5.1 Technology

Total agricultural production has increased 1.9 percent annually since 1948. Agricultural productivity (output per unit of input) has grown 2 percent per year over the same period, exceeding the productivity growth rate for manufacturing. Productivity growth has come largely from technological innovation in agricultural production and processing systems. The strengthening of intellectual property rights over biological innovations has increased incentives for private sector research and development in agriculture.

In the 20th century, U.S. agriculture has become increasingly dependent upon science for technological advances to increase productivity, ensure a safe and competitive food supply, and maintain environmental quality. Until the close of the land frontier in the early part of the 1900's, most new agricultural production came from expanding the area devoted to crops and livestock. Today, growth in U.S. agricultural production comes almost entirely from increases in yields per acre and per animal. The basis of this growth is the application of modern science and technology to agricultural production and food processing systems. This chapter describes trends in agricultural productivity, investments in agricultural research, and emerging developments in agricultural technology.

U.S. Agricultural Productivity Continues To Advance

From 1948 to 1991, U.S. agricultural production more than doubled, increasing at an average annual rate of 1.9 percent (fig. 5.1.1, table 5.1.1). Total input use (the sum of land, labor, machinery, chemicals, etc.), on the other hand, declined slightly. This increase in output per unit of input, as indicated by the multifactor productivity index, is due to a variety of factors, including the application of new agricultural technology. According to the multifactor productivity index, the productivity of all agricultural resources grew by an average of 2 percent per year over 1948-91.

Table 5.1.1—Growth rates for U.S. agriculture, 1948-91

Item	Average annual growth rate
	1948-91
	Percent
Total output	1.90
Total inputs	-0.05
Multifactor productivity	1.95
Labor input	-2.58
Labor productivity	4.53

Source: Ball, 1994.

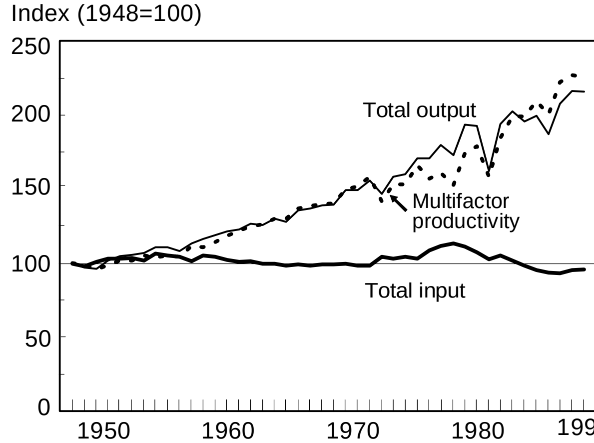
Annual production appeared to be less stable in the 1980's than in previous decades (fig. 5.1.1). The significant dips in output recorded in 1983 and 1988 were due primarily to severe and widespread drought. The production drop in 1983 was also due to the Payment-in-Kind (PIK) program, which paid farmers to withdraw cropland from production in order to reduce accumulated government-held commodity surpluses.

Total agricultural inputs remained roughly constant until the early 1970s. Input use increased in the 1970's due to the strong growth in export demand and commodity prices. Slackening of export demand, a farm financial crisis, and land retirement and set-aside programs all contributed to a reduction in the inputs devoted to agriculture in the 1980's.

The ability to significantly increase production using the same or fewer aggregate inputs could not have occurred without the development of new agricultural technologies. New technology enables farmers to substitute new and cheaper inputs for more expensive inputs, thereby lowering unit production costs, and to produce higher valued products. Higher yielding varieties, improved livestock breeds, improved

Figure 5.1.1

Productivity growth in U.S. agriculture, 1948-90



Source: Ball, 1994.

methods of pest and disease control, and increased mechanization are examples of new technologies that have increased agricultural productivity.

Productivity growth in agriculture has outpaced most other sectors of the economy. Between 1949 and 1988 (the period for which comparable figures are available), total factor productivity in agriculture grew 1.9 percent per year, compared with 1.7 percent for manufacturing (Bureau of Labor Statistics, 1994). Labor productivity in agriculture also grew more rapidly than in manufacturing. Output per worker in agriculture grew six-fold over this period, or by 4.3 percent per year, compared with 2.6 percent for manufacturing. New technology enabled fewer farmers to produce larger quantities of agricultural commodities. Total employment in agriculture steadily declined, and the average skill level of the remaining agricultural workforce increased. The faster growth of agricultural labor productivity helped to close the historic gap between farm and nonfarm income.

Input and output estimates are based on the value of commodities produced and the costs of conventional inputs used, such as land, labor, buildings, machinery, fertilizers, and agrichemicals. Environmental and health costs from agricultural production were not included in these estimates. Ongoing research at ERS aims to include these nonconventional costs in productivity measurements in the future (Ball and Nehring, 1994).

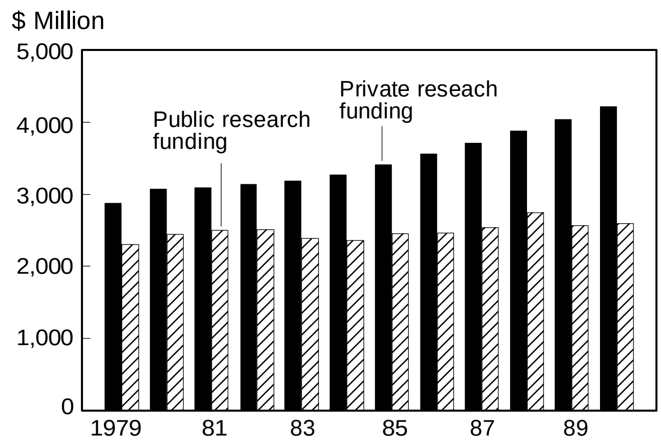
Trends Show Increasing Role for Private Sector in Agricultural Research

Agricultural research provides the foundation for technological innovation and productivity growth. Both the public and private sectors are heavily involved in agricultural research and the development of new technologies. A key rationale for the public sector's support of agricultural research has been that, in many areas, the incentives for private sector research have not been adequate to induce an optimum level of research. The most obvious is the case of basic or fundamental research. It also holds for many applied areas, such as environmental protection, natural resource conservation, and food safety (Ruttan, 1982).

