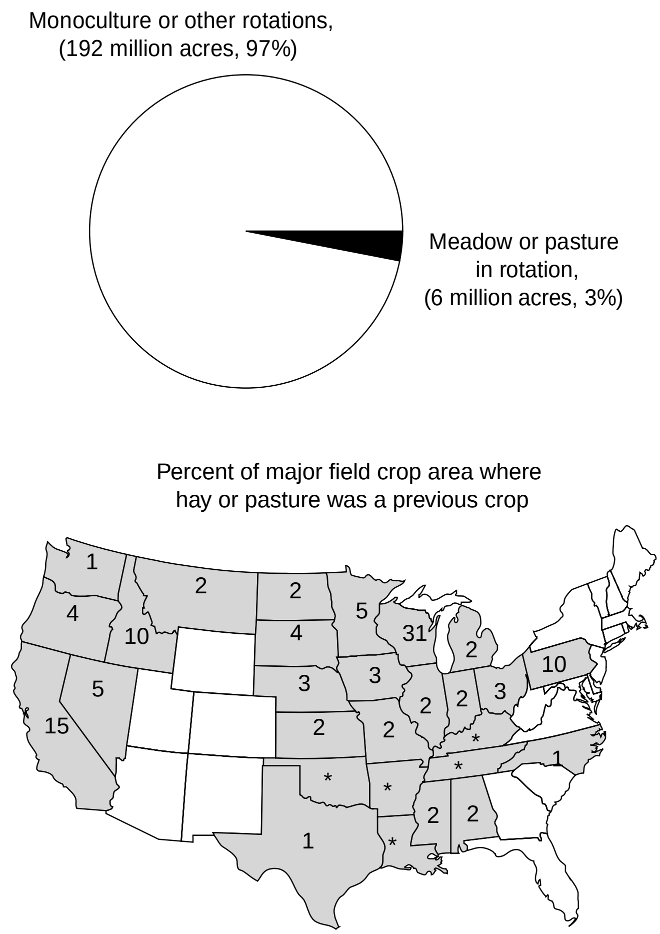


* Less than 1 percent.
1/ Represents 198 million acres of corn, cotton, potatoes, and wheat. The rotation includes any combination of row crops and small grains planted between 1995 and 1997. Double-cropped soybeans or small grains planted as winter cover crops are not included.

Source: USDA, NASS and ERS, 1996c.

Figure 4F

Rotations with hay or pasture crops, 1997 1/



* Less than 1 percent.
1/ Represents 198 million acres of corn, cotton, potatoes, and wheat. The rotation includes only acreage where alfalfa, other hay, or pasture was grown in either of the two preceding years. Areas in hay or pasture in 1997 are excluded.

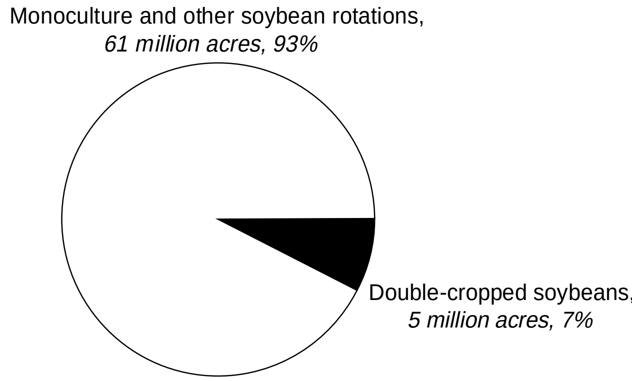
Source: USDA, NASS and ERS, 1996c.

Double-Cropped Winter Wheat-Soybeans

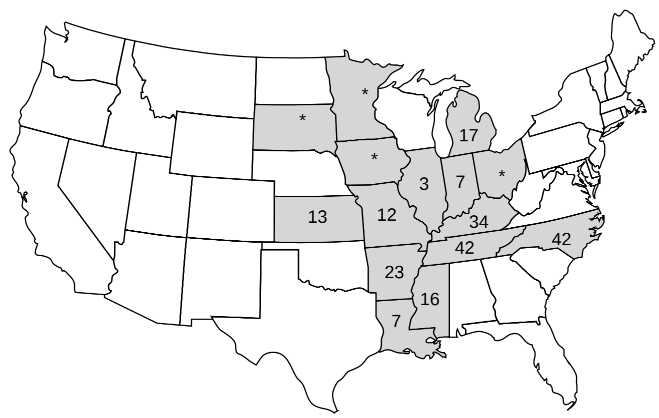
In regions with longer growing seasons and sufficient rainfall, soybeans can be planted immediately after winter wheat or barley and allow the production and economic returns for two crops in one growing season (fig. 4G). Where feasible to use, this rotation also offers some environmental benefits. The winter wheat or rye provides the nutrient and soil erosion benefits of a cover crop as well as providing crop residue to reduce soil erosion during the soybean production period. The total annual applications of fertilizer and pesticide ingredients for both crops, however, are usually higher than for a single crop.

Figure 4G

Double-cropped winter wheat-soybeans, 1997 1/



Share of double-cropped soybean area



* Less than 1 percent.

1/ Represents 67 million acres of soybeans planted in 1997. It does not include winter wheat harvested in 1997 when soybeans were planted in the spring of 1996.

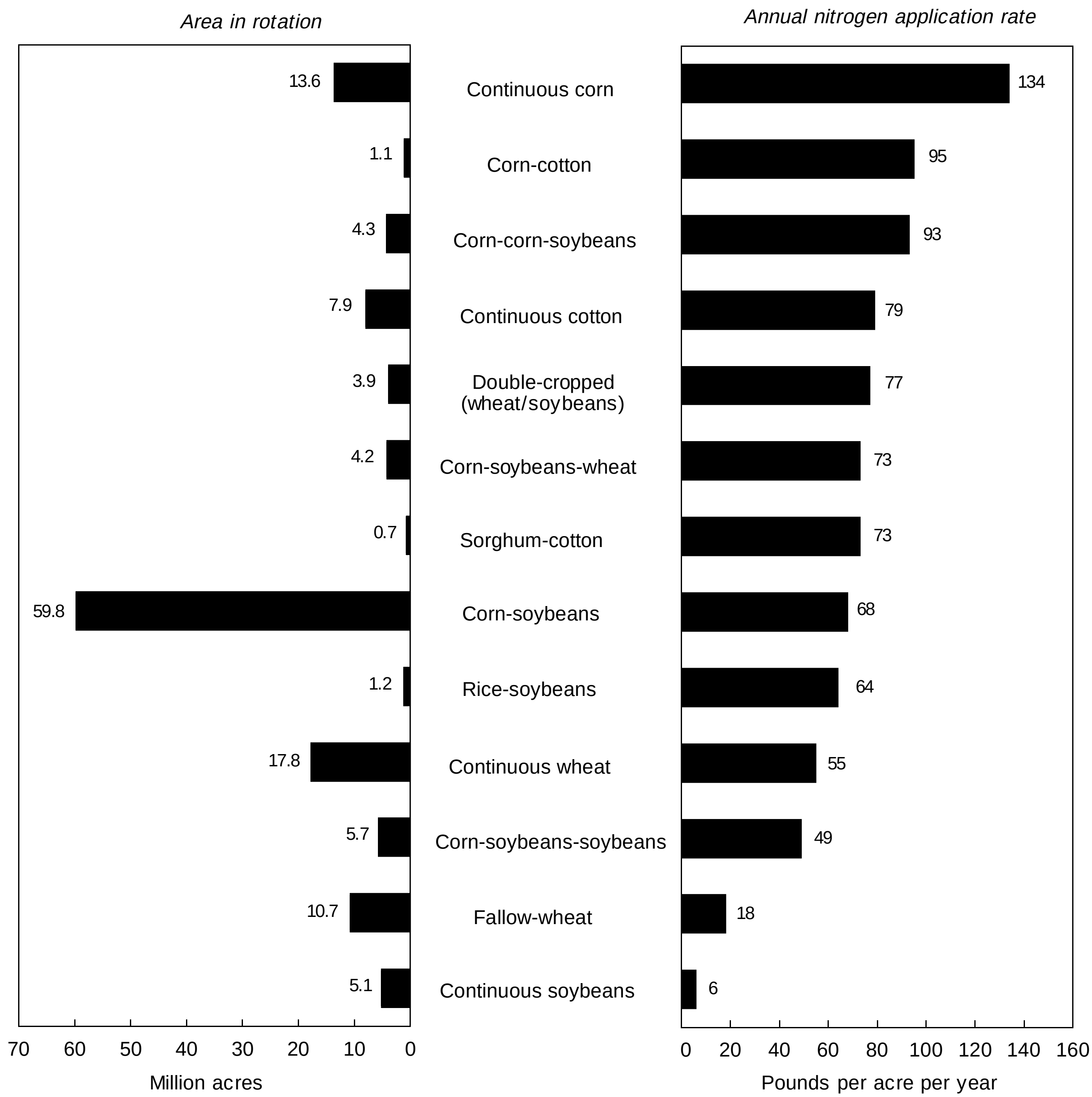
Source: USDA, NASS and ERS, 1996c.

Average Annual Nitrogen Use with Alternative Crop Rotations

Crop rotations affect the amount of nutrients and pesticides applied to crops in two different ways—one is the offsetting effects of crops with different nutrient needs and pest problems and the other is the effect one crop has on a following crop (fig. 4H). The survey data were used to construct average annual estimates of nitrogen use to illustrate differences in input levels for several commonly used crop rotations. Estimates of usage rates for individual crops are also reported to illustrate the effect that one crop has on another when grown in a crop rotation. In a corn-soybean rotation, the average annual nitrogen application rate was 68 pounds compared with 134 pounds for corn in a monoculture system.

Figure 4H

Average annual nitrogen use with alternative crop rotations, 1995

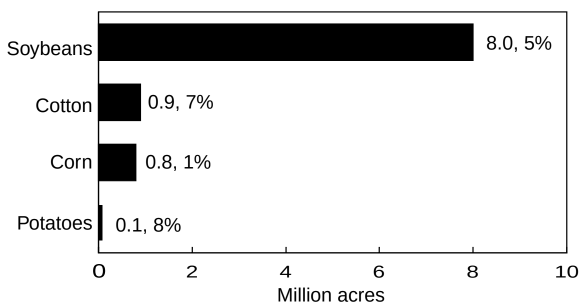


Source: USDA, ERS and NASS, 1995c.

Crop Area with Winter Cover Crops

Cover crops can be used to protect soil and water resources and improve soil productivity (fig. 4I). However, unless a harvestable grain or forage is produced, they may offer little economic gain to producers. The previous crop information from USDA's Agricultural Resource Management Study provides an estimate of the use of winter cover crops. The use of cover crops with corn, cotton, and soybeans was small compared with the total crop acreage, and its use varied widely between the crops and production regions. The most prominent use of cover crops was with soybeans in Southern States. The cover crop was usually winter wheat or rye and was usually harvested (double-cropping). Cover crops are less common with corn and cotton, partially because they have longer growing seasons and there is less opportunity for the cover crop to mature and be harvested. Because winter wheat is planted in the fall, the total acreage provides cover crop benefits, even when a crop is not planted in the following spring or summer.

Figure 4I
Crop area with winter cover crop, 1997 1/



Percent of crop area with a cover crop planted

* Less than 1 percent or none reported.
1/ The first value at the end of the bar is the number of acres with a preceding winter cover crop, and the second value is the percentage of crop area with a winter cover crop.
Source: USDA, NASS and ERS, 1996c.

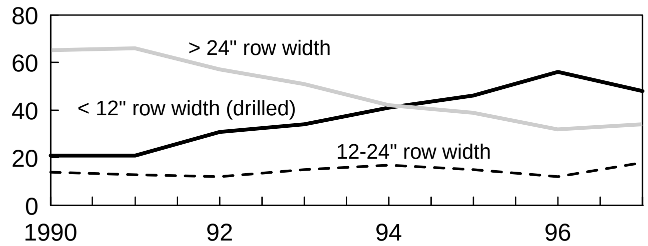
Drilled and Narrow-Row Soybeans

Reducing row spacing by using either a drill or row-planter is a practice that can help some producers increase profits, but it also can be environmentally beneficial (fig. 4J). Narrower spacing between plants allows the crop to develop a full canopy over the land earlier, which can lead to increased photosynthesis and higher yields. Such planting also results in fewer pods developing at the bottom of plants, reducing harvest loss. An earlier crop canopy and more uniform distribution of roots from drilled or narrow-row soybeans can also reduce soil erosion and decrease the ability for late germinating weeds to compete. Some disadvantages to drilled and narrow-row soybeans are increased reliance on pre-emergence herbicides, elimination of row cultivation options, increased disease potential, and higher seed cost.

Since 1990, the share of soybean acreage drilled or planted in narrow rows has doubled with a corresponding acreage decrease in the area planted in rows 24 inches and wider. Besides the above advantages, the increase in no-till acreage and improved technology of no-till drills have also been factors affecting the adoption. While differences occur in the ingredients and timing of herbicide application between fields planted at different row widths, the overall application rates are nearly equal for all row widths.

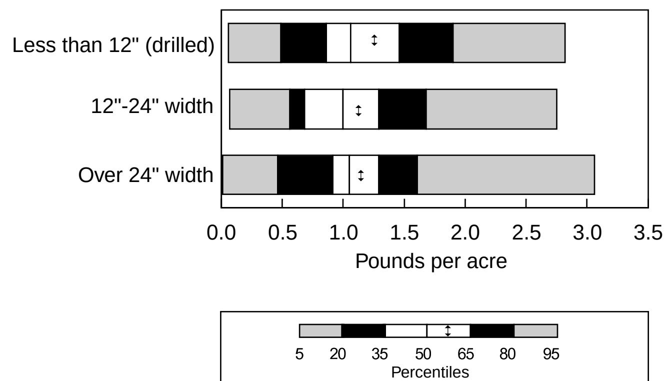
Figure 4J

Drilled and narrow-row soybeans, 1990-97 1/



1/Represents only soybeans grown in OH, NE, IL, IN, IA, MN, and MO.

Soybean herbicide use rates by row widths, 1997



Each bar represents the range in application rates from the 5th percentile (area with no pesticide applied or lowest rates) to the 95th percentile (area with the highest rates). The bar segments represent ranges in application rates at 15 percentile intervals. At the 50th percentile (median) half of the area received less than the identified rate and half received more. The double arrow indicates the average (mean) rate for the treated area.

Sources: USDA, NASS and ERS, 1996c.

Cover Crop Benefits

Cover crops are grasses, small grains, legumes, or other crops grown between regular crop production periods for the purpose of protecting and improving soil and water resources. Cover crops prevent soil erosion and nitrogen leaching and help control weeds. They can also improve soil structure and nutrients by returning organic matter to the soil. Cover crops are most frequently planted in the fall following the harvest of a regular crop and then incorporated into the soil or used as a mulch before planting another crop the following spring. Cover crops also are used between crops at other times of the year and in orchards and vineyards to provide permanent vegetation. For some regions and crops, the growing season between regular crops allows the cover crop to mature and be harvested for grain, as with double-cropped soybeans. Cover crops can also be grazed or harvested as forage to provide economic benefits.

Cover crops such as rye, wheat, or other small grains germinate quickly and develop a vegetative cover that protects soils from wind and water erosion. The fast growing vegetation also takes up soil nitrogen thus reducing potential leaching. Compared with conditions without a cover crop, evapo-transpiration from the plants removes excess soil moisture, which can also reduce the potential for nitrate leaching. Besides returning nitrogen back to the soil when their residue is incorporated, these crops also add other organic matter to improve soil productivity. Legume cover crops such as clover or vetch can add nitrogen to the soil and may be planted to precede nitrogen-demanding crops such as potatoes, cotton, or corn. These legume crops are also used in orchards and vineyards to help supply nitrogen needs. Another advantage to cover crops is that the vegetative cover established over the winter helps to prevent spring germination of weeds.