Public support for agricultural research remained roughly constant at slightly over $2 billion annually in real terms since 1979 (fig. 5.1.2), with about $1 billion provided by the Federal Government and the rest by the States. Private agricultural research increased from around $3 billion in the early 1980's to over $4 billion annually by 1990 (1990 dollars). The strengthening of intellectual property rights for agricultural innovations increased the incentives for private research. Additionally, major scientific advances, particularly in the area of biotechnology, provided new opportunities in applied research.

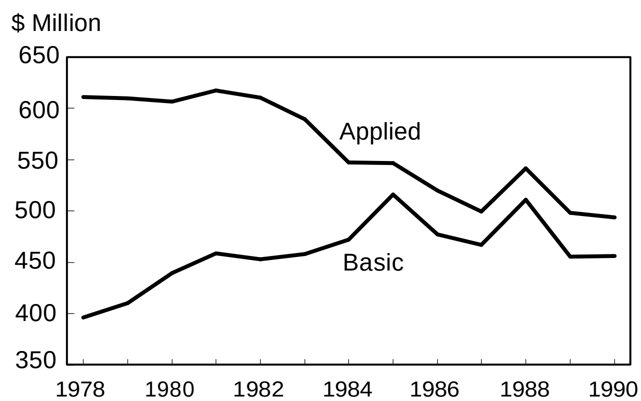
Public agricultural research contains a greater level of basic research compared with the private sector. While the division between basic and applied research is somewhat artificial, basic research is less obviously directed toward marketable products, instead concentrating on expanding general knowledge. Basic research can provide the foundation for further applied research to produce new technologies. In this way, basic research by public institutions can provide

Figure 5.1.2
Agricultural research funding, 1979-90



1990 dollars.
Source: Huffman and Evenson, 1993.

Figure 5.1.3
USDA expenditures for basic and applied research, 1978-90



1990 dollars.
Source: National Science Foundation.

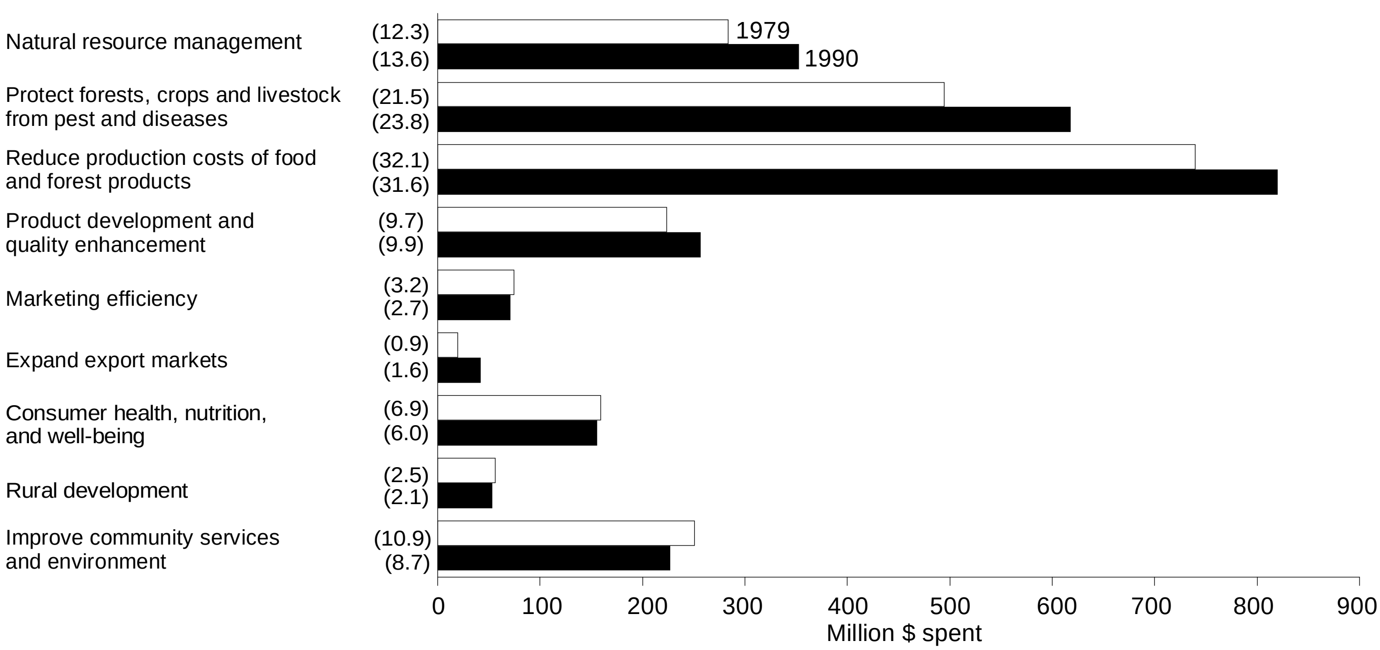
fundamental science to private researchers. Over the past 12 years, the National Science Foundation reports that an increasing share of USDA research was devoted to basic research (fig. 5.1.3). Of the roughly $1-billion annual research budget administered by the USDA, the share going to basic research increased from under $400 million in 1978 to $450-$500 million in the late 1980's. With science-based industries like biotechnology, there is an even less clear distinction between basic and applied research since scientific discoveries can often quickly lead to new commercial applications.

Public funding of agricultural research has several objectives. The USDA's Current Research Information System (CRIS), which details public agricultural research expenditures, separates this research into nine goals (fig. 5.1.4). In 1990, the largest shares of the research budget went to production cost reduction of food and forest products (32 percent); protection of forest, crops and livestock from pests and diseases (24 percent); natural resource management (14 percent); and product development and quality (10 percent). These four goals accounted for about 80 percent of the total research budget. Between 1979 and 1990, the shares of the research budget devoted to pest and disease control and natural resource management increased, while shares going to production cost reduction and product development remained about the same. Research on improving community services and the environment decreased by 9.5 percent over this period.

Agricultural research collaboration between USDA scientists and the private sector increased following the passage of the Technology Transfer Act of 1986. Under the Act's Cooperative Research and Development Agreements (CRADA's), government scientists and private companies each agree to commit resources to the development of specific new technologies. Public sector resources are typically devoted to basic research, with the private sector focusing on product development and marketing. Under certain restrictions, the agreements usually give private companies the exclusive right to market the technological applications that are developed (see box, "Public-Private Research Collaboration and Genetic Resources: The Case of Taxol").

In addition to CRADA's, technology transfer activities by the USDA include the patenting and licensing of new technologies. Resources committed to CRADA's and revenue from licensing have experienced exceptional growth over the past several

Figure 5.1.4
Allocation of public funds for agricultural research, 1979 and 1990



Numbers in parentheses indicate each item's percentage of public funds for agricultural research that year. 1990 dollars.

Source: USDA, Current Research Information System data.

years (table 5.1.2). In 1993, USDA laboratories received nearly $1.5 million from licenses and were engaged in 185 CRADA's involving $34 million of public and private research resources.

The private sector's interest in agricultural research was further enhanced by the strengthening of intellectual property rights (IPR's) over biological inventions. IPR's provide incentives to invest resources in new discoveries by granting the inventor a period over which the individual or company shall have the exclusive right to sell or license the invention. The granting of an IPR usually requires the inventor to disclose information about the nature of the invention. The description of the invention is then public information that can be used by others to make refinements to the invention or to develop new inventions.

Table 5.1.2—USDA technology transfer activities, 1987-93

Year	Patents awarded	Patent license royalties	Number of active CRADA's[1]	Value of CRADA's[2]
		-------- *$ thousand* --------		*$ million*
1987	34	85	9	1.6
1988	28	97	48	8.7
1989	47	418	86	15.6
1990	42	567	104	18.9
1991	57	834	139	25.6
1992	56	1,044	160	30.0
1993	57	1,483	185	34.0

[1] Cooperative Research and Development Agreements.

[2] Includes the value of USDA and private sector resources committed to CRADA's.

Source: Talent, 1994

Public-Private Research Collaboration and Genetic Resources: The Case of Taxol

Taxol is an anticancer drug derived from the bark of the Pacific yew tree. The development of Taxol illustrates the effects of a Cooperative Research and Development Agreement (CRADA) on the medical development of an agricultural resource. Pacific yew bark was first collected in 1961 by USDA as part of an interagency agreement with the National Cancer Institute (NCI) to search for anticancer agents. Paclitaxel, the active ingredient in Taxol, was isolated in 1971 but was never patented. After revisiting paclitaxel in the 1980's, NCI decided that the substance was a promising drug and should be rapidly commercialized. Through a competitive bidding process, NCI signed a CRADA with the Bristol-Myers Squibb pharmaceutical company. The CRADA specified that NCI would give Bristol exclusive access to clinical trial data, while Bristol would provide NCI with paclitaxel for trials and seek FDA approval of the drug. Shortly after, Bristol entered an agreement with USDA and the Department of the Interior, which granted Bristol exclusive rights to harvest Pacific yews on Federal lands. In 1992, the FDA approved Taxol for treatment of ovarian cancer.

This CRADA allowed NCI, which cannot commercialize products, to speed the introduction of an important new drug. NCI was able to select a cooperator experienced in gaining FDA approval for cancer drugs and familiar with natural product development. Bristol received exclusive data from NCI, which allowed the company to pursue a New Drug Application rapidly. A number of additional agreements made by Bristol with universities and smaller firms allowed Bristol to access imperfectly tradeable assets, especially human capital. Bristol was able to utilize research scientists without making long-term employment agreements, particularly in the case of certain university scientists who were willing to be privately funded but wished to remain in an academic setting.

In this example, CRADA's and other public-private agreements served to protect intellectual property rights. Because the paclitaxel molecule was not patentable, the NCI CRADA provided an incentive for a pharmaceutical firm to invest in development of the drug. Access to clinical trial data removed the need for company-conducted clinical trials (and consequently lowered commercial risk) and reduced Bristol's risk of competition. Exclusive rights to Pacific yew on Federal lands gave Bristol control over the agricultural resource needed to manufacture the drug. These two agreements gave Bristol a substantial head start over competitors, and in many ways temporarily provided patent-type protection.

One issue that arises with public-private research agreements is the distribution of profits or monopoly rents. Bristol will gain the profits from a venture that was publicly funded in part. Because NCI desired rapid commercialization of paclitaxel, the agency needed to provide economic incentives. NCI used two mechanisms to ensure that Bristol demanded a fair price for Taxol. First, within the CRADA itself, NCI specified that the price charged for Taxol must bear a "reasonable relation to cost." Second, NCI continued to facilitate other research, including a CRADA with the manufacturers of Taxotere, a similar drug.

More detailed discussion can be found in Kelly A. Day and George B. Frisvold, "Medical Research and Genetic Resources Management: The Case of Taxol," *Contemporary Policy Issues* 11 (July 1993): 1-11.