Organic Production Practices

Organic production practices were implemented on 0.2 percent of the 435 million acres of U.S. cropland and on over 1 percent of U.S. fruit and vegetable acreage in 1994, according to USDA's Agricultural Marketing Service (AMS) [Dunn, 1995] (figs. 4K1, 4K2, and 4K3). Fifty-nine percent of all organic acreage was devoted to cropland (669,000 acres). The majority of organic acres was for food crops, and fruits and vegetables represented 6 and 7 percent of the acreage, respectively. Other food crops included grain, dry beans, coffee, and other produce such as nuts, mushrooms, aloe vera, and herbs. The number of certified organic farmers grew by over 70 percent between 1991 and 1995 to approximately 5,000, according to USDA and private-sector reports [Fernandez-Cornejo, 1998].

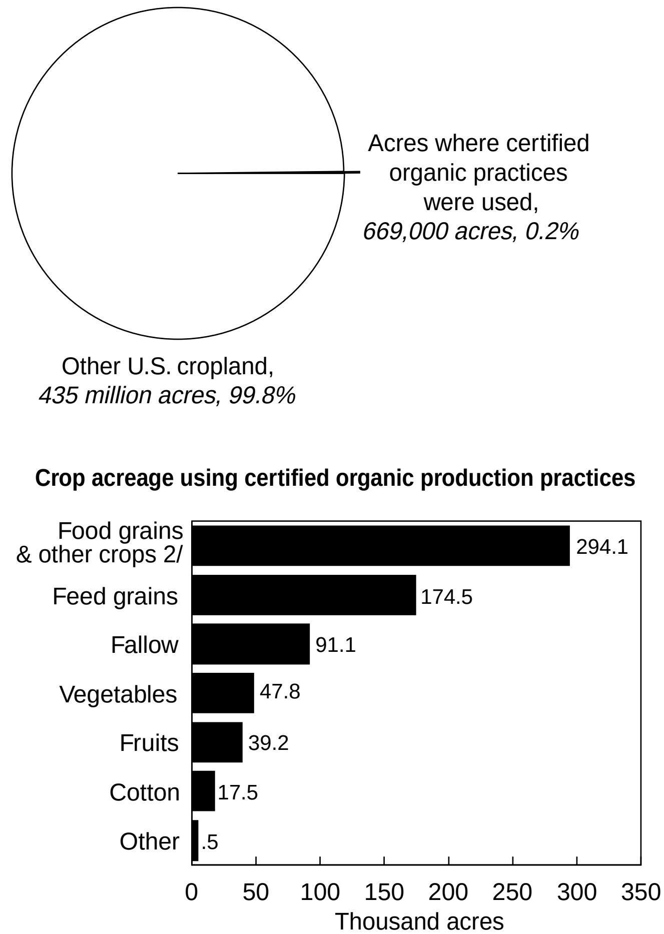
Though organic acreage is small, there is interest in organic production practices as an alternative technology to reduce chemical use and to maintain soil productivity. There is no national standard for certifying that a product is "organic," although USDA is in the process of developing uniform standards for all organic production. These standards will provide a national definition of "organic" that will better inform customers about organic products and may encourage organic production. Over 43 States have private and/or State organic certification programs that handle organic certification of production, but the standards differ between States. According to AMS, 73 percent of these organizations handle fruit and vegetable production.

USDA's Vegetable and Fruit Chemical Usage Surveys included questions about organic production and practices. In general, questions covered pest and nutrient management, operator characteristics, bearing or planted and harvested acreage, and other characteristics.

The sample of organic vegetable growers in 1994 (close to one-fifth of all certified organic growers of vegetables) showed that most of the growers used crop rotation and resistant varieties for disease and insect control [Fernandez-Cornejo, 1998]. Fruit growers were sampled in 1995 (15 percent of all certified organic fruit growers), and the analysis showed that most growers scouted their fields and used mechanical tillage for weed control. These growers also often planted legume crops and applied manure to provide nutrients to their cropland.

Figure 4K1

Certified organic acreage, 1994 1/

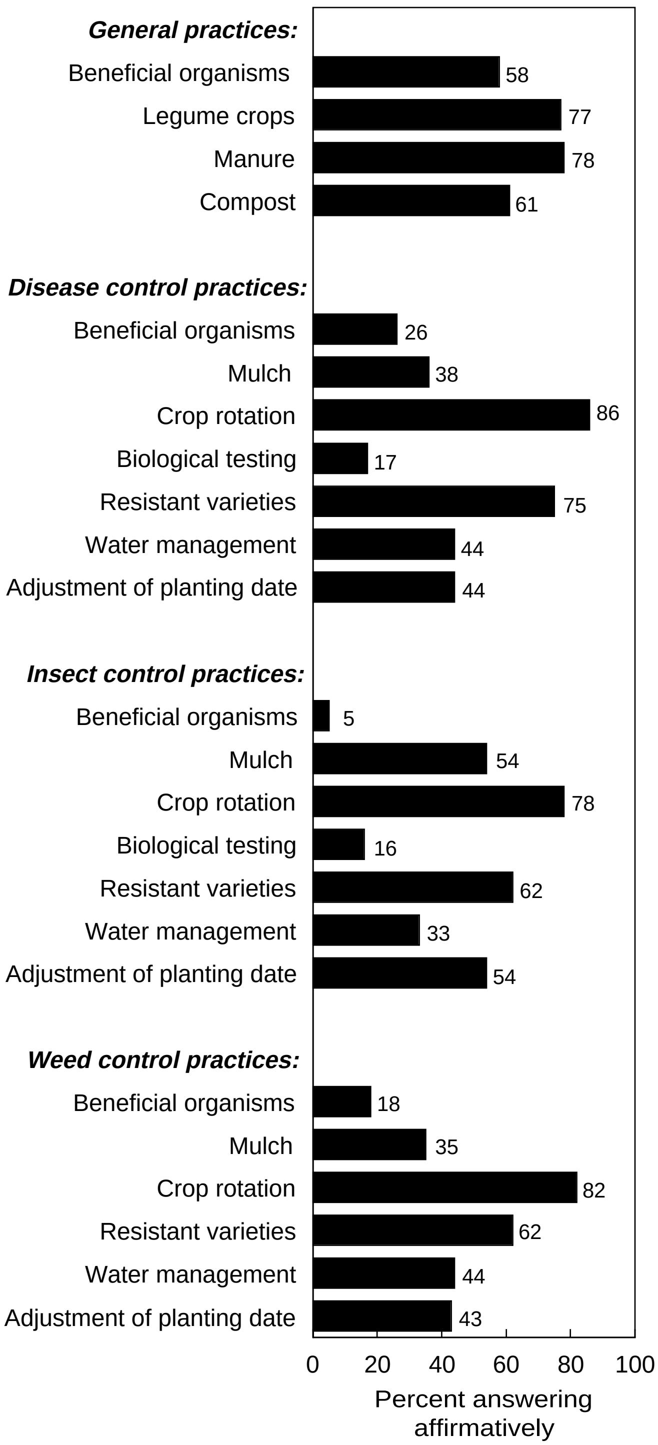


1/ Reflects private and State organic certification programs. Cropland total includes cropland harvested, pastured, idle, and other.
2/ Includes food grains, dry beans, coffee, and other produce such as nuts, mushrooms, aloe vera, and herbs.

Sources: Dunn, 1995.

Figure 4K2

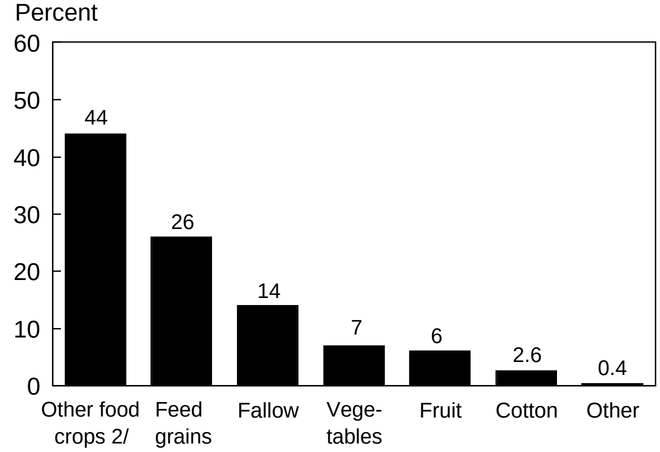
Pest management practices used by organic farmers to produce vegetables, 1994



Sources: USDA, NASS and ERS, 1994

Figure 4K3

Proportion of organic cropland, by crop, 1994 1/



1/ Crop area is reported as a percentage of the total organic cropland acres (668,690).

2/ Other food crops include grains, dry beans, coffee, and other produce such as nuts, mushrooms, aloe vera, and herbs.

Source: Dunn, 1995.

Crop Residue Management Practices

Crop residue management (CRM), a cultural practice that involves fewer and/or less intensive tillage operations and preserves more residue from the previous crop, is designed to help protect soil and water resources and provide additional environmental benefits. CRM is generally cost effective in meeting conservation requirements and reducing fuel, machinery, and labor costs while maintaining or increasing crop yields. However, improved managerial skills are often needed to capture the full economic benefits of CRM. [See box, "Benefits from Crop Residue Management" on next page.]

Crop residue management practices include reduced tillage or conservation tillage, such as no-till, ridge-till, and mulch-till, as well as the use of cover crops and other conservation practices that provide sufficient residue cover to significantly reduce the erosive effects of wind and water. These practices can benefit society through an improved environment and can benefit farmers through enhanced farm economic returns. However, adoption of CRM may not lead to clear environmental benefits in all regions and, similarly, may not be economically profitable on all farms.

With fewer trips over the fields, equipment lasts longer and/or can cover more acres. In either case, machinery ownership costs per acre are reduced (Monson and Wollenhaupt, 1995). In addition, the size and number of machines required decline as the intensity of tillage or the number of operations is reduced. This can result in significant savings in operation and maintenance costs. Fewer trips alone can save an estimated $5 per acre on machinery wear and maintenance costs (CTIC, 1996). While new or retrofitted machinery may be required to adopt conservation tillage practices, machinery costs usually decline in the long run because a smaller complement of machinery is needed for high-residue no-till systems. Conservation tillage equipment designs have improved over the last decade and these improvements enhance the opportunity for successful conversion to a CRM system. Farm equipment manufacturers are now producing a wide range of conservation tillage equipment suitable for use under a variety of field conditions (Sandretto and Bull, 1996).

Reducing the intensity or number of tillage operations also results in lower fuel and maintenance costs. Fuel costs, like labor costs, can drop nearly 60 percent per acre by some estimates (Monson and Wollenhaupt, 1995; Weersink and others, 1992). If fuel prices increase, conservation tillage practices become relatively more profitable.

Benefits from Crop Residue Management

Crop residue management practices, when appropriately applied, have been shown to provide the following soil, water quality, and economic benefits:

Soil Benefits: Tillage practices that leave substantial amounts of crop residue evenly distributed over the soil surface provide several soil benefits that increase crop yields. These practices reduce soil erosion, increase soil organic matter, improve soil tilth, increase soil moisture, and minimize soil compaction. These changes can maintain or increase the productivity of many soils, especially those that are fragile and subject to damage from soil erosion or compaction (CTIC, 1996).

Water Quality and Environmental Benefits: CRM practices keep more nutrients and pesticides in the soil where they can be used by crops and help to prevent their movement into surface or ground water. Surface residues intercept nutrients and chemicals and hold them in place until they are used by the crop or degrade into harmless components (Dick and Daniel, 1987; Helling, 1987; Wagenet, 1987). In addition, the filtering action of increased organic matter in the top layer of soil results in cleaner runoff by reducing contaminants such as sediment and adsorbed or dissolved chemicals (Onstad and Voorhees, 1987; CTIC, 1996). Studies under field conditions indicate that the quantity of water runoff from no-till fields varied depending on the frequency and intensity of rainfall events. However, runoff from no-till and mulch-till fields averaged about 30 and 40 percent, respectively, of the amounts from moldboard-plowed fields (Baker and Johnson, 1979; Glenn and Angle, 1987; Hall and others, 1984; Sander and others, 1989). Herbicide contaminants in the runoff were similarly reduced by no-till and mulch-till systems (Fawcett and others, 1994; Fawcett, 1987).

Intensive tillage contributes to the conversion of soil carbon to carbon dioxide, which, in the atmosphere, can combine with other gases to affect global warming. Increased crop residue and reduced tillage enhance the level of naturally occurring carbon in the soil and contribute to lower carbon dioxide emissions. In addition, CRM involves fewer trips across the field and less horsepower, reducing fossil fuel emissions. Crop residues reduce wind erosion and the generation of dust-caused air pollution (CTIC, 1996).

Farm Economic Benefits: Higher economic returns with CRM result primarily from some combination of increased or stable crop yields and an overall reduction in input costs. The changes in both input costs and yields depend heavily on characteristics of the resource base and management (Clark and others, 1994). Yield response with soil-conserving tillage systems varies with location, site-specific soil characteristics, local climate, cropping patterns, and level of management skills. The effects of increased organic matter, improved moisture retention and permeability, and reduced nutrient losses from erosion have beneficial impacts on crop yields. In general, long-term field trials on well-drained to moderately well-drained soils or on sloping land show slightly higher no-till yields, particularly with crop rotations, compared with conventional tillage (Hudson and Bradley, 1995; CTIC, 1996).

Choice of tillage system affects machinery, chemical, fuel, and labor costs. Decreasing the intensity of tillage or reducing the number of operations generally reduces machinery, fuel, and labor costs. These cost savings may be offset somewhat by potential increases in chemical costs depending on the herbicides selected for weed control and the fertilizers required to attain optimal yields (Siemens and Doster, 1992). The cost of pesticides with alternative tillage systems is not simply related to the total quantity used. Alternative pesticides (active ingredients) and/or different quantities of the same or similar pesticides are often used with different tillage systems. Newer pesticides are often used at a much lower rate but are quite often more expensive. This complicates the prediction of cost relationships between tillage systems. When one compares tillage systems, the cost calculation must be based on the specific quantity and price of each pesticide used.

The reduction in labor requirements per acre for higher residue tillage systems can be significant and can result in immediate cost savings. Less hired labor results in direct savings, while less operator or family labor leaves more time to generate additional income by expanding farm operations or working at off-farm jobs. However, the benefits from tillage systems that reduce labor and time requirements may be greater than perceived from just the cost savings per acre. Consideration must be given to the opportunity cost of the labor and time saved. Farmers who spend less time in the field have more time for other aspects of the farm business, such as financial management, improved marketing, or other activities to improve farm profitability (Sandretto and Bull, 1996).

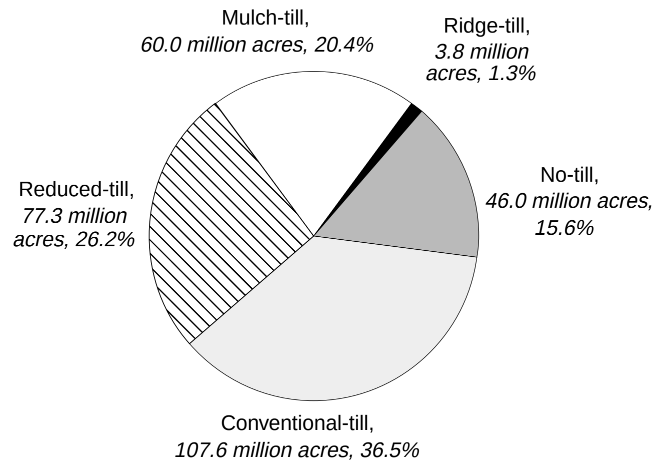
Crop Residue Management in the United States, 1997

Conservation tillage (no-till, ridge-till, and mulch-till), the major form of CRM, was used on almost 110 million acres in 1997, over 37 percent of U.S. planted cropland area (fig. 5A). [See box, "Crop Residue Management and Tillage Definitions," p. 72.] Most of the growth in conservation tillage since 1990 has come from expanded adoption of no-till, which can leave as much as 70 percent of the soil surface covered with crop residues. Use of no-till practices increased as farmers implemented conservation compliance plans during 1990-95 as required under the Food Security Act and subsequent farm legislation.

U.S. crop area planted with no-till expanded 2½ times to over 46 million acres between 1990 and 1997, while the area planted with clean tillage systems (less than 15 percent residue cover) declined by about one-fourth. Since 1990, no-till's share of conservation tillage acreage has increased, while the share with mulch-till and ridge-till has remained fairly stable.