Prior to 1930, no living organism or crop variety could be patented in the United States. The Plant Patent Act of 1930 extended "plant breeder's rights," or IPR's, to asexually reproduced plants (with the exception of root and tuber crops). Fruits, nuts, and flowers were most affected by this legislation. The Plant Variety Protection Act of 1970 extended IPR's to sexually reproduced crops, including the most important U.S. crops such as corn, soybeans, wheat, and cotton. Under this Act, the USDA grants Plant Variety Protection Certificates (PVPC's) to plant breeders who can demonstrate that a variety they developed is distinct, uniform, and stable. Both Plant Patents and PVPC's give the owner the unique right to sell or license the named variety for a period of 18 years. However, farmers are allowed to reproduce seed that is protected by a PVPC for their own use or for limited sale. Researchers may also use protected varieties in plant breeding programs to develop new varieties without having to compensate the owner of the protected variety.

Biotechnology Raises Intellectual Property Rights Issues

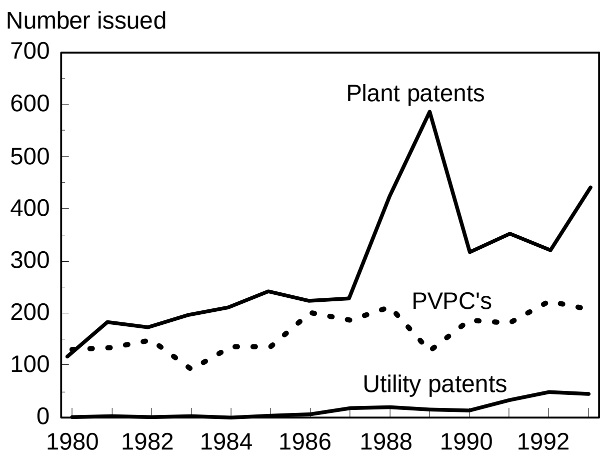
The emergence of biotechnology led to important new issues concerning the coverage and scope of IPR's for biological innovations. Biotechnology greatly expanded the opportunities for developing new types of microbes, plants, and animal breeds. Through biotechnology, scientists can incorporate specific traits from one organism to another through gene transfer methods.

In 1980, the Supreme Court ruled in *Diamond v. Chakrabarty* that genetically engineered organisms could be patented. The U.S. Patent and Trademark Office interprets this ruling to include new crop varieties and animal breeds, including those developed through genetic engineering. These types of patents, called utility patents, have a broad coverage. Utility patents granted for new crop varieties do not have a farmer-use exemption. Furthermore, researchers who use varieties or materials protected by utility patents to develop new commercial technologies must obtain the permission of the patent owner. Confusion arises, however, over determining what research has a commercial versus a noncommercial objective. The USDA has advocated clarification of this issue through a research exemption policy. But the private sector has resisted such efforts (Baenziger and others, 1993).

Plant patents, PVPC's, and utility patents are not the only means by which an inventor of a biological innovation can protect intellectual property. Plant breeders may protect their varieties by maintaining trade secrets. Parental lines for hybrid varieties, for example, are closely guarded by seed companies. Hybrid seeds give high and uniform yields for only one generation, so each season farmers who plant hybrids must repurchase their seed. In this way, companies that develop hybrid varieties are able to recoup their research investments. However, hybrid technology has been successfully developed only for certain crops, most notably corn and sorghum.

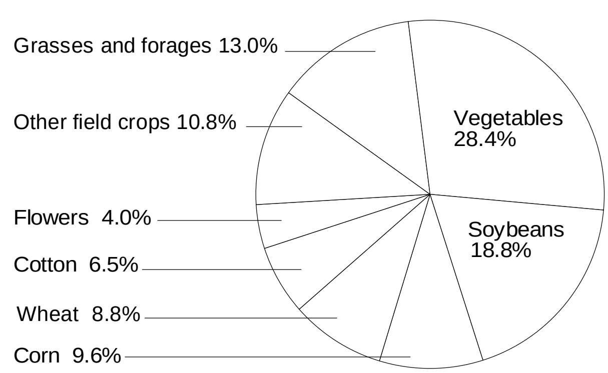
Each year, 100-200 PVPC's are awarded by the USDA for new crop varieties (fig. 5.1.5). In addition, the Patent and Trademark Office (PTO) grants 200 or

Figure 5.5
Property rights for biological inventions



Source: PTO, AMS.

Figure 5.1.6
Utilization of plant variety protection certificates issued between 1970 and 1993



A total of 3,088 PVPC's were issued between 1970 and 1993.
Source: USDA, AMS, various issues.

more Plant Patents (with a notable increase in 1988 and 1989). By the early 1990's, the PTO was issuing about 50 utility patents per year for living organisms.

Of over 3,000 PVPC's granted by the USDA for new crop varieties between 1970 and 1993, nearly 19 percent were for soybean varieties, 10 percent for corn varieties, and 9 percent for wheat varieties (fig. 5.1.6). About 90 percent of all PVPC's were awarded to private companies, with the remaining going to public research institutions. The strengthening of IPR's appears to have significantly increased the investment by private companies in developing new crop varieties for several important crops, soybeans in particular. Prior to 1970, nearly all soybean varietal improvement research was conducted in the public sector. By 1982, there were 26 private companies with soybean breeding programs in the United States and the private sector had become the primary source for new soybean varieties (Huffman and Evenson, 1993).

Measuring Economic Benefits from Agricultural Research

Several studies have attempted to assess the contribution of research investments to agricultural productivity growth and to determine whether the level of research expenditures in agriculture may be too high or too low. In a recent study, Huffman and

Economic Implications of Biotechnology: The Case of bST

Bovine somatotropin (bST) is a naturally occurring protein that stimulates milk production in dairy cows. In the 1930's, it was discovered that injecting cows with bST could greatly increase milk production per cow. However, bST could not be economically produced until the development of biotechnology techniques. The commercial application of bST in the United States was approved recently by the Food and Drug Administration (FDA) after several years of deliberation about bST safety and efficacy.

There exists considerable uncertainty in the marketplace concerning consumer acceptance of milk produced from cows treated with biotechnology-derived bST. Smith and Warland (1992) summarized several consumer surveys that were conducted over the preceding 6 years on bST. Aggregating the survey results, they estimated that about 60 percent of respondents would not change milk consumption, 30 percent would reduce consumption slightly, and 10 percent would stop drinking milk altogether if producers supplemented milk production with bST.

Consumer and producer concerns over bST center around perceived human and animal health effects and potential impact on the structure of the dairy industry. Although the FDA determined that milk from bST-supplemented cows is safe for human consumption, some consumers are still wary. Human safety concerns include secondary health effects that may be induced by bST, such as the potential for greater use of antibiotics in cows due to increased incidence of udder infections (such as mastitis). In addition, many members of the public are concerned that encouraging additional milk production could cause a further movement toward fewer and larger dairy farms. Overproduction could also increase government dairy program expenditures. Whether or not bST and other biotechnology applications will be more cost-efficient for large operators or small ones will depend on regional factors and management ability.

Food marketers believe that public concerns about food safety and social change associated with supplemental bST could reduce the demand for all milk products. One way to differentiate the milk market into bST and nonsupplemental bST milk and to provide consumers with a choice, is to use labeling. Although the FDA will not require labeling, retailers not marketing bST-supplemented milk products may voluntarily label their products as such. These retailers may require milk producers to sign affidavits certifying that delivered milk was produced without use of supplemental bST. But verifying the affidavits is problematic because bST-supplemented milk products are indistinguishable from nonsupplemental bST milk.

The uncertainty about consumer acceptance of bST-supplemented milk has left many farmers wary about adopting bST technology. A 1992 survey of California dairy farmers indicated that only 7-9 percent would adopt bST immediately and 34-38 percent would adopt overall (Butler, 1992), suggesting that only a limited number of producers may actually adopt bST.

For further information on the economic implications of agricultural biotechnology, see Margriet Caswell, Keith O. Fuglie, and Cassandra Klotz. "Agricultural Biotechnology: An Economic Perspective," AER-687, Econ. Res. Serv., U.S. Dept. Agr., May 1994.

Table 5.1.3—Rates of return to investments in agricultural research and education in the United States

Investment type	Social rate of return[1]	
	Huffman and Evenson	Other studies
	Percent	
Public sector research: all	41	0-100
Public sector research: basic	74	57-110
Private sector research	46	26- 90
Public extension	20	23-110
Farmers schooling	40	15- 83

[1] The social rate of return is the marginal internal rate of return that equates the stream of benefits to society from increased output with the stream of research and education investments made by the investing group, that is, taxpayers, private firms, or individuals.

Source: Huffman and Evenson, 1993

Evenson (1993) estimated the rate of return to investments in agricultural research, extension, and farmer education in the United States (table 5.1.3). The social rate of return to investments in research and education quanitifies benefits to society from increased agricultural productivity relative to the cost of the investments (made by taxpayers, companies, or individuals). Results suggest that the benefits from investments in agricultural research and human capital significantly exceeded their cost. Public sector investment in basic agricultural research achieved a particularly high rate of return, around 74 percent, according to Huffman and Evenson. (Other studies cited in Huffman and Evenson have estimated the rate of return to basic agricultural research at 57-110 percent.) The social rate of return to private sector agricultural research was comparable to the near 40-percent return for all (basic and applied) public agricultural research and investments in farmer education.

The impressive rates of return to agricultural research, extension, and education may suggest that these investments have been too low (Ruttan, 1982). On the other hand, these estimates have several limitations. For example, these studies have not included environmental costs and benefits from the application of new agricultural technology. Nor do they consider the costs of dislocation of human and other resources brought about by technological change. In addition, there are often significant "research spillovers" from nonagricultural sciences (physics and engineering, chemistry, biology, genetics) that benefit agriculture. Research spillovers may also occur across geographic regions and countries. Rate-of-return studies typically take into account only the costs of agricultural research in one region or country. A further limitation of these studies is the difficulty of accurately measuring the level of private investment in agricultural research. Nevertheless, though they use different data, assumptions, and methodologies, studies have consistently reported a high rate of return to investments in agricultural research not only in the United States but also in other countries (Echeverria, 1990).

New Agricultural Technologies in the Pipeline

Current agricultural research is pursuing many endeavors that will affect future food supply, economic competitiveness, and environmental quality. Some key developments in selected research areas are highlighted below.

Biotechnology. Since the mystery of the DNA double helix was unraveled in the 1950's, science has been making steady progress in understanding the basic genetic codes that guide biological processes. Scientists have learned how to identify the functions of specific genes and how to transfer genes from one organism to another.

Biotechnology is being used to improve plant and animal productivity and food processing. However, few applications of agricultural biotechnology have been commercialized. The first genetically engineered food product entered the marketplace in March 1990 when the Food and Drug Administration (FDA) approved the use of recombinant chymosin (a replacement for the enzyme rennet) in the production of cheese and other processed dairy products. In 1994, the FDA also approved a tomato variety with longer shelf life and the use of bovine somatotropin (bST) to enhance milk production by dairy cows (see box, "Economic Implications of Biotechnology: The Case of bST"). More than 50 other genetically modified food and fiber products await FDA approval.