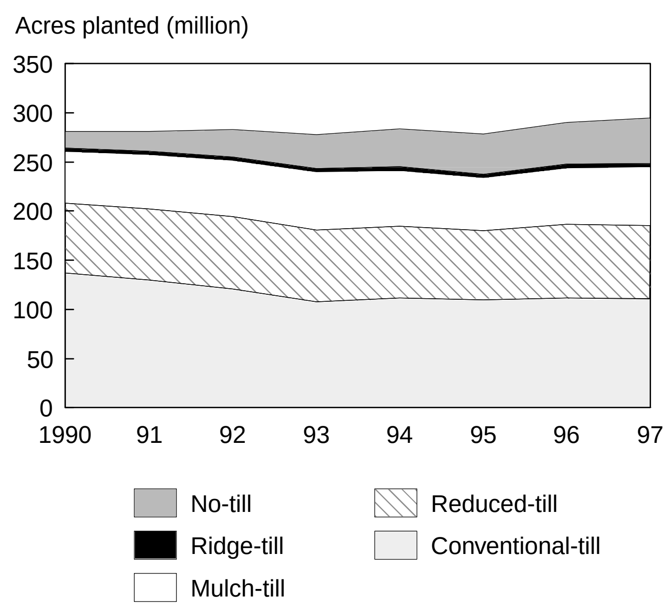
Figure 5A

Crop residue management in the United States, 1997



Represents 294.7 million acres planted to crops in 1997.

Trend in crop residue management use, 1990-97



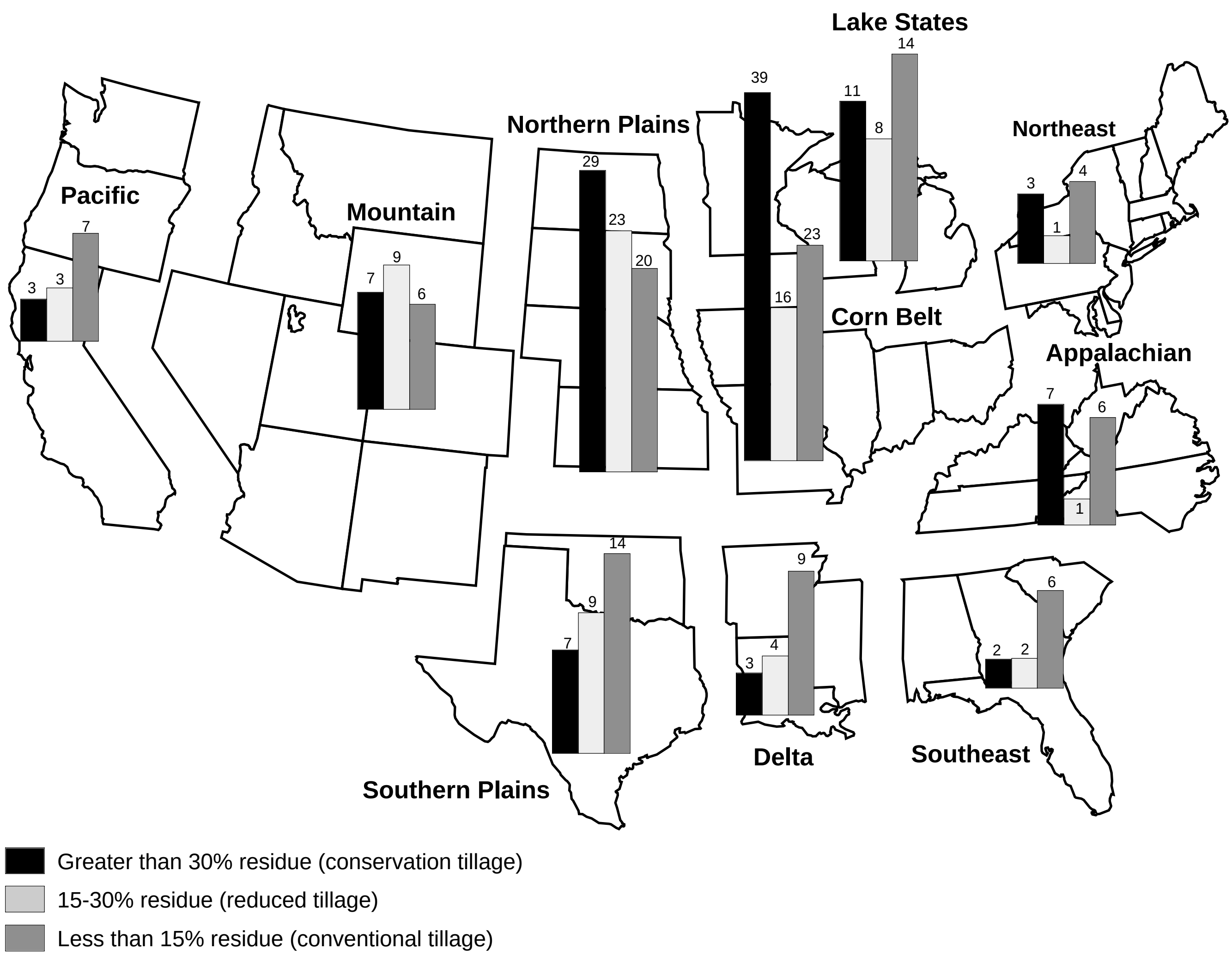
Source: USDA, ERS, based on Conservation Technology Information Center data.

Crop Residue Levels on Planted Acreage by Regions, 1997

The Corn Belt and Northern Plains, with 51 percent of the Nation's planted cropland, account for three-fifths of total conservation tillage acres (map A and fig. 5B). These regions, plus the Lake States, Mountain Region, and Southern Plains, have substantial acreage with 15-30 percent residue cover which, with improved crop residue management, has the potential to qualify for conservation tillage status (which requires 30 percent or more surface residue cover). Over half of the planted crop acreage in many counties in major agricultural regions used conservation tillage practices. The adoption of the practice is particularly high (exceeding 70 percent of the cropland) in the more erodible counties in Kentucky, Tennessee, Missouri, Iowa, and Nebraska.

Figure 5B

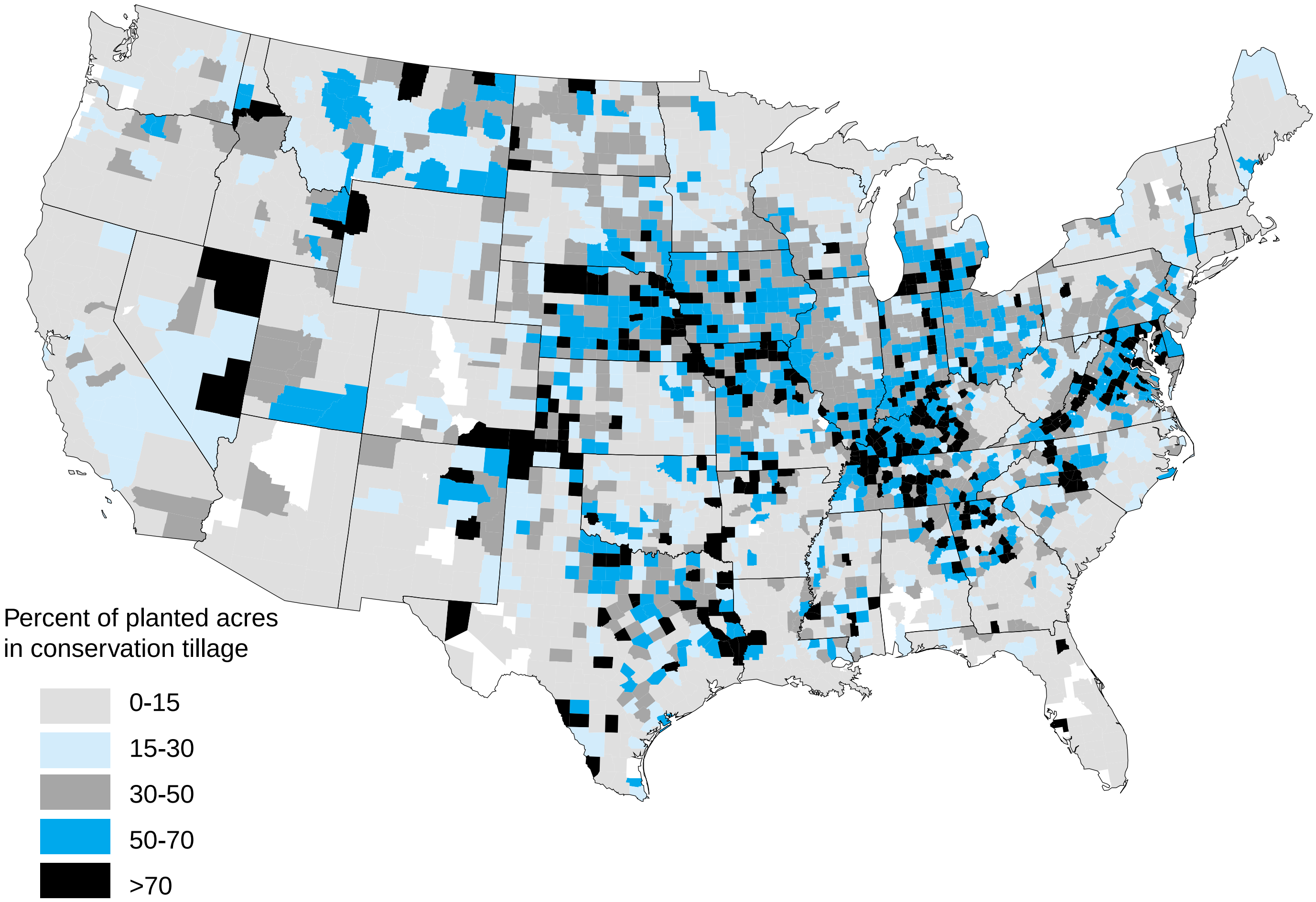
Crop residue levels on planted acreage by region, 1997 1/



1/ The value at the top of the bar is million acres with the crop residue characteristics.

Source: USDA, ERS based on Conservation Technology Information Center data.

Map A. Adoption of conservation tillage practices, 1995



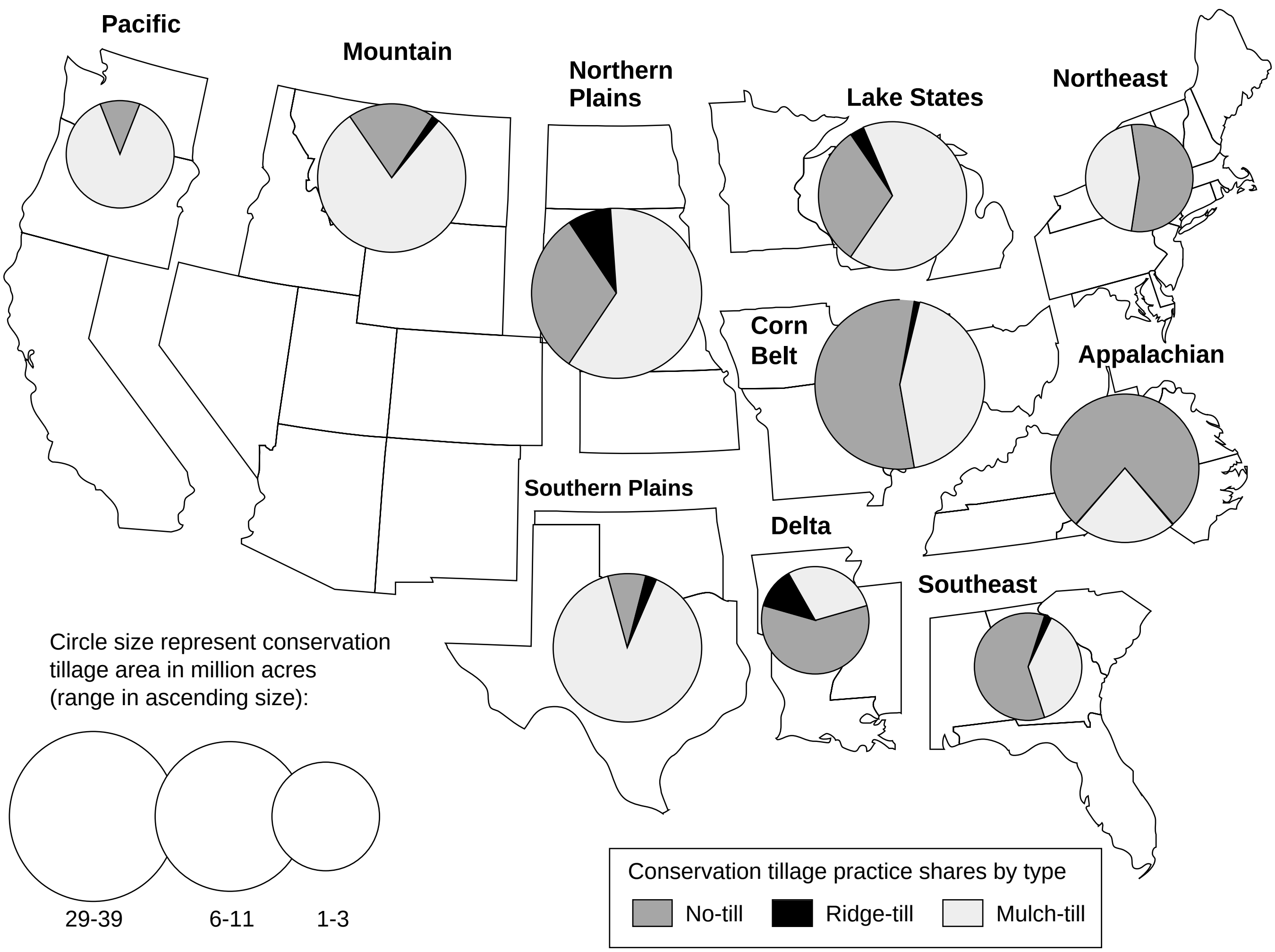
Source: USDA, ERS based on Conservation Technology Information Center data.

Applied Conservation Tillage Practices, 1997

No-till's share of conservation-tilled cropland was greatest in the southern Corn Belt area and in Tennessee and Kentucky (maps B, C, and D and fig. 5C). Mulch-till was more widespread in the northern Corn Belt and Plains regions. Ridge-till is a conservation tillage practice that is not widely used, except in portions of the Northern Plains where it was prevalent in areas with extensive continuous corn production, much of which was irrigated. For example, over one-fourth of the acreage in some counties in Nebraska use ridge-till.