Biotechnology has raised concerns about food safety, environmental quality, and the future structure of agriculture (see boxes, "Economic Implications of Biotechnology: The Case of bST" and "Plant Biotechnology: Out of the Laboratory and Into the Field"). Research involving genetically modified organisms is more stringently regulated than most other types of research. Scientists who release any genetically engineered organism into the environment must first either notify or obtain a permit from the Animal and Plant Health Inspection Service (APHIS)

Plant Biotechnology: Out of the Laboratory and Into the Field

As the first products of plant biotechnology reach commercialization, some questions have arisen about the research goals of companies undertaking plant biotechnology research. These concerns were heightened by a number of takeovers of seed companies by chemical/pesticide firms. Some researchers suggested that the chemical/pesticide companies might dominate the industry and develop only seed varieties that require the use of more pesticides than current varieties at the expense of seeds that can substitute for chemicals (Hueth and Just, 1987; Kloppenburg, 1991).

USDA regulations require that any researcher planning to field-test a genetically modified plant variety first notify or obtain a permit from the Animal and Plant Health Inspection Service (APHIS). APHIS field test data were used to categorize plant biotechnology research by area of research and type of organization conducting the research. Five types of organizations were identified as undertaking plant biotechnology research: chemical/pesticide firms, seed companies, food and other companies, biotechnology companies, and public institutions. The field tests covered research in five areas: herbicide tolerance, insect resistance, virus resistance, product quality characteristics, and general research. While herbicide-tolerant varieties may encourage the use of chemical pesticides, insect- and viral-resistant varieties would generally require fewer pesticides.

The study found that chemical/pesticide companies had 41 percent of the field permits, seed companies 19 percent, public institutions 18 percent, biotechnology companies 16 percent, and food and other companies 6 percent of all permits issued through July 1993. Forty-five percent of all permits were obtained for insect/pest/virus resistance and 31 percent were for herbicide tolerance. The remaining were for product quality characteristics or research applications. In contrast to early concerns, chemical/pesticide companies obtained less than half of their total permits for herbicide tolerance and proportionately more field permits for insect resistance (24 percent), which can act as a substitute for pesticides, than either seed, biotechnology, and food companies (17 percent), or public institutions (11 percent).

For further reading, see Michael Ollinger and Leslie Pope, "Plant Biotechnology: Out of the Laboratory and Into the Field." AER-697. Econ. Res. Serv., U. S. Dept. Agr., 1995.

of the USDA. A genetically engineered product may also require FDA approval before it can enter the marketplace.

Between 1987 (when field tests involving genetically modified plants were first permitted by APHIS) and July 1993, 432 permits were issued (table 5.1.4). Taken together, the greatest number of permits were granted for tests for insect and virus resistance (see box, "Plant Biotechnology: Out of the Laboratory and Into the Field"). Tests on varieties engineered for this trait were particularly significant for *Solanaceae* crops (tomatoes, potatoes, and tobacco). If permits issued for virus resistance and insect resistance are counted separately (table 5.1.4), then these traits rank second and third behind the number of permits issued for tests involving plant varieties engineered for herbicide tolerance to improve weed control. Soybeans, corn, and cotton received the most permits for tests involving herbicide tolerance. A third area of research is to enhance product quality. Biotechnology research on rapeseed (canola) concentrated primarily on modifying the oil composition, mainly for industrial uses.

Biotechnology has been less promising for some important food grains. For example, only seven permits have been issued for rice, and none for either wheat or barley (table 5.1.4). Significant technical difficulties have been encountered in using genetic engineering techniques on these crops. Traditional plant breeding methods are likely to remain an essential component of the varietal improvement programs for all major commodities.

New products. Developing new products from agricultural commodities may expand demand and thereby reduce production surpluses. Significant research resources are currently directed at developing new products from both novel and traditional crops and livestock.

One area of research on new products is to develop novel crops. Kenaf, a fiber plant that can be used to make paper, is one such crop. Interest in kenaf arose when newsprint prices increased during the late 1970's. Kenaf is readily renewable and requires fewer chemical inputs during processing than timber newsprint. Kenaf can also be used as a substitute for fiber glass, seedling mats, and oil-absorption

Table 5.1.4—Uses of biotechnology field test permits in the United States through July 1993

Crop	Herbicide tolerance	Insect resistance	Virus resistance	Product quality	Research	Total
			Number of permits issued			
Corn	31	22	12	5	6	76
Tomato	11	15	13	27	8	74
Potato	2	7	39	10	6	64
Soybean	48	0	1	4	4	57
Cotton	25	14	0	0	0	39
Tobacco	6	11	9	3	6	35
Rapeseed	4	1	0	11	0	16
Alfalfa	3	0	8	1	0	12
Melon	0	0	10	0	0	10
Cantaloup	0	0	10	0	0	10
Rice	1	2	1	1	2	7
Other	1	6	12	5	8	32
Total	132	78	115	67	40	432
Percent	31	18	27	16	9	100

Source: USDA, APHIS, 1994

materials. The guayule shrub, native to Texas and a source of natural rubber, is another potential novel crop. A predicted shortage of hevea rubber may make guayule rubber economically viable. Oilseeds, such as crambe, castor, and lesquella, also show considerable potential. At present, research on novel crops is aimed at increasing yields and reducing production costs in order to make them economically competitive (USDA, 1993).

New uses are also being developed for traditional crops. One of the most significant possibilities is the production of biofuels. The 1990 Clean Air Act Amendments mandated carbon monoxide reduction, which increased the demand for oxygenates such as ethanol derived from corn. Ethanol production costs are falling as research continues to improve the production technology (Hohmann and Rendleman, 1993). Producing diesel fuel from fats, oils, and waste grease is also under study. Biodiesel fuel may be blended with petroleum diesel as a way to reduce emissions, but is not economically competitive by itself at present.

Starch from traditional crops can be used for biodegradable plastics, for biopolymer plastics, as a water-absorbent material, and to encapsulate pesticides. Since the advantages of starch-based products are environmental rather than economic, the commercial success of these products is partially dependent on environmental regulations. Oils, such as soybean and linseed, can replace petroleum oils. Soybean oil inks, particularly colored inks that are cost-competitive, are a good example (USDA, 1993).

Pharmaceuticals are a promising nonfood use of both crops and livestock. Pharmaceutical research on natural substances is increasing, which has led to new linkages between the medical and agricultural communities. Several important cancer treatments, produced partially or completely from natural sources, have prompted demand for plants like madagascar periwinkle (used to make the drugs vinblastine and vincristine) and Pacific yews (used to make the drug Taxol) (see box, "Public-Private Research Collaboration and Genetic Resources: The Case of Taxol"). Farm animals have been used for biomedical products, such as replacement heart valves and insulin, for some time. To meet the growing demand for human hormones, enzymes, blood coagulation factors, and immunological agents, researchers are experimenting with using mammalian tissue for synthesis via gene transfer. Production could potentially be expanded by transferring human genes to farm animals so they could produce needed human proteins for medical treatment (Pursel and others, 1992).

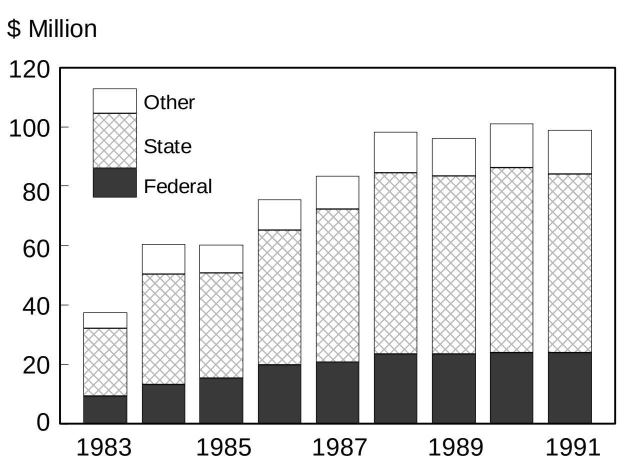
Improved environment and sustainable agriculture. Another group of emerging technologies are those aimed at reducing the environmental costs that can arise from agricultural production practices. Publicly funded research activities to develop such technologies include improved pest control, fertilizer management, and livestock waste management.

In order to reduce reliance on chemical pesticides, both biotechnology and conventional breeding are being used to enhance plant and animal resistance to pests, disease, and stress. Disease resistance is particularly important since many fungicides may cease to be available given current legislation.

Integrated Pest Management (IPM) methods are being developed to make more judicious use of chemical pesticides. IPM differs from conventional pest management in that chemicals are not used prophylactically, and organisms are viewed as members of an integrated ecological system (National Research Council, 1989). IPM research has focused primarily on problems associated with insects, although IPM techniques can be applied to disease and weed management as well. IPM is applied more often to fruit and vegetables than to major field crops. IPM research at nonfederal institutions increased by 163 percent between 1983 and 1991, with the majority of funds coming from State appropriations (fig. 5.1.7).

Public research efforts are also developing improved nutrient management methods. Nutrient management seeks to supply plants with the proper amount of nutrients at the correct time in order to improve efficiency and reduce excess applications, which can contaminate the environment. Nutrient management focuses on several interrelated techniques, including soil testing, split applications, green manuring, and the use of crops that capture nitrogen. Advancement of these technologies requires basic research to improve understanding of plant/nutrient relationships, and applied research to refine specific management practices.

Figure 5.1.7
IPM research at nonfederal institutions, 1983-91



1990 dollars.
Source: USDA, Current Research Information System data.

Livestock waste management arises out of environmental concerns from animal waste disposal. As livestock operations have become larger and more concentrated, waste disposal problems have increased, along with the potential for groundwater contamination. Research is underway to improve the storage and utilization of livestock waste. Technologies such as composting, anaerobic digestion, and gasification could potentially produce fertilizers and fuel from livestock wastes (National Research Council, 1993).

The transition to a science-based industry dramatically increased the productivity of American agriculture. The development of technologies such as biotechnology or sustainable production systems may afford agricultural producers the opportunity to pursue additional goals such as product quality enhancement and improving the environment. Research can give agriculture the technologies necessary to achieve these new goals and maintain a safe and competitive food production system.

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4.1 Crop Residue Management

Crop residue management (CRM) practices are increasingly used to conserve soil and water. CRM systems meeting conservation tillage requirements were used on 97 million acres in 1993, about 37 percent of U.S. planted crop area. No-till, which leaves the most protective residue, is expanding more rapidly than other types of conservation tillage.

USDA aims to mitigate environmental problems while maintaining agricultural profitability and competitiveness. The 1985 Food Security Act implemented new programs to conserve soil resources. The 1990 Food, Agriculture, Conservation, and Trade Act further strengthened the Federal role of protecting soil and water resources. (See chapter 6 for more information on conservation programs.) USDA farm conservation plans, developed to meet Farm Act requirements, frequently specify the use of crop residue management systems to reduce soil loss and protect water resources from agricultural contaminants (see boxes, "Crop Residue Management System Definitions and Survey" and "Environmental Effects of Conservation Tillage").

National and Regional Use of Crop Residue Management

Crop residue management systems include conservation tillage practices such as no-till, ridge till, and mulch till and other conservation practices that provide sufficient residue cover to protect the soil surface from the erosive effects of wind and water. According to the annual Crop Residue Management Survey, farmers practiced conservation tillage on over 97 million acres in 1993, up from 89 million acres in 1992 and 72 million acres in 1989 (table 4.1.1). Conservation tillage now accounts for 37 percent of U.S. planted crop acreage (fig. 4.1.1). Increased use of no-till and mulch-till practices will likely continue as farmers use crop residue management to implement their conservation compliance plans.