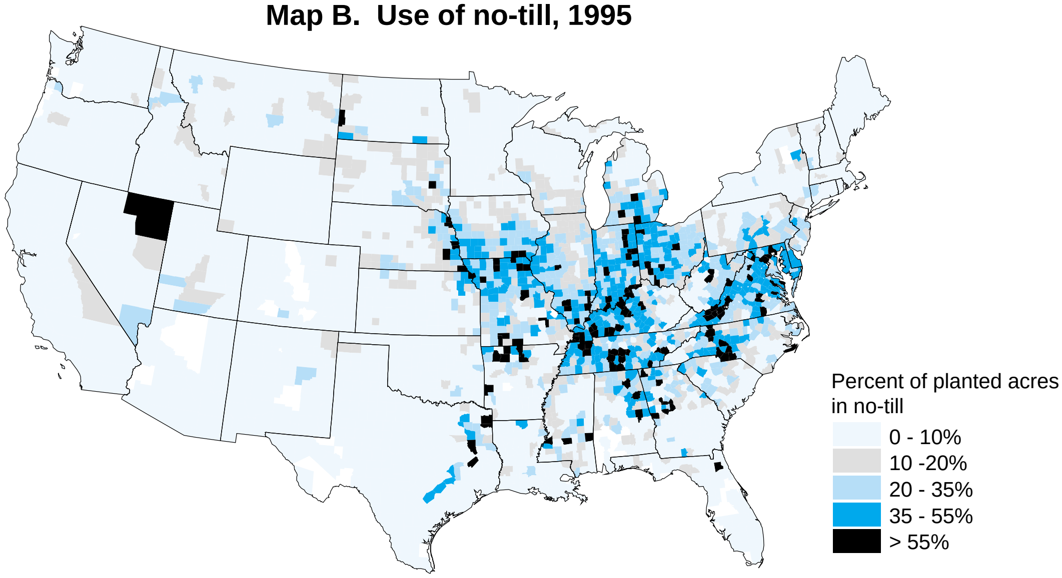
Figure 5C

Applied conservation tillage practices, 1997

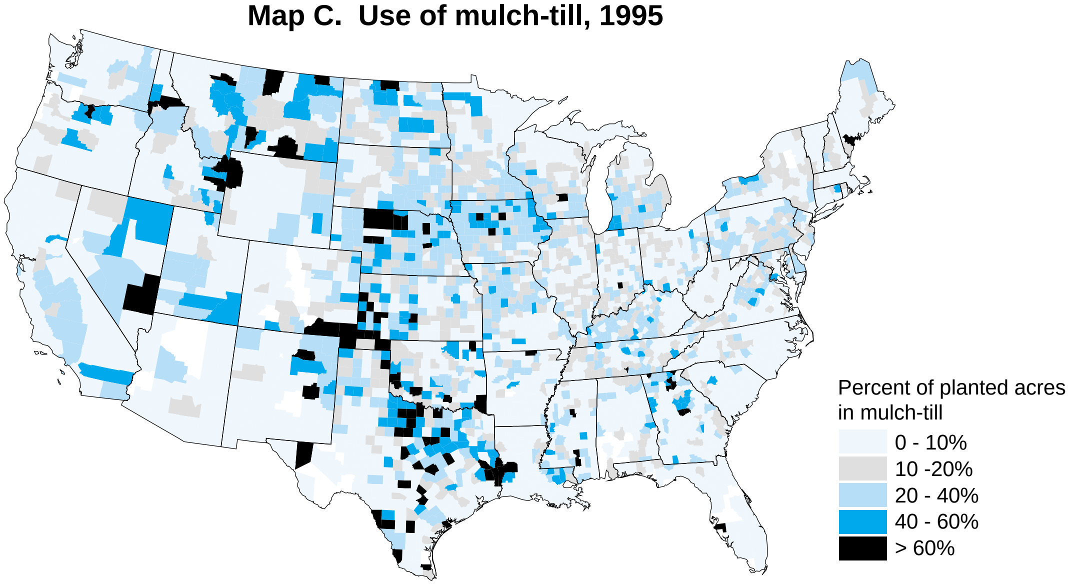


Source: USDA, NASS and ERS based on Conservation Technology Information Center data.

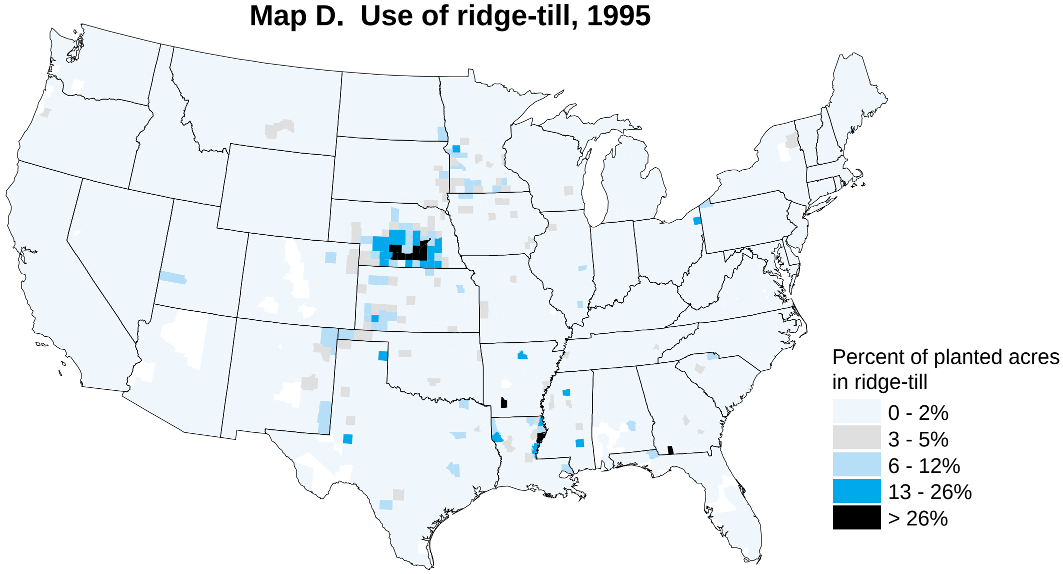
Map B. Use of no-till, 1995



Map C. Use of mulch-till, 1995



Map D. Use of ridge-till, 1995



Source: USDA, ERS based on Conservation Technology Information Center data.

Crop Residue Management and Tillage Definitions

Conventional tillage	Reduced tillage	Conservation tillage		
		Mulch-till	Ridge-till	No-till
Moldboard plow or intensive tillage used	No use of moldboard plow and intensity of tillage reduced	Further decrease in tillage (see below)	Only ridges are tilled (see below)	No tillage performed (see below)
< 15% residue cover remaining	15-30% residue cover remaining	- - - - - 30% or greater residue cover remaining - - -		

Crop Residue Management (CRM) is a year-round conservation system that usually involves a reduction in the number of passes over the field with tillage implements and/or in the intensity of tillage operations, including the elimination of plowing (inversion of the surface layer of soil). CRM begins with the selection of crops that produce sufficient quantities of residue to reduce wind and water erosion and may include the use of cover crops after low residue-producing crops. CRM includes all field operations that affect residue amounts, orientation, and distribution throughout the period requiring protection. Site specific residue cover amounts needed are usually expressed in percentage but may also be in pounds. Tillage systems included under CRM are conservation tillage (no-till, ridge-till, and mulch-till) and reduced tillage.

Conservation tillage describes any tillage and planting system that covers 30 percent or more of the soil surface with crop residue after planting, to reduce soil erosion by water. Where soil erosion by wind is the primary concern, conservation tillage is any system that maintains at least 1,000 pounds per acre of flat, small-grain residue equivalent on the surface throughout the critical wind erosion period. Two key factors influencing crop residue are (1) the type of crop, which establishes the initial residue amount and its fragility, and (2) the type of tillage operations prior to and including planting.

Conservation Tillage Systems include:

No-till—The soil is left undisturbed from harvest to planting except for nutrient injection. Planting or drilling is accomplished in a narrow seedbed or slot created by coulters, row cleaners, disk openers, in-row chisels, or roto-tillers. Weed control is accomplished primarily with herbicides. Cultivation may be used for emergency weed control.

Ridge-till—The soil is left undisturbed from harvest to planting except for nutrient injection. Planting is completed in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is accomplished with herbicides and/or cultivation. Ridges are rebuilt during cultivation.

Mulch-till—The soil is disturbed prior to planting. Tillage tools such as chisels, field cultivators, disks, sweeps, or blades are used. Weed control is accomplished with herbicides and/or cultivation.

Reduced tillage (15-30% residue)—Tillage types that leave 15-30 percent residue cover after planting, or 500-1,000 pounds per acre of small grain residue equivalent throughout the critical wind erosion period. Weed control is accomplished with herbicides and/or cultivation.

Conventional tillage (less than 15% residue)—Tillage types that leave less than 15 percent residue cover after planting, or less than 500 pounds per acre of small grain residue equivalent throughout the critical wind erosion period. Generally includes plowing or other intensive tillage. Weed control is accomplished with herbicides and/or cultivation.

Conventional tillage systems (as defined in the Cropping Practices Survey):

Conventional tillage with moldboard plow—Any tillage system that includes the use of a moldboard plow.

Conventional tillage without moldboard plow—Any tillage system that has less than 30 percent remaining residue cover and does not use a moldboard plow.

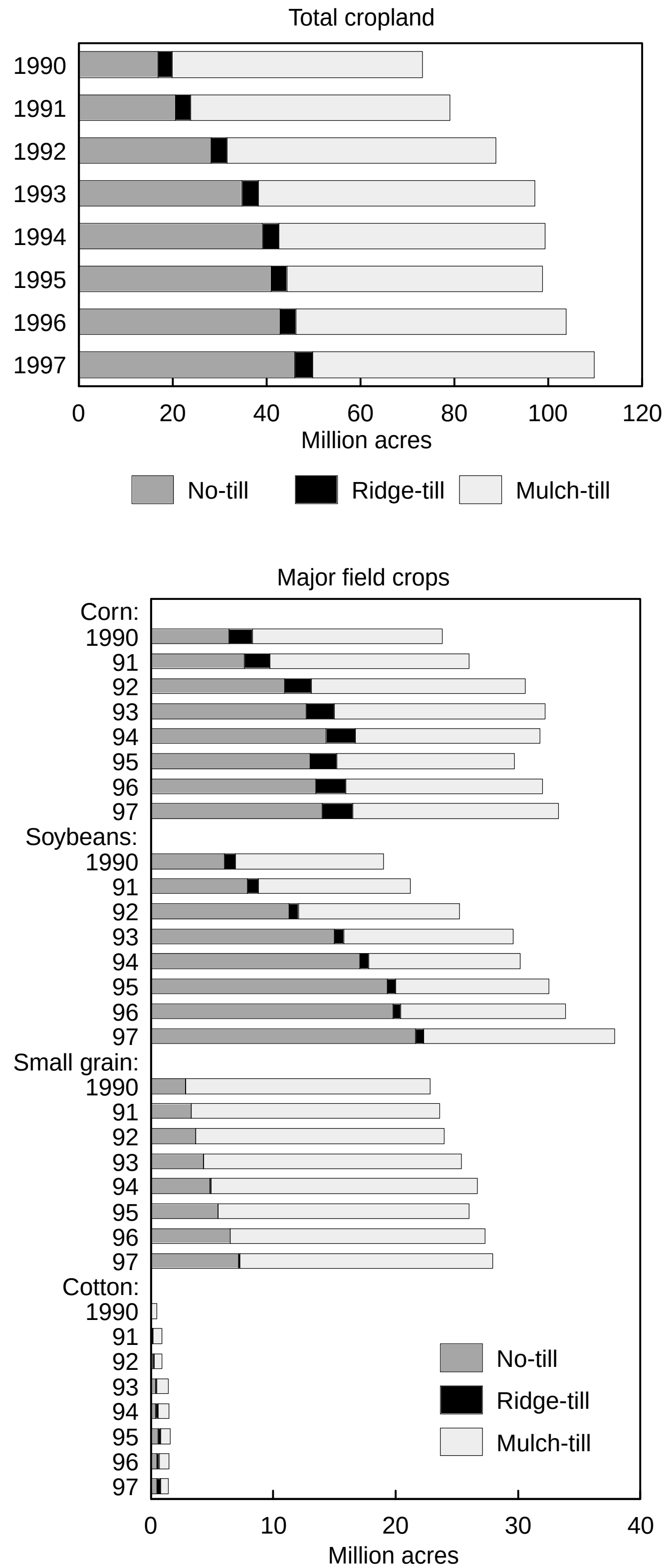
Sources: Bull, 1993, and Conservation Tillage Information Center, 1996.

Trends in Conservation Tillage Use, 1990-97

Conservation tillage was used mainly on corn, soybeans, and small grains in 1997. More than 47 percent of the total acreage planted to corn and soybeans was conservation-tilled (fig. 5D). Expanded use of no-till has been greater for corn and soybeans than for small grains or cotton. Fields planted to row crops tend to be more susceptible to erosion because these crops provide less vegetative cover, especially earlier in the growing season. On double-cropped fields, conservation tillage was used on more than two-thirds of soybean acreage, slightly less than half of corn acreage, and about one-third of sorghum acreage. The use of no-till with double-cropping facilitates getting the second crop planted quickly and limits potential moisture losses from the germination zone in the seedbed, allowing greater flexibility in cropping sequence or rotation.

Figure 5D

Trends in conservation tillage use, 1990-97



Source: USDA, ERS, based on Conservation Technology Information Center data.

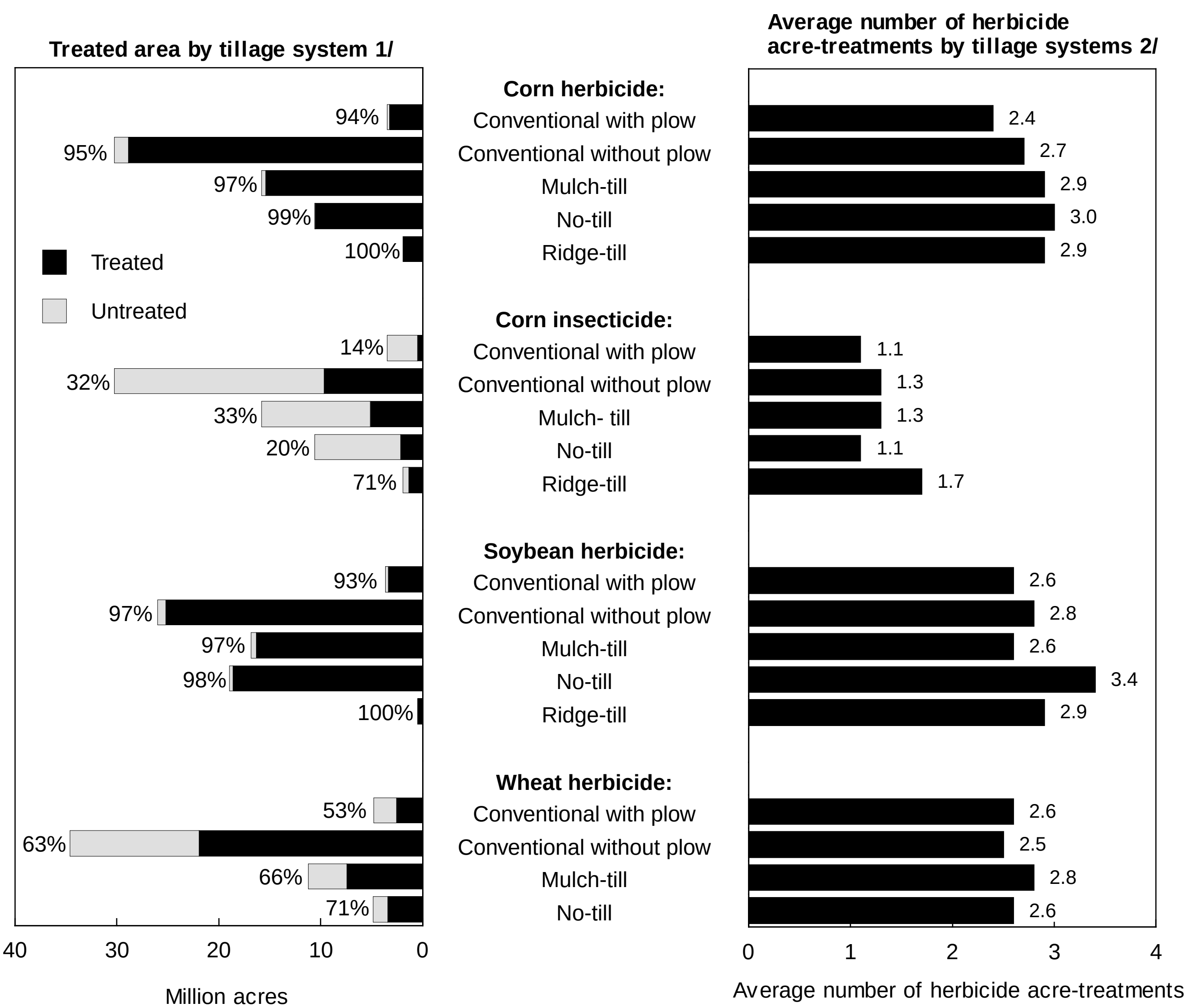
Pesticide Use by Tillage System, 1997

Pesticide use on major crops differs between tillage systems, but it is difficult to distinguish the effects related to tillage systems from differences in pest populations between areas and from one year to the next, and from use of other pest control practices (fig. 5E). Factors other than tillage that affect pest populations may have greater impact on pesticide use than type of tillage. The 1997 Agricultural Resource Management Study data for major field crops (USDA, NASS and ERS, 1996c) also illustrate that differences among tillage systems tend to be more in the combinations of active ingredients applied rather than in the overall proportion of acres treated, the number of pesticide applications per acre treated, or the amount applied per treated acre.

Nearly all corn and soybean acres under all tillage systems were treated with herbicides in 1997. The average number of corn and soybean herbicide acre-treatments was highest for no-till and lowest for conventional tillage with the moldboard plow. The reported higher level of herbicide acre-treatments with no-till is mostly due to the inclusion of an additional "burndown" herbicide treatment prior to planting as a substitute for mechanical weed control. Seventy percent of ridge-tilled corn acres were treated with insecticides while no-till had the lowest share of acres treated and the lowest average number of insecticide acre-treatments. Few soybean or wheat acres were treated with insecticides or fungicides.

Figure 5E

Herbicide use by tillage system, 1997



1/ The value at the end of each bar is the percentage treated.

2/ The value at the end of the bar is the average number of herbicide acre-treatments per treated acre.

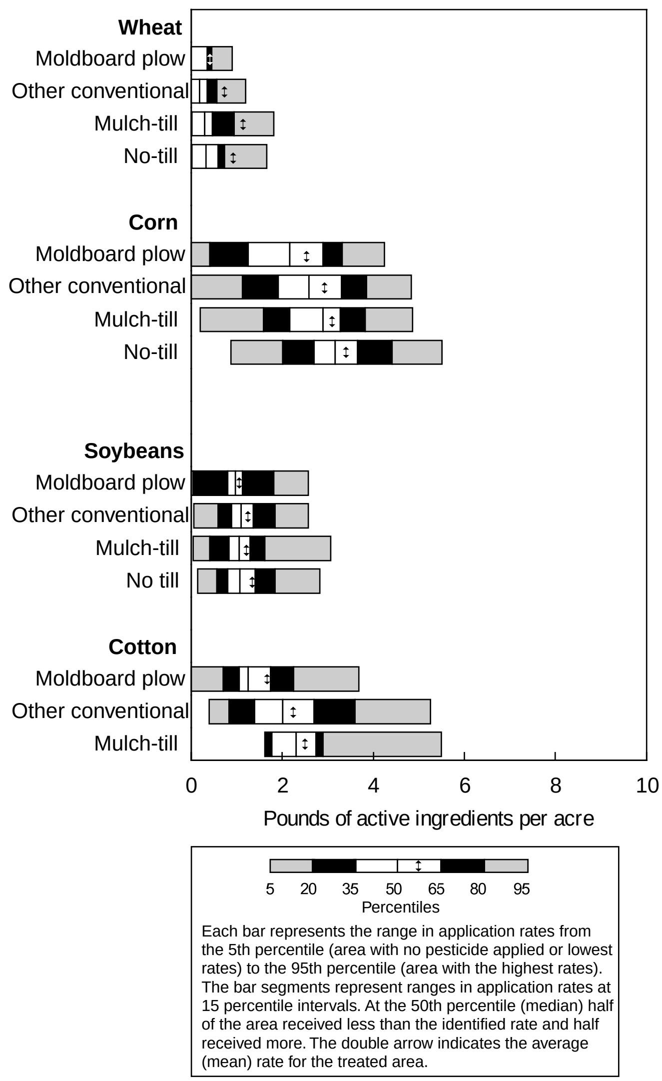
Source: 1997 Agricultural Resource Management Study

Herbicide Application Rate Variation between Fields, by Tillage Systems

Many factors other than tillage affect the quantity of herbicide applied per acre (fig. 5E1). The variation in herbicide application rates between fields is much greater than the variation that may result from the type of tillage system used. For corn and soybeans, the median (50th acreage percentile) and mean application rates were slightly higher for no-till, but the variability in rates between fields was similar for all tillage types.

Figure 5E1

Herbicide application rate variation between fields, by tillage class, 1997



Source: 1997 Agricultural Resource Management Study.

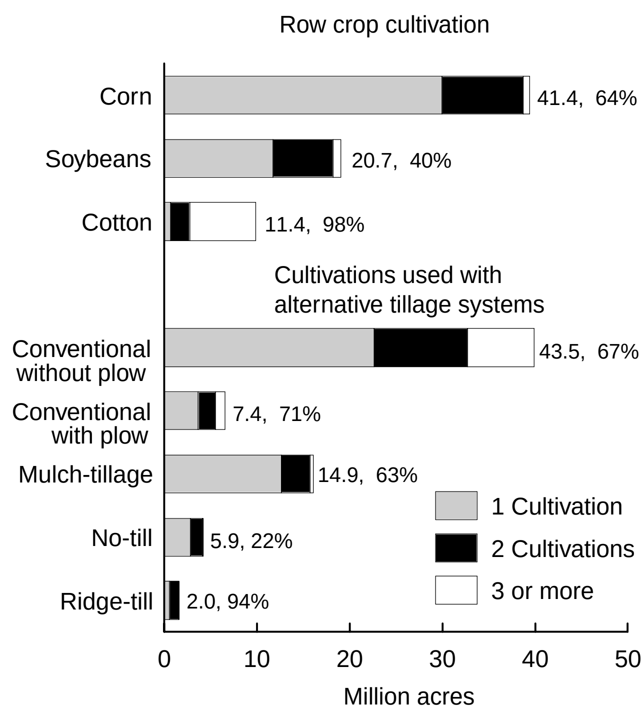
Cultivation of Row Crops

The purpose of cultivating row crops is primarily to kill weeds, but it also loosens the soil (fig. 5F1). Farmers also cultivate to shape the surface for furrow irrigation or to maintain ridges in ridge-till systems. The 1995 Cropping Practices Survey data (USDA, NASS and ERS, 1995c) indicate that nearly all cotton is cultivated, and most cotton acreage is cultivated three or more times during the growing season. About two-thirds of the corn is cultivated, but generally only once or twice during the season.

Cultivation of row crops occurs with all tillage types, but the high level of residue left on the surface with no-till and mulch-till can make the practice difficult without causing some injury to the plants. Most of the acreage in all tillage types, except no-till, was cultivated at least once. Only 22 percent of the no-till acres received any cultivations.

Figure 5F1

Cultivation of row crops, 1994



Represents 128 million acres of corn, soybeans, and cotton.
1/ The first value at the end of the bar is the area cultivated one or more times, and the second value is the percentage of area cultivated one or more times.

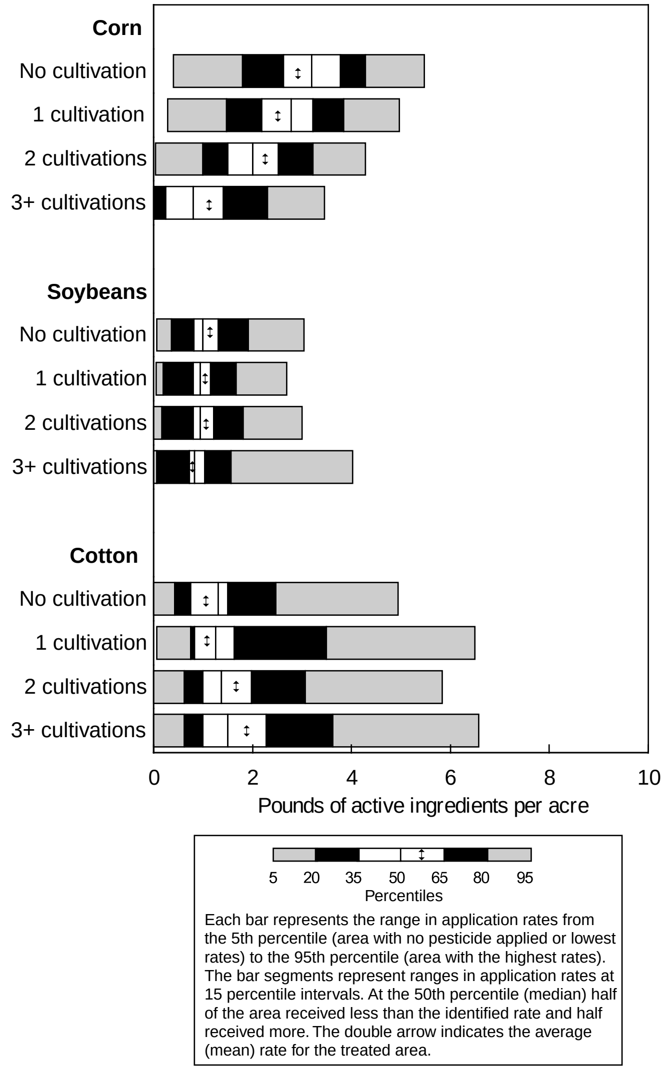
Source: 1994 Cropping Practices Survey

Herbicide Application Rate Variation between Fields, by Number of Cultivations

Increased use of row crop cultivation can control many weeds and reduce the need for herbicide treatments (fig. 5F2). Corn, soybean, and cotton acreage showed only small differences in the intensity and variation in herbicide use for fields that received two or fewer cultivations, but less herbicide use occurred on fields receiving three or more cultivations. For fields cultivated three or more times, a larger share of the acres received no herbicide treatments and the mean rate on the treated acres was lower.

Figure 5F2

Herbicide application rate variation between fields, by number of cultivations, 1994



Source: 1994 Cropping Practices Survey.

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Appendix A

Description of Surveys

Agricultural Resource Management Study (ARMS)

The ARMS, developed from combining the former Cropping Practices Survey and the Farm Costs and Returns Survey, was first conducted in 1996. A multiframe, stratified sampling procedure is used to select farms and crop fields to collect detailed information on production inputs, practices, costs, and returns. The inputs include detailed measurements of fertilizer and pesticide use and the time and methods of their application. The survey also obtains information on other nutrient and pest management practices applied by the producer. The results are weighted and aggregated to develop State, regional, and national estimates. Table A.1 reports the 1996 and 1997 sample size, by crop, for this survey.

Cropping Practices Surveys, 1990-95

The Cropping Practices Surveys were commodity surveys that collected data on fertilizer and pesticide use, tillage operations, crop sequence, and other inputs and cultural practices. The 1995 survey gathered data for corn, cotton, soybeans, wheat, and potatoes and represented about 182 million acres. The represented area included the acreage in major producing States for each commodity and accounted for 70-90 percent of the total U.S. acreage for each of these crops. See the following table for the States included in the survey and the number of fields sampled to develop estimates.

The Cropping Practices Surveys used a stratified sampling procedure to gather data about a randomly selected acre of the crop. Because the random acre within a field was not identified, respondents (farm operators) were asked to provide field-level information on all fertilizer and nutrient treatments, all tillage operations prior to planting, crops planted in the previous 2 years, and data on other inputs and cultural practices. The operator also identified whether the field had been designated as highly erodible land (HEL) by the Natural Resources Conservation Service and whether the farm unit participated in a Federal commodity price or income support program.

The Cropping Practices Surveys were annual surveys, although the commodities and States surveyed changed from year to year because of priority data needs and regional shifts in crop production. Consistent data for selected States were collected between 1990 and 1995 and were used to develop the time series data in this report. The sample number and statistical reliability of estimates for preceding years is generally similar to that for 1995.

Chemical Use Surveys

The Chemical Use Surveys collect nutrient and pesticide use and other production data on fruit and vegetable crops. Since 1990, data on vegetable crops were collected for even numbered years (1990, 1992, and 1994), while data for fruit crops were collected in odd numbered years (1991, 1993, and 1995). Besides gathering chemical use data, these surveys also focused on data related to integrated pest management, the use of organic production practices, and farm enterprise and operator characteristics. Specific field-level information on nutrient and pest management was collected for apples, oranges, grapes, peaches, fresh market tomatoes, and strawberries. The surveys were a stratified systematic sample of growers who produce at least an acre of the targeted crop.

Table A.1—Completed sample sizes for the 1996 and 1997 Agricultural Resource Management Study

State	Corn	Soybeans	Upland cotton	Winter wheat	Durum wheat	Spring wheat	Fall potatoes	Total
				1996 sample number				
AZ	.	.	76	.	.	.	.	76
AR	.	171	95	.	.	.	.	266
CA	.	.	137	.	.	.	.	137
CO	.	.	.	72	.	.	.	72
DE	.	.	.	76	.	.	.	76
GA	.	.	106	.	.	.	.	106
ID	.	.	.	66	.	.	226	292
IL	271	247	.	.	.	.	.	518
IN	236	182	.	.	.	.	.	418
IA	1,009	948	.	.	.	.	.	1,957
KS	217	.	.	174	.	.	.	391
KY	73	.	.	.	.	.	.	73
LA	.	122	78	.	.	.	.	200
ME	.	.	.	.	.	.	118	118
MI	152	.	.	.	.	.	.	152
MN	222	242	.	.	.	64	.	528
MS	.	147	158	.	.	.	.	305
MO	156	171	.	.	.	.	.	327
MT	.	.	.	49	.	85	.	134
NE	275	152	.	40	.	.	.	467
NC	73	.	.	.	.	.	.	73
ND	.	.	.	.	99	99	.	198
OH	173	163	.	.	.	.	.	336
OK	.	.	.	83	.	.	.	83
OR	.	.	.	76	.	.	.	76
PA	93	.	.	.	.	.	.	93
SC	55	.	.	.	.	.	.	55
SD	178	.	.	56	.	.	.	234
TN	.	150	111	.	.	.	.	261
TX	58	.	388	103	.	.	.	549
WA	.	.	.	108	.	.	61	169
WI	700	154	.	.	.	.	.	854
MN/ND 1/	.	.	.	.	.	.	69	69
Total	3,941	2,849	1,149	903	99	248	474	9,663

See notes at end of table.

—Continued

Table A.1—Completed sample sizes for the 1996 and 1997 Agricultural Resource Management Study—continued

State	Corn	Soybeans	Upland cotton	Winter wheat	Spring wheat	Durum wheat	Fall potatoes	Total
				1997 sample number				
AL	.	.	75	.	.	.	.	75
AZ	.	.	55	.	.	.	.	55
AR	.	83	49	.	.	.	.	132
CA	.	.	54	.	.	.	.	54
CO	.	.	.	81	.	.	.	81
DE	.	159	.	.	.	.	.	159
GA	.	.	95	.	.	.	.	95
ID	.	.	.	83	.	.	185	268
IL	226	217	.	65	.	.	.	508
IN	150	154	.	.	.	.	.	304
IA	205	209	.	.	.	.	.	414
KS	.	136	.	229	.	.	.	365
KY	.	108	.	.	.	.	.	108
LA	.	126	84	.	.	.	.	210
ME	.	.	.	.	.	.	122	122
MI	146	61	.	.	.	.	.	207
MN	144	174	.	.	48	.	49	415
MS	.	167	126	.	.	.	.	293
MO	144	138	53	67	.	.	.	402
MT	.	.	.	75	90	.	.	165
NE	192	177	.	81	.	.	.	450
NC	.	75	74	.	.	.	.	149
ND	.	.	.	.	92	119	47	258
OH	157	134	.	67	.	.	.	358
OK	.	.	.	149	.	.	.	149
OR	.	.	.	82	.	.	91	173
PA	.	162	.	158	.	.	.	320
SC	.	.	56	.	.	.	.	56
SD	171	116	.	62	69	.	.	418
TN	.	102	102	.	.	.	.	204
TX	.	.	308	135	.	.	.	443
WA	.	.	.	101	.	.	71	172
WI	159	56	.	.	.	.	71	286
Total	1,694	2,554	1,131	1,435	299	119	636	7,868

. = No survey conducted in State.
1/ Includes only counties along the Red River Valley in Minnesota and North Dakota.
Source: USDA, National Agricultural Statistics Service and Economic Research Service, 1996c.

Table A.2—Completed sample sizes for the 1995 Cropping Practices Survey

State	Soybeans	Upland cotton	Corn	Fall potatoes	Winter wheat	Spring wheat	Durum wheat
				Number of fields			
AZ	.	69	.	.	.	.	.
AR 1/	125	117	.	.	.	.	.
CA	.	160	.	.	.	.	.
CO	.	.	.	72	82	.	.
DE	.	.	76	.	.	.	.
GA	122	.	115	.	.	.	.
ID	.	.	.	262	85	.	.
IL 1/	206	.	265	.	76	.	.
IN 1/	138	.	164	.	.	.	.
IA 1/	209	.	624	.	.	.	.
KS	.	.	69	.	391	.	.
KY	158	.	153	.	.	.	.
LA	160	93	.	.	.	.	.
ME	.	.	.	146	.	.	.
MI 1/	.	.	84	83	.	.	.
MN 1/	98	.	171	94	.	61	.
MS	179	149	.	.	.	.	.
MO 1/	122	.	119	.	64	.	.
MT	.	.	.	.	94	82	.
NE 1/	83	.	199	.	93	.	.
NY	.	.	.	57	.	.	.
NC	153	.	132	.	.	.	.
ND	.	.	.	133	.	102	116
OH 1/	126	.	133	.	72	.	.
OK	.	.	.	.	478	.	.
OR	.	.	.	143	93	.	.
PA	.	.	82	56	.	.	.
SD 1/	.	.	104	.	56	58	.
TN	157	.	.	.	.	.	.
TX	.	439	69	.	153	.	.
WA	.	.	.	144	135	.	.
WI 1/	.	.	136	130	.	.	.
Total	2,036	1,027	2,695	1,320	1,872	303	116

. = No survey conducted in the State.

1/ For corn and soybeans, no pest management information was collected in this State. However pest management data were collected in 1994 on a similar size of sample and used to calculate estimates for this report.

Source: USDA, National Agricultural Statistics Service and Economic Research Service, 1995c.

Table A.3—Completed sample sizes for the 1995 Fruit Chemical Use Survey

Item	Total	CA	FL	GA	MI	NJ	NY	OR	PA	SC	WA
						Number of growers					
Apples	1,120	91	.	34	175	68	182	141	139	39	251
Apricots	78	78	.	.	.	.	.	.	.	.	.
Avocados	101	51	50	.	.	.	.	.	.	.	.
Blackberries	110	.	.	.	.	.	.	110	.	.	.
Blueberries	322	.	.	55	131	64	.	72	.	.	.
Dates	33	33	.	.	.	.	.	.	.	.	.
Figs	14	14	.	.	.	.	.	.	.	.	.
Grapes	704	255	.	.	99	.	81	104	83	.	82
Kiwifruit	48	48	.	.	.	.	.	.	.	.	.
Nectarines	98	98	.	.	.	.	.	.	.	.	.
Olives	65	65	.	.	.	.	.	.	.	.	.
Peaches	684	169	.	41	93	77	55	.	107	75	67
Pears	390	78	.	.	.	.	74	111	.	.	127
Plums	116	116	.	.	.	.	.	.	.	.	.
Prunes	150	150	.	.	.	.	.	.	.	.	.
Grapefruit	258	75	183	.	.	.	.	.	.	.	.
Lemons	87	87	.	.	.	.	.	.	.	.	.
Limes	16	.	16	.	.	.	.	.	.	.	.
Oranges	454	183	271	.	.	.	.	.	.	.	.
Tangelos	126	.	126	.	.	.	.	.	.	.	.
Tangerines	193	59	134	.	.	.	.	.	.	.	.
Raspberries	162	.	.	.	.	.	.	81	.	.	81
Cherries, sweet	449	98	.	.	100	.	.	112	.	.	139
Cherries, tart	298	.	.	.	139	.	51	45	63	.	.
Temples	97	.	97	.	.	.	.	.	.	.	.
Total	6,551	1,924	892	178	746	228	450	843	396	118	776

. = No survey conducted in the State.
Source: USDA, National Agricultural Statistics Service and Economic Research Service, 1995d.

Table A.4—Completed sample sizes for the 1994 Vegetable Chemical Use Survey

Item	ALL	AZ	CA	FL	GA	IL	MI	MN	NJ	NY	NC	OR	TX	WA	WI
								Number of growers							
Watermelons	798	35	76	101	222	.	.	.	.	.	142	.	222	.	.
Other melons	457	21	93	.	94	.	88	.	.	.	.	.	161	.	.
Strawberries	623	.	90	49	.	.	87	.	59	72	65	91	.	32	78
Asparagus	398	.	27	.	.	80	119	.	61	.	.	18	.	93	.
Broccoli	230	15	130	.	.	.	.	.	.	.	.	48	37	.	.
Carrots	337	7	95	7	.	.	52	.	.	30	.	43	45	26	32
Cauliflower	221	8	65	.	.	.	38	.	.	47	.	50	13	.	.
Celery	72	.	36	5	.	.	28	.	.	.	.	.	3	.	.
Eggplant	197	.	.	35	.	.	.	.	162	.	.	.	.	.	.
Lettuce, head	164	19	65	3	.	.	.	.	51	26	.	.	.	.	.
Onions	787	19	136	.	112	.	64	.	.	107	.	129	134	54	32
Peppers, bell	647	.	100	53	.	.	106	.	241	.	78	.	69	.	.
Lettuce, other	141	13	122	6	.	.	.	.	.	.	.	.	.	.	.
Cabbage, fresh	718	.	55	25	64	.	72	.	113	124	129	.	79	.	57
Sweet corn, fresh	1,447	.	93	87	126	106	152	.	228	182	170	84	64	63	92
Cucumbers, fresh	663	.	79	40	57	.	77	.	160	69	96	.	85	.	.
Beans, lima, fresh	78	.	.	.	78	.	.	.	.	.	.	.	.	.	.
Beans, snap, fresh	619	.	82	77	109	.	65	.	108	69	109	.	.	.	.
Spinach, fresh	158	.	53	.	.	.	.	.	66	.	.	.	39	.	.
Tomatoes, fresh	974	.	168	53	42	.	118	.	270	127	93	.	103	.	.
Cabbage, processed	57	.	.	.	.	.	6	.	.	30	.	.	.	.	21
Sweet corn, processed	792	.	.	.	.	140	12	99	.	73	.	150	.	87	231
Cucumbers, processed	319	.	13	4	5	.	104	.	.	.	105	17	33	15	23
Beans, lima, processed	165	.	31	.	.	37	.	.	32	.	.	4	.	43	18
Peas, processed	564	.	.	.	.	102	.	94	.	56	.	55	.	87	170
Beans, snap, processed	471	.	6	.	.	68	71	.	22	34	8	125	.	4	133
Spinach, processed	21	.	10	.	.	.	.	.	.	.	.	.	11	.	.
Tomatoes, processed	166	.	139	.	.	.	27	.	.	.	.	.	.	.	.
Total	12,284	137	1,764	545	909	533	1,286	193	1,573	1,046	995	814	1,098	504	887

.= No survey conducted in State.
Source: USDA, National Agricultural Statistics Service and Economic Research Service, 1994.

Table B.1—Fertilizer use on crops 1/

Crop	Area not treated	Area treated	Area receiving— Nitrogen	Phosphate	Potash	Quantities applied Nitrogen	Phosphate	Potash
	1,000 acres					*1,000 pounds*		
Corn	874	79,353	79,425	67,391	47,763	10,335	3,823	4.656
Cotton	1,129	12,679	12,427	9,251	8,009	1,051	434	571
Wheat	8,973	62,016	61,831	45,149	12,707	3,957	1,404	521
Soybeans	44,154	26,696	14,170	19,838	23,381	368	1,001	2,131
Subtotal for following	834	7,133	5,200	5,239	5,237	1,112	589	687
Potatoes	-	1,362	1,362	1,335	1,239	322	240	194
Vegetables 2/	494	3,032	1,099	2,705	2,320	489	292	275
Citrus 2/	20	1,130	1,130	579	860	177	26	148
Apples 2/	104	349	349	167	200	22	6	11
Other fruit 2/, 3/	216	1,260	1,260	453	618	102	24	59
Total	55,964	187,877	173,053	146,868	107,097	16,823	7,250	8,566

- = None reported or insufficient data available to make an estimate.
[1]Constructed to represent 244 million acres of 1997 U.S. cropland. Estimates were constructed using 1997 planted crop acres for all crops and fertilizer use rates from the 1997 Agricultural Resource Management Study (corn, cotton, wheat, soybeans, and potatoes), the 1995 Fruit Chemical Use Survey, and the 1994 Vegetable Chemical Use Survey.
[2]Treated area includes only the area treated with nitrogen.
[3]Excludes citrus and apples, but includes other deciduous fruits and berries.

Source: USDA, National Agricultural Statistics Service and Economic Research Service, 1998b; USDA National Agricultural Statistics Service and Economic Research Service, 1996b; and USDA, National Agricultural Statistics Service and Economic Research Service, 1995a.

Table B.2—Nutrient application rates on field crops, 1990-97

Nutrient/crop	1990	1991	1992	1993	1994	1995	1996	1997
				Pounds/acre				
Nitrogen:								
Corn	132	128	127	123	129	129	133	132
Cotton	86	91	88	90	110	96	98	83
Wheat	59	62	63	64	67	59	57	59
Soybeans	23	24	20	20	24	28	24	21
Potatoes	231	230	242	271	240	251	220	268
Phosphate:								
Corn	61	60	57	56	57	56	59	57
Cotton	44	46	48	47	43	43	44	43
Wheat	36	36	34	34	35	30	29	29
Soybeans	48	48	46	46	47	55	49	54
Potatoes	184	187	192	210	176	199	196	218
Potash:								
Corn	84	81	79	79	81	81	82	81
Cotton	47	49	56	58	55	51	58	52
Wheat	44	43	39	35	38	20	28	19
Soybeans	85	78	76	81	81	88	86	93
Potatoes	139	137	148	168	170	163	147	153

Source: USDA, National Agricultural Statistics Service and Economic Research Service, 1995c, 1996a, and 1997b. Represents planted corn area in IL, IN, IA, MI, MN, MO, NE, OH, SD, and WI; cotton area in AZ, AR, CA, LA, MS, and TX; wheat area in CO, KS, MT, NE, OK, SD, TX, and WA; soybean area in AR, IL, IN, IA, MN, MO, NE, and OH; and potato area in ID, ME, and WA.

Table B.3—Nutrient management practices

Item (unit)	Total	Corn	Soybeans	Wheat	Cotton	Potatoes	Oranges	Apples	Grapes	Peaches	Tomatoes	Strawberries
Represented crop area (000 acres)	196,337	62,150	62,215	55,865	13,080	990	671	329	743	144	104	46
Time of nitrogen applications:												
Amount applied in Fall (000 lbs)	3,703	1,694	109	1,684	187	29	na	na	na	na	na	na
Amount applied in Spring before planting (000 lbs)	6,092	4,572	193	946	286	95	na	na	na	na	na	na
Amount applied in Spring after planting (000 lbs)	3,226	1,857	33	669	567	100	na	na	na	na	na	na
Total	12,991	8,123	335	3,299	1,010	224	na	na	na	na	na	na
Area with only fall application (000 acres)	30,231	7,851	3,699	16,759	1,880	42	na	na	na	na	na	na
Amount applied (000 lbs)	2,304	1,083	97	997	119	8	na	na	na	na	na	na
Area with only spring applications (000 acres)	80,758	44,677	9,085	17,984	8,324	688	na	na	na	na	na	na
Amount applied (000 lbs)	7,891	5,722	181	1,125	707	156	na	na	na	na	na	na
Area with split applications between fall and spring (000 acres)	25,908	8,980	505	14,467	1,747	209	na	na	na	na	na	na
Amount Fall applied (000 lbs)	1,400	611	12	687	69	21	na	na	na	na	na	na
Amount Spring applied (000 lbs)	1,398	707	46	491	115	39	na	na	na	na	na	na
Livestock manure usage:[1]												
Area receiving (000 acres)	15,675	10,325	3,607	1,234	337	25	41	10	73	12	2	9
Manure analyzed for nutrients (000 acres)	1,122	800	193	107	108	12	na	na	na	2	na	na
Soil nutrient testing:[1]												
Tested for pH or nutrient status (000 acres)	59,221	26,459	15,226	12,610	3,171	945	381	119	184	51	52	23
Tested for nitrogen content (000 acres)	37,278	14,603	6,450	11,607	2,998	888	369	115	183	na	44	21
Area treated with nitrogen stabilizer (000 acres)[1]	na	6,366	na	na	na	na	na	na	na	na	na	na

na = No data available to make estimate.
[1]Estimates for livestock manure usage and soil nutrient testing for corn, soybeans, wheat, cotton, and potatoes are from the 1995 Cropping Practices Survey representing 64.1, 51.8, 53.0, 11.7, 1.1 million acres, respectively. Estimates for area treated with nitrogen stabilizers are from the 1996 Cropping Practices Survey representing 61.5 million acres of corn.
Source: USDA, National Agricultural Statistics Service and Economic Research Service, 1996c, 1996d, and 1994.

Table B.4—Pest management practices on selected crops

Item (unit)	Total	Corn	Soybeans	Wheat	Cotton	Potatoes	Oranges	Apples	Grapes	Peaches	Tomatoes	Strawberries
					1,000 acres							
Planted crop area	187,738	69,755	50,665	52,965	11,650	666	671	329	743	144	104	46
Scouting for pests	144,895	51,283	38,705	42,488	10,216	572	602	277	509	102	96	45
Scouted by operator or employee	116,469	42,031	34,428	35,364	3,723	133	327	108	262	27	39	27
Scouted by chemical dealer	9,020	3,240	2,290	1,898	833	259	162	100	165	53	15	5
Scouted by a professional service	9,958	1,780	432	1,817	5,504	144	79	53	77	21	39	12
					Dollars							
Average cost per acre	3.46	4.52	3.28	2.78	6.00	na	na	na	na	na	na	na
					1,000 acres							
Scouted by other	9,448	4,232	1,555	3,409	156	36	34	16	5	1	3	1
Soil and plant tissue testing for pests	6,460	2,052	1,498	1,101	1,034	361	173	37	151	12	32	9
Pheromone traps to monitor pests	3,453	na	na	108	2,854	na	107	227	92	47	16	2
Weed mapping for preventive treatments	20,486	9,294	7,197	1,563	2,432	na	na	na	na	na	na	na
Planting resistant varieties/rootstock	33,271	na	na	28,745	4,204	na	85	32	86	63	39	17
Protection of beneficial insects	23,376	na	na	13,252	8,921	149	407	264	231	59	66	27
Purchasing/releasing beneficial insects	557	na	na	326	108	8	53	3	39	1	3	16
Adjustment of planting dates	22,551	na	na	18,789	3,751	na	na	na	na	na	11	0
Pheromone use for pest control	1,389	na	na	92	1,140	na	20	50	36	30	21	0
Seed treatments with pesticides	93,827	49,382	12,247	22,761	9,437	na	na	na	na	na	na	na
Alternating pesticides to reduce occurrence of pesticide-resistant species	103,712	41,896	33,457	20,492	6,227	509	409	248	269	96	76	33
Decision strategies for pesticide application decisions:												
Use of pest thresholds	82,689	16,280	14,219	39,857	10,729	517	489	183	304	4	73	34
Preventive or routine schedule treatments	48,078	24,999	14,253	7,512	794	48	108	133	183	13	26	9
Requirement of processor and/or sales contract	32	na	na	na	na	na	3	1	16	0	6	6
Information sources used for pest management:												
Extension Service	10,061	na	na	8,362	1,302	na	119	63	160	32	15	8
Chemical dealer	35,235	na	na	30,501	3,805	na	359	160	306	47	38	19
Professional scouting service	10,653	na	na	4,457	5,763	na	133	75	120	44	45	16
Media or demonstration events	2,947	na	na	2,559	331	na	31	7	11	6	1	1
Other information sources	6,417	na	na	5,806	425	na	28	21	123	9	2	3
Produced using organic system	2,718	950	573	886	264	15	1	6	22	1	0	0

na = No data available to make estimate.
Source: USDA, National Agricultural Statistics Service and Economic Research Service, 1995c, 1995d, and 1994

Table B.5—Overall pesticide use on selected U.S. crops by pesticide type, 1990-97 1/

Item	1990	1991	1992	1993	1994	1995	1996	1997
				Million pounds of active ingredients				
Herbicides	344.6	335.2	350.5	323.5	350.6	324.9	365.7	366.4
Insecticides	57.4	52.8	60.0	58.1	68.2	69.9	59.2	60.5
Fungicides	27.8	29.4	34.9	36.6	43.6	47.5	46.8	50.5
Other pesticides	67.9	60.1	72.7	80.0	101.1	101.0	104.0	110.2
Total	497.7	477.5	518.2	498.2	563.4	543.3	575.8	587.6
				Million cropland acres				
Area represented	228.5	226.0	231.5	226.6	232.8	228.0	242.1	243.8
Total cropland used for crops	341.0	337.0	337.0	330.0	339.0	332.0	346.0	353.0
				Pounds of active ingredient per planted acre				
Herbicides	1.508	1.483	1.514	1.428	1.505	1.425	1.5111	1.502
Insecticides	.251	.234	.259	.256	.293	.306	.245	.248
Fungicides	.121	.130	.151	.161	.187	.208	.193	.207
Other pesticides	.297	.266	.314	.353	.434	.443	.430	.452
Total	2.178	2.113	2.238	2.199	2.419	2.383	2.379	2.410
				Percent				
Share of cropland represented 2/	67	67	69	69	69	69	70	69

1/ Estimates include corn, soybeans, wheat, cotton, potatoes, other vegetables, citrus fruit, apples, and other fruit.
2/ Share of total for the selected crops to total cropland used for crops.
Source: Lin, Biing, M. Padgitt, L., Bull, H. Delvo, D. Shank, and H. Taylor 1995 (prior to 1993); unpublished USDA survey data (following 1993).

Table B.6—Estimated quantity of pesticide active ingredient applied to selected U.S. crops, 1990-97 1/

Item/commodity	1990	1991	1992	1993	1994	1995	1996	1997
	Million pounds of herbicides							
Herbicides	344.6	335.2	350.5	323.5	350.6	324.9	365.7	366.4
Corn	217.5	210.2	224.4	202.0	215.6	186.3	211.6	211.8
Cotton	21.1	26.0	25.8	23.6	28.6	32.9	27.7	29.2
Wheat	16.6	13.6	17.4	18.3	20.7	20.0	30.5	24.3
Soybeans	74.4	69.9	67.4	64.1	69.3	68.1	77.8	83.7
Potatoes	2.4	2.5	2.2	2.5	2.9	2.9	2.9	2.4
Other vegetables	4.9	4.7	5.8	5.7	6.2	7.2	7.7	7.5
Citrus	5.7	6.1	5.5	5.1	4.8	4.7	4.6	4.5
Apples	.4	.4	.4	.4	.6	.8	.8	.9
Other deciduous	1.7	1.7	1.7	1.8	2.0	2.0	2.1	2.1
	Million pounds of insecticides							
Corn	23.2	23.0	20.9	18.5	17.3	15.0	16.1	17.5
Cotton	13.6	8.2	15.3	15.4	23.9	30.0	18.7	19.3
Wheat	1.0	.2	1.2	.2	2.0	.9	2.3	1.2
Soybeans	.	.4	.4	.3	.2	.5	.4	.8
Potatoes	3.6	3.6	3.5	3.9	4.4	3.1	2.5	3.3
Other vegetables	4.7	4.5	5.5	5.3	5.7	5.7	5.4	5.3
Citrus	2.8	4.0	4.5	5.3	5.1	5.2	5.3	5.5
Apples	3.7	4.0	3.9	4.1	3.8	3.5	3.4	3.3
Other deciduous	4.8	4.9	4.9	5.0	5.6	6.0	5.2	4.4
	Million pounds of fungicides							
Corn	.	.	.	.	.	.	.	.
Cotton	1.0	0.7	0.8	0.7	1.1	1.0	0.5	0.9
Wheat	.2	.1	1.2	.7	1.0	.5	.2	.1
Soybeans	.	.	.1	.	.	.	.	.
Potatoes	2.8	3.2	3.6	4.4	6.3	8.0	7.2	10.8
Other Vegetables	12.9	13.1	17.3	18.7	22.3	24.4	25.0	24.4
Citrus	2.6	3.6	3.4	3.3	3.6	4.0	4.0	4.0
Apples	4.2	4.5	4.4	4.6	4.6	4.6	5.3	6.0
Other deciduous	4.1	4.2	4.2	4.2	4.7	4.9	4.6	4.4
	Million pounds of other pesticides							
Corn	.	.	.	.	.	.	.	.
Cotton	15.2	15.5	15.8	12.7	15.6	19.7	18.7	18.5
Wheat	.	.	.	.	.	.	.	.
Soybeans	.	.	.	.	.	.	.	.
Potatoes	35.1	26.2	32.3	39.7	50.6	39.1	36.9	42.0
Other vegetables	17.3	18.0	24.2	27.5	34.0	40.6	44.7	43.5
Citrus	.	.	.	.	.1	.2	.6	1.1
Apples	.1	.1	.1	.1	.1	.1	.1	.1
Other deciduous	.3	.3	.3	.	.7	1.3	3.1	5.0
	Million pounds of all pesticide types							
Corn	240.7	233.2	245.2	220.5	233.0	201.3	227.7	229.3
Cotton	50.9	50.3	57.6	52.3	69.1	83.7	65.6	68.0
Wheat	17.8	13.8	19.7	19.1	23.8	21.5	32.9	25.7
Soybeans	74.4	70.4	67.8	64.4	69.5	68.7	78.1	84.5
Potatoes	43.8	35.6	41.6	50.5	64.2	53.1	49.5	58.5
Other vegetables	39.8	40.3	52.8	57.3	68.2	78.0	82.8	80.7
Citrus	11.0	13.7	13.5	13.7	13.6	14.0	14.5	15.0
Apples	8.3	9.1	8.8	9.3	9.1	9.0	9.7	10.3
Other deciduous	10.9	11.1	11.1	11.0	12.9	14.1	14.9	15.9

. = None reported or too little reported to make an estimate.
1/ Estimates are constructed for the total U.S. acreage of the selected commodities. In years when the surveys did not include all States producing the crop, the estimates assume similar use rates for those States.
Source: Lin, Biing, M. Padgitt, L., Bull, H. Delvo, D. Shank, and H. Taylor 1995 (prior to 1993); unpublished USDA survey data (following 1993).

Table B.7—Acres treated with leading pesticide ingredients

Item	Total	Corn	Soybean	All wheat	Cotton	Fall potatoes	Selected vegetables	Selected fruit
				1,000 acres 2/				
Planted area	204,285	62,150	66,215	55,865	13,075	944	2,748	3,001
Herbicides: 1/								
Atrazine (r)	43,232	42,809	4	100	0	0	319	0
Glyphosate	31,634	2,982	18,688	4,632	3,451	46	231	1,605
2,4-D	31,438	5,747	5,397	20,113	53	1	28	99
Metolachlor	27,659	21,855	4,818	0	622	77	277	0
Dicamba	25,872	18,119	6	7,634	112	0	1	0
Imazethapyr	25,492	667	24,823	0 0	0	61	2	
Trifluralin	24,279	336	13,805	2,586	7,104	46	393	9
Pendimethalin	21,928	1,564	16,382	0	3,612	246	124	0
Acetochlor (r)	14,839	14,839	0	0	0	0	0	0
Thifensulfuron	10,907	985	5,658	4,264	0	0	0	0
Cyanazine (r)	10,827	8,469	0	1	2,303	0	54	0
MCPA	10,108	0	0	10,108	0	0	0	0
Fenoxaprop-ethyl	10,051	0	4,144	5895	12	0	0	0
Bentazon	9,360	2,110	7,130	0	0	0	120	0
Chlorminuron-ethyl	8,882	0	8,882	0	0	0	0	0
Imazaquin	8,761	0	8,761	0	0	0	0	0
Metribuzin	8,335	356	6,594	663	0	620	102	0
Acifluorfen	7,831	0	7,831	0	0	0	0	0
Bromoxymil	7,265	4,022	0	3,089	107	0	47	0
Tribenuron-methyl	7,166	0	53	7,113	0	0	0	0
Nicosulfuron	6,209	6,197	0	0	0	0	12	0
Metsulfuron-methyl	6,115	0	0	6,115	0	0	0	0
Fluzaifop-butyl	6,043	0	5,272	0	739	0	31	1
Alachlor (r)	4,552	2,549	1,890	0	0	0	113	0
Chlorsulfuron	3,825	0	0	3,825	0	0	0	0
Insecticides: 1/								
Chlorpyrifos (r)	6,362	4,356	130	548	551	1	205	572
Methyl parathion (r)	5,262	2,316	413	595	1,633	4	85	216
Tefluthrin (r)	4,243	4,239	0	0	0	0	4	0
Permethrin (r)	3,676	2,932	33	0	30	37	58	62
Aldicarb (r)	3,661	0	0	0	3,522	86	0	53
Lamdacyhalothrin (r)	3,384	532	204	79	2,380	0	189	0
Cyfluthrin (r)	2,690	884	0	0	1,695	0	3	108
Terbufos (r)	2,375	2,359	0	0	0	0	16	0
Dimethoate	2,064	123	148	1,007	316	101	304	64
Carbofuran (r)	2,128	1,451	13	47	351	204	27	36
Oxamyl (r)	2,071	0	0	0	1,925	1	82	63
Malathion (r)	1,689	0	6	99	1,459	0	33	92
Phorate (r)	1,528	368	0	44	899	217	0	0
Bt	1,380	515	7	0	274	0	323	261
Imidacloprid	1,431	0	0	0	830	159	256	186
Acephate	1,509	0	60	0	1,240	0	209	0
Chlorethoxyfos (r)	1,178	1,178	0	0	0	0	0	0
Azinophos-methyl (r)	1,154	0	0	0	636	75	17	426
Dicrotophos (r)	1,060	0	0	0	1,060	0	0	0
Abamectin (r)	1,085	0	0	0	481	0	132	472

1/ The letter 'r' in parentheses identifies ingredients that are restricted-use products. Restrictions may apply to only some formulations of the ingredient.

2/ Area treated one or more times with the ingredient.

Sources: USDA, National Agricultural Statistics Service and Economic Research Service, 1996c, 1995d, and 1994.

Table B.8—Change in pesticide use indicators, by crop and pesticide type, 1990-97

Item	Planted area	Share treated	Avg. treat-ments	Rate	Planted	Percent area	No. acres treated	Rate per acre
	1,000 ac.	*Percent*	*No.*	*Lbs/acre*	*Index: 1990=100*			
Corn (total pesticides):								
1990	58,800	96.5	2.5	1.42	100	100	100	100
1991	60,350	96.8	2.5	1.30	103	100	99	91
1992	62,850	97.9	2.6	1.21	107	101	103	85
1993	57,350	98.0	2.7	1.22	98	101	106	86
1994	62,500	98.4	2.8	1.06	106	102	112	75
1995	55,850	98.1	2.8	1.04	95	102	112	74
1996	61,500	98.2	3.0	1.00	105	102	119	71
1997	62,150	97.4	3.2	.93	106	101	126	66
Soybeans (total pesticides):								
1990	39,500	96.0	2.3	.61	100	100	100	100
1991	42,062	96.9	2.3	.58	107	101	100	94
1992	41,350	98.3	2.4	.48	105	102	104	78
1993	42,500	97.6	2.5	.44	108	102	109	72
1994	43,750	98.5	2.8	.42	111	103	121	69
1995	45,150	97.7	2.8	.39	114	102	123	63
1996	45,950	97.5	2.9	.43	116	102	128	69
1997	49,250	97.7	2.9	.43	125	102	126	71
Cotton (total pesticides):								
1991	10,860	97.6	6.7	.55	100	100	100	100
1992	10,200	98.1	8.2	.52	94	100	123	94
1993	10,360	98.7	8.8	.50	95	101	133	91
1994	10,023	98.9	10.7	.49	92	101	161	88
1995	11,650	99.6	11.0	.48	107	102	165	87
1996	10,025	96.5	9.2	.51	92	99	138	92
1997	9,265	99.8	9.1	.53	85	102	136	95
Wheat (total pesticides):								
1990	52,500	58.7	1.8	.27	100	100	100	100
1991	43,450	56.3	2.0	.24	82	96	109	88
1992	49,950	58.6	1.9	.23	95	100	107	87
1993	50,450	64.5	2.1	.21	96	110	118	78
1994	49,450	72.7	2.1	.23	94	124	116	86
1995	47,540	74.8	2.2	.20	91	127	122	74
1996	46,160	73.5	2.5	.25	88	125	139	93
1997	50,700	66.1	2.6	.23	97	113	143	87
Potatoes (total pesticides):								
1990	605	99.3	5.6	6.85	100	100	100	100
1991	620	99.6	5.9	7.35	103	100	104	107
1992	586	99.8	6.5	8.44	97	101	115	123
1993	616	100.0	6.6	10.32	102	101	116	151
1994	640	99.0	8.1	11.99	106	100	144	175
1995	625	99.0	9.6	8.91	103	100	170	130
1996	641	98.9	9.4	13.37	106	99	167	195
1997	609	96.8	12.6	7.9	101	98	223	115

—Continued

Table B.8—Change in pesticide use indicators, by crop and pesticide type, 1990-97—Continued

Item	Planted area	Share treated	Avg. treat-ments	Rate	Planted	Percent area	No. acres treated	Rate per acre
	1,000 ac.	*Percent*	*No.*	*Lbs/acre*	*—Index: 1990=100—*			
Herbicides:								
1990	161,135	82.7	2.2	.92	100	100	100	100
1991	157,330	84.7	2.2	.88	98	102	103	95
1992	164,936	84.5	2.3	.80	102	102	107	86
1993	161,276	86.6	2.4	.73	100	105	112	79
1994	166,363	88.8	2.6	.69	103	107	119	74
1995	160,815	9035	2.6	.63	100	109	120	69
1996	164,276	89.4	2.7	.66	102	108	127	71
1997	171,974	87.3	2.8	.63	107	106	130	68
Insecticides:								
1991	157,330	18.7	1.8	.57	100	100	100	100
1992	164,936	16.5	2.3	.48	105	88	131	85
1993	161,276	15.1	2.6	.47	103	81	148	83
1994	166,363	17.0	2.8	.44	106	91	158	78
1995	160,815	16.3	3.5	.38	102	87	197	66
1996	164,276	19.5	2.2	.43	104	104	123	76
1997	171,974	17.0	2.3	.48	109	91	129	85
Fungicides:								
1991	157,330	1.0	1.8	.65	100	100	100	100
1992	164,936	1.4	1.8	.64	105	140	100	99
1993	161,276	1.2	2.0	.67	103	120	114	104
1994	166,363	1.1	2.8	.72	106	110	155	112
1995	160,815	1.5	2.6	.65	102	150	144	100
1996	164,276	1.1	2.7	.65	104	110	154	100
1997	171,974	0.9	3.9	.75	109	90	218	115
Other pesticides:								
1991	157,330	4.1	2.4	2.15	100	100	100	100
1992	164,936	3.1	2.3	3.40	105	76	98	158
1993	161,276	4.2	2.1	3.36	103	102	90	156
1994	166,363	4.2	2.6	3.69	106	102	109	172
1995	160,815	4.3	2.6	3.40	102	105	112	158
1996	164,276	3.9	2.7	4.98	104	95	115	231
1997	171,974	3.9	2.4	3.79	109	95	103	176

Source: USDA, National Agricultural Statistics Service and Economic Research Service, 1995c.

Table B.9—Pesticide application methods used on major field crops, and selected fruits and vegetables, by pesticide type

Item	Ground broadcast	Aerial broadcast	Chemigation	Band or spot treatment	Injected into soil	Alternate row spraying	Total
				1,000 acre-treatments			
All pesticide types:							
Wheat	64,733	17,906	.	499	603	.	83,741
Soybeans	132,492	2,534	37	9,603	1,016	.	145,681
Cotton	53,292	47,596	120	18,590	5,513	.	125,112
Corn	140,434	6,046	423	21,551	7,196	.	175,651
Potatoes	5,586	4,636	1,881	425	309	.	12,837
Tomatoes	177	124	0	2,220	65	.	2,586
Lettuce	485	1,054	17	100	7	.	1,664
Strawberries	125	7	1	301	25	.	459
Apples	4,330	103	3	49	.	1,155	5,639
Grapes	2,480	90	25	83	.	318	2,996
Peaches	3,217	94	0	224	.	987	4,521
Oranges	4,582	72	46	303	.	8	5,011
Total	411,933	80,261	2,555	53,948	14,735	2,468	565,900
				Percent			
Share of total	72.8	14.2	.4	9.5	2.6	.4	100
				1,000 acre-treatments			
Herbicides:							
Wheat	63,286	16,133	.	454	603	.	80,476
Soybeans	131,831	2,112	.	9,564	1,016	.	144,523
Cotton	20,550	2,015	79	13,053	1,386	.	37,083
Corn	136,603	2,083	.	14,582	1,977	.	155,245
Potatoes	1,168	201	508	26	27	.	1,931
Tomatoes	18	0	.	77	.	.	96
Lettuce	72	47	.	13	.	.	132
Strawberries	15	1	.	12	0	.	28
Apples	233	3	.	14	.	8	257
Grapes	284	1	.	65	.	20	371
Peaches	300	7	.	90	.	16	412
Oranges	1,937	19	46	231	.	4	2,237
Total	356,297	22,621	634	38,182	5,010	48	422,792
Insecticides:							
Wheat	934	1,137	.	45	.	.	2,116
Soybeans	583	391	37	39	.	.	1,050
Cotton	25,735	36,156	41	4,190	2,624	.	68,746
Corn	3,725	3,964	423	6,969	5,219	.	20,300
Potatoes	998	1,047	168	191	232	.	2,637
Tomatoes	72	66	0	873	0	.	1,011
Lettuce	353	994	17	64	7	.	1,436
Strawberries	57	4	0	94	0	.	155
Apples	2,249	35	.	19	.	588	2,891
Grapes	212	2	25	15	.	13	267
Peaches	1,463	43	0	88	.	483	2,078
Oranges	1,845	35	0	21	.	.	1,901
Total	38,226	43,874	713	12,608	8,083	1,085	104,589
Fungicides:							
Wheat	513	636	.	.	.	.	1,149
Soybeans	77	31	.	.	.	.	108
Cotton	42	24	.	542	1,233	.	1,842
Corn	106	.	.	.	.	.	106
Potatoes	2,779	3,227	1,075	168	2	.	7,251
Tomatoes	87	58	0	1,267	.	.	1,412
Lettuce	60	13	.	23	.	.	95
Strawberries	52	1	1	191	0	.	245

See note at end of table

—Continued

Table B.9—Pesticide application methods used on major field crops, and selected fruits and vegetables, by pesticide type–Continued

Item	Ground broadcast	Aerial broadcast	Chemigation	Band or spot treatment	Injected into soil	Alternate row spraying	Total
				1,000 acre-treatments			
Apples	1,466	26	3	11	.	549	2,055
Grapes	1,967	78	.	1	.	285	2,332
Peaches	1,426	44	.	46	.	486	2,002
Oranges	692	14	.	5	.	.	710
Total	9,267	4,151	1,079	2,254	1,235	1,320	19,307
Other pesticides:							
Cotton	6,965	9,401	.	805	270	.	17,442
Potatoes	641	162	129	39	48	.	1,019
Tomatoes	0	.	.	2	65	.	67
Strawberries	1	1	.	4	25	.	31
Apples	382	39	.	6	.	9	436
Grapes	17	8	.	1	.	.	26
Peaches	28	.	.	0	.	2	30
Oranges	108	4	.	46	.	4	162
Total	8,143	9,615	129	903	408	15	19,213

. = None reported or insufficient data to develop an estimate.
Source: USDA, National Agricultural Statistics Service and Economic Research Service, 1996c, 1995d, and 1994.

Table B.10—Monoculture and crop rotation systems used in the production of major field crops, 1997

State	Area in monoculture system					Area in crop rotation				
	Wheat	Soybeans	Cotton	Corn	Potatoes	Wheat	Soybeans	Cotton	Corn	Potatoes
	1,000 acres									
AL	.	.	277	.	.	.	.	258	.	.
AZ	.	.	191	.	.	.	.	121	.	.
AR	.	1,348	814	.	.	.	2,252	74	.	.
CA	.	.	359	.	.	.	.	521	.	.
CO	50	.	.	.	.	2,798	.	.	.	.
DE	.	1	.	.	.	.	153	.	.	.
GA	.	.	536	.	.	.	.	904	.	.
ID	100	.	.	.	3	770	.	.	.	384
IL	25	112	.	1,151	.	1,122	9,854	.	9,987	.
IN	.	203	.	317	.	.	5,226	.	5,508	.
IA	.	.	.	867	.	.	10,058	.	11,027	.
KS	5,351	446	.	.	.	5,649	2,004	.	.	.
KY	.	96	.	.	.	.	1,177	.	.	.
LA	.	347	472	.	.	.	1,053	158	.	.
ME	.	.	.	.	6	.	.	.	.	62
MI	.	43	.	709	.	.	1,857	.	1,891	.
MN	.	.	.	519	1	2,450	6,730	.	6,468	73
MS	.	1,113	858	.	.	.	987	127	.	.
MO	92	876	292	74	.	932	3,988	88	2,849	.
MT	178	.	.	.	.	5,622	.	.	.	.
NE	105	14	.	4,471	.	1,795	3,455	.	4,451	.
NC	.	27	323	.	.	.	1,373	334	.	.
ND	.	.	.	.	.	10,231	.	.	.	120
OH	3	343	.	340	.	1,087	4,157	.	3,260	.
OK	4,632	.	.	.	.	705	.	.	.	.
OR	48	.	.	.	0	791	.	.	.	54
PA	1	9	.	.	.	174	356	.	.	.
SC	.	.	110	.	.	.	.	180	.	.
SD	154	313	.	219	.	3,394	3,187	.	3,578	.
TN	.	293	435	.	.	.	964	49	.	.
TX	2,468	.	3,213	.	.	1,632	.	2,145	.	.
WA	491	.	.	.	2	1,609	.	.	.	116
WI	.	.	.	634	.	.	1,000	.	3,166	69
Total	13,698	5,586	7,882	9,301	12	42,167	60,404	5,198	52,849	932
	Percent in monoculture					*Percent in crop rotations*				
AL	.	.	52	.	.	.	.	48	.	.
AZ	.	.	61	.	.	.	.	39	.	.
AR	.	37	92	.	.	.	63	8	.	.
CA	.	.	41	.	.	.	.	59	.	.
CO	2	.	.	.	.	98	.	.	.	.
DE	.	1	.	.	.	.	99	.	.	.
GA	.	.	37	.	.	.	.	63	.	.
ID	12	.	.	.	1	88	.	.	.	99
IL	2	1	.	10	.	98	99	.	90	.
IN	.	4	.	5	.	.	96	.	95	.
IA	.	.	.	7	.	.	100	.	93	.
KS	49	18	.	.	.	51	82	.	.	.

See note at end of table

—Continued

Table B.10—Monoculture and crop rotation systems used in the production of major field crops, 1997—Continued

State	Area in monoculture system					Area in crop rotation				
	Wheat	Soybeans	Cotton	Corn	Potatoes	Wheat	Soybeans	Cotton	Corn	Potatoes
	Percent in monoculture					*Percent in crop rotations*				
KY	.	8	.	.	.	.	92	.	.	.
LA	.	25	75	.	.	.	75	25	.	.
ME	.	.	.	.	9	.	.	.	.	91
MI	.	2	.	27	.	.	98	.	73	.
MN	.	.	.	7	1	100	100	.	93	99
MS	.	53	87	.	.	.	47	13	.	.
MO	9	18	77	3	.	91	82	23	97	.
MT	3	.	.	.	.	97	.	.	.	.
NE	6	0	.	50	.	94	100	.	50	.
NC	.	2	49	.	.	.	98	51	.	.
ND	.	.	.	.	.	100	.	.	.	100
OH	0	8	.	9	.	100	92	.	91	.
OK	87	.	.	.	.	13	.	.	.	.
OR	6	.	.	.	.	94	.	.	.	100
PA	1	2	.	.	.	99	98	.	.	.
SC	.	.	38	.	.	.	.	62	.	.
SD	4	9	.	6	.	96	91	.	94	.
TN	.	23	90	.	.	.	77	10	.	.
TX	60	.	60	.	.	40	.	40	.	.
WA	23	.	.	.	1	77	.	.	.	99
WI	.	.	.	17	.	.	100	.	83	100
Total	25	8	60	15	1	75	92	40	85	99

. = None or insufficient data to develop an estimate.
Source: USDA, National Agricultural Statistics Service and Economic Research Service, 1996c.

Table B.11—Crop rotation systems used in the production of major field crops, 1997

State	Continuous wheat	Wheat-fallow	Wheat rotation systems: Continuous small grains	Mix of row crop and small grain	With meadow crops	With idle land	Double-cropped	Total
				1,000 acres				
CO	50	2,099	.	614	2	84	.	2,848
ID	100	54	275	337	104	.	.	870
IL	25	5	7	1,053	.	.	57	1,147
KS	5,351	1,972	1,062	2,158	229	.	228	11,000
MN	.	121	1,294	1,036	.	.	.	2,450
MO	92	6	.	688	9	.	228	1,024
MT	178	3,239	1,658	72	125	527	.	5,800
NE	105	727	126	811	131	.	.	1,900
ND	.	1,191	5,456	2,899	184	502	.	10,231
OH	3	.	7	995	5	1	79	1,090
OK	4,632	58	304	279	3	.	61	5,337
OR	48	626	55	86	23	.	.	840
PA	1	.	6	155	6	1	6	175
SD	154	749	583	1,556	295	201	9	3,548
TX	2,468	187	135	1,261	45	.	5	4,100
WA	491	1,007	202	327	3	70	.	2,100
Total	13,698	12,041	11,169	14,326	1,166	1,386	673	54,460
				Percent in each rotation				
CO	2	74	.	22	0	3	.	100
ID	12	6	32	39	12	.	.	100
IL	2	0	1	92	.	.	5	100
KS	49	18	10	20	2	.	2	100
MN	.	5	53	42	.	.	.	100
MO	9	1	.	67	1	.	22	100
MT	3	56	29	1	2	9	.	100
NE	6	38	7	43	7	.	.	100
ND	.	12	53	28	2	5	.	100
OH	0	.	1	91	0	0	7	100
OK	87	1	6	5	0	.	1	100
OR	6	75	7	10	3	.	.	100
PA	1	.	3	89	3	1	3	100
SD	4	21	16	44	8	6	0	100
TX	60	5	3	31	1	.	0	100
WA	23	48	10	16	0	3	.	100
Total	25	22	21	26	2	3	1	100

See note at end of table

—Continued

Table B.11—Crop rotation systems used in the production of major field crops, 1997–Continued

			Soybean rotation systems					
State	Continuous soybeans	Corn-soybeans	Continuous row crops	Mix of row crop and small grain	With meadow crops	With idle land	Double-cropped	Total
				1,000 acres				
CO	50	2,099	.	614	2	84	.	2,848
AR	1,348	49	7	1,373	.	.	822	3,600
DE	1	10	50	.	.	3	90	155
IL	112	7,755	1,064	.	420	293	322	9,966
IN	203	3,854	740	10	86	171	364	5,429
IA	.	9,126	770	22	100	40	.	10,058
KS	446	452	651	16	58	514	313	2,450
KY	96	366	237	.	5	119	449	1,273
LA	347	90	685	162	.	21	94	1,400
MI	43	503	549	12	.	463	329	1,900
MN	.	4,735	1,135	655	184	21	.	6,730
MS	1,113	110	148	321	60	18	330	2,100
MO	876	1,420	652	341	64	936	575	4,865
NE	14	1,899	1,156	14	42	345	.	3,470
NC	27	172	375	3	22	218	582	1,400
OH	343	1,441	1,955	5	56	699	.	4,500
PA	9	133	131	7	50	25	11	365
SD	313	1,627	204	472	18	854	12	3,500
TN	293	194	173	.	6	28	564	1,258
WI	.	411	492	34	56	8	.	1,000
Total	5,586	34,347	11,176	3,448	1,226	4,776	4,859	65,418
				Percent in each rotation				
AR	37	1	0	38	.	.	23	100
DE	1	7	33	.	.	2	58	100
IL	1	78	11	.	4	3	3	100
IN	4	71	14	0	2	3	7	100
IA	.	91	8	0	1	0	.	100
KS	18	18	27	1	2	21	13	100
KY	8	29	19	.	0	9	35	100
LA	25	6	49	12	.	1	7	100
MI	2	26	29	1	.	24	17	100
MN	.	70	17	10	3	0	.	100
MS	53	5	7	15	3	1	16	100
MO	18	29	13	7	1	19	12	100
NE	0	55	33	0	1	10	.	100
NC	2	12	27	0	2	16	42	100
OH	8	32	43	0	1	16	.	100
PA	2	36	36	2	14	7	3	100
SD	9	46	6	13	1	24	0	100
TN	23	15	14	.	0	2	45	100
WI	.	41	49	3	6	1	.	100
Total	9	53	17	5	2	7	7	100

See note at end of table.

—Continued

Table B.11—Crop rotation systems used in the production of major field crops, 1997–Continued

State	Continuous cotton	Cotton rotation systems: Continuous row crops	Mix of row crop and small grain	With meadow crops	With idle land	Total
			1,000 acres			
AL	277	207	37	9	6	535
AZ	191	26	49	16	30	312
AR	814	40	34	.	.	888
CA	359	219	36	129	136	880
GA	536	756	.	.	148	1,440
LA	472	158	.	.	0	630
MS	858	106	.	.	20	985
MO	292	88	.	.	.	380
NC	323	325	5	.	4	657
SC	110	130	.	2	48	290
TN	435	49	.	.	.	484
TX	3,213	1,820	.	55	270	5,358
Total	7,882	3,923	162	210	662	12,839
			Percent in each rotation			
AL	52	39	7	2	1	100
AZ	61	8	16	5	10	100
AR	92	5	4	.	.	100
CA	41	25	4	15	15	100
GA	37	53	.	.	10	100
LA	75	25	.	.	0	100
MS	87	11	.	.	2	100
MO	77	23	.	.	.	100
NC	49	49	1	.	1	100
SC	38	45	.	1	17	100
TN	90	10	.	.	.	100
TX	60	34	.	1	5	100
Total	61	31	1	2	5	100

See note at end of table

—Continued

Table B.11—Crop rotation systems used in the production of major field crops, 1997–Continued

State	Continuous corn	Corn-soybeans	Cotton rotation systems: Continuous row crops	Mix of row crop and small grain	With meadow crops	With idle land	Total
			1,000 acres				
IL	1,151	7,515	2,182	12	99	178	11,138
IN	317	4,031	1,148	1	94	233	5,825
IA	867	9,277	884	112	507	246	11,894
MI	709	509	645	26	101	610	2,600
MN	519	4,712	577	382	554	244	6,988
MO	74	987	1,457	12	123	270	2,923
NE	4,471	2,414	1,287	10	234	505	8,922
OH	340	1,761	623	.	193	682	3,600
SD	219	1,807	768	584	90	328	3,797
WI	634	1,098	434	19	1,441	173	3,800
Total	9,301	34,113	10,006	1,160	3,437	3,470	61,486
			Percent in each rotation				
IL	10	67	20	0	1	2	100
IN	5	69	20	0	2	4	100
IA	7	78	7	1	4	2	100
MI	27	20	25	1	4	23	100
MN	7	67	8	5	8	3	100
MO	3	34	50	0	4	9	100
NE	50	27	14	0	3	6	100
OH	9	49	17	.	5	19	100
SD	6	48	20	15	2	9	100
WI	17	29	11	1	38	5	100
Total	15	55	16	2	6	6	100

State	Continuous potatoes	Potato rotation systems: Continuous row crops	Mix of row crop and small grain	With meadow crops	With idle land	Total
			1,000 acres			
ID	3	6	204	21	154	387
ME	6	3	49	4	5	68
MN	1	10	58	2	3	74
ND	.	10	70	16	24	120
OR	0	6	15	9	25	54
WA	2	67	5	19	26	118
WI	.	48	11	8	3	69
Total	12	151	410	79	239	891
			Percent in each rotation			
ID	1	1	53	5	40	100
ME	9	5	73	6	7	100
MN	1	14	78	3	4	100
ND	.	9	58	13	20	100
OR	0	11	27	16	46	100
WA	1	57	4	16	22	100
WI	.	70	15	11	4	100
Total	1	17	46	9	27	100

. = None reported or insufficient data available to make an estimate.
Source: USDA, National Agricultural Statistics Service and Economic Research Service, 1996c.

Electronic Data Files

The production practices for major crops have also been tabulated for the major production States. The tables for State estimates are available from the ERS home page: "http://www.ers.usda.gov."