Besides providing soil-conserving benefits, crop residue management practices are adopted in many instances for their cost-effectiveness. Fuel and labor savings, lower machinery investments, and long-term benefits to soil structure and fertility are commonly cited advantages of crop residue management systems over conventional systems. While new or retrofitted machinery may be required to adopt crop residue

Table 4.1.1—National use of crop residue management practices, 1989-93[1]

Item	1989	1990	1991	1992	1993	1994	1995
				Million acres			
Total area planted	279.6	280.9	281.2	282.9	278.1	283.9	
Area planted with:							
No-till	14.1	16.9	20.6	28.1	34.8	39.0	
Ridge till	2.7	3.0	3.2	3.4	3.5	3.6	
Mulch till	54.9	53.3	55.3	57.3	58.9	56.8	
Total conservation tillage	71.7	73.2	79.1	88.7	97.1	99.3	
Other tillage types:							
15-30% residue	70.6	71.0	72.3	73.4	73.2	73.1	
< 15% residue	137.3	136.7	129.8	120.8	107.9	111.4	
Total other tillage types	207.9	207.7	202.1	194.2	181.0	184.6	
				Percent			
Percentage of area with:							
No-till	5.1	6.0	7.3	9.9	12.5	13.7	
Ridge till	1.0	1.1	1.1	1.2	1.2	1.3	
Mulch till	19.6	19.0	19.7	20.2	21.2	20.0	
Total conservation tillage	25.6	26.1	28.1	31.4	34.9	35.0	
Other tillage types:							
15-30% residue	25.3	25.3	25.7	25.9	26.3	25.8	
< 15% residue	49.1	48.7	46.1	42.7	38.8	39.3	
Total other tillage types	74.4	73.9	71.9	68.6	65.1	65.0	

[1] For tillage system definitions, see box "Crop Residue Management System Definitions."

Source: Conservation Technology Information Center, National Crop Residue Management Surveys.

Crop Residue Management System Definitions and Survey

Crop Residue Management (CRM) is a conservation practice 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). This practice is designed to leave sufficient residue on the soil surface to reduce wind and/or water erosion.

CRM is a year-round system that includes all field operations that affect the amount of residue, its orientation to the soil surface and prevailing wind and rainfall patterns, and the evenness of residue distribution throughout the period requiring protection. This may include the use of cover crops where sufficient quantities of other residue are not available to reduce the vulnerability of the soil to erosion during critical periods.

Conservation Tillage--Any tillage and planting system that maintains at least 30 percent of the soil surface covered by residue after planting to reduce soil erosion by water; or where soil erosion by wind is the primary concern, maintains at least 1,000 pounds (per acre) of flat, small grain residue equivalent on the surface during the critical wind erosion period. Two key factors influencing crop residue are (1) the previous crop, which establishes the initial residue amount and determines its fragility, and (2) the type of tillage operations prior to and including planting.

Conservation Tillage Systems (as defined in both the Crop Residue Management Survey and the Cropping Practices Survey)

Mulch till--The soil is disturbed prior to planting. Tillage tools such as chisels, field cultivators, disks, sweeps, or blades are used. The Cropping Practices Survey assumes any system with 30 percent or more residue after planting that is not a no-till or ridge-till system is a mulch-till system.

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.

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, inrow chisels, or roto-tillers.

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 and does not use a moldboard plow.

Other Tillage Systems (as defined in the Crop Residue Management Survey)

Reduced till (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.

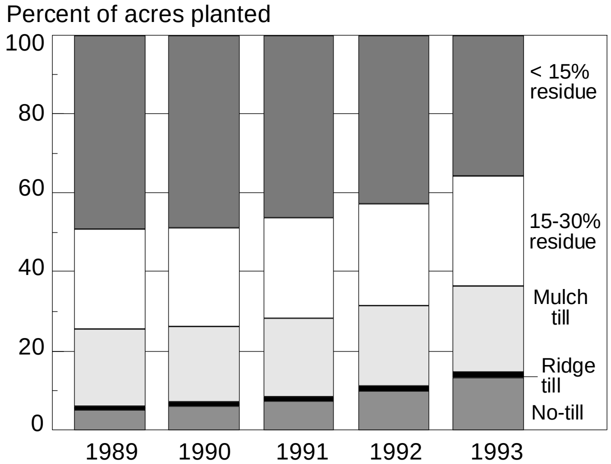
Conventional till (less than 15% residue)--Tillage types that leave less than 15 percent residue cover after planting, or less than 500 pounds per acre of small grain residue equivalent throughout the critical wind erosion period.

Crop Residue Management Survey

The Crop Residue Management (CRM) Survey, conducted by the Conservation Technology Information Center, provides State and national statistics on adoption of alternative crop residue management systems for all U.S. planted cropland. The CRM Survey provides estimates on five different tillage systems: no-till, mulch till, ridge till, reduced till (15-30 percent residue), and conventional till (less than 15 percent residue). A panel of local directors of USDA program agencies and others knowledgeable about local residue management practices complete the survey each summer. These local judgments about the use of practices are summarized to provide State, regional, and national estimates.

management systems, fewer trips over the field and reduced fuel and labor requirements can result in immediate cost savings. Machinery cost usually declines in the long run because a smaller machinery complement is needed. Farmers apply conservation tillage mostly at their own cost; only 600,000 acres were cost-shared in 1993 under the Agricultural Conservation Program, USDA's major cost-sharing program.

Figure 4.1.1
National use of crop residue management, 1989-93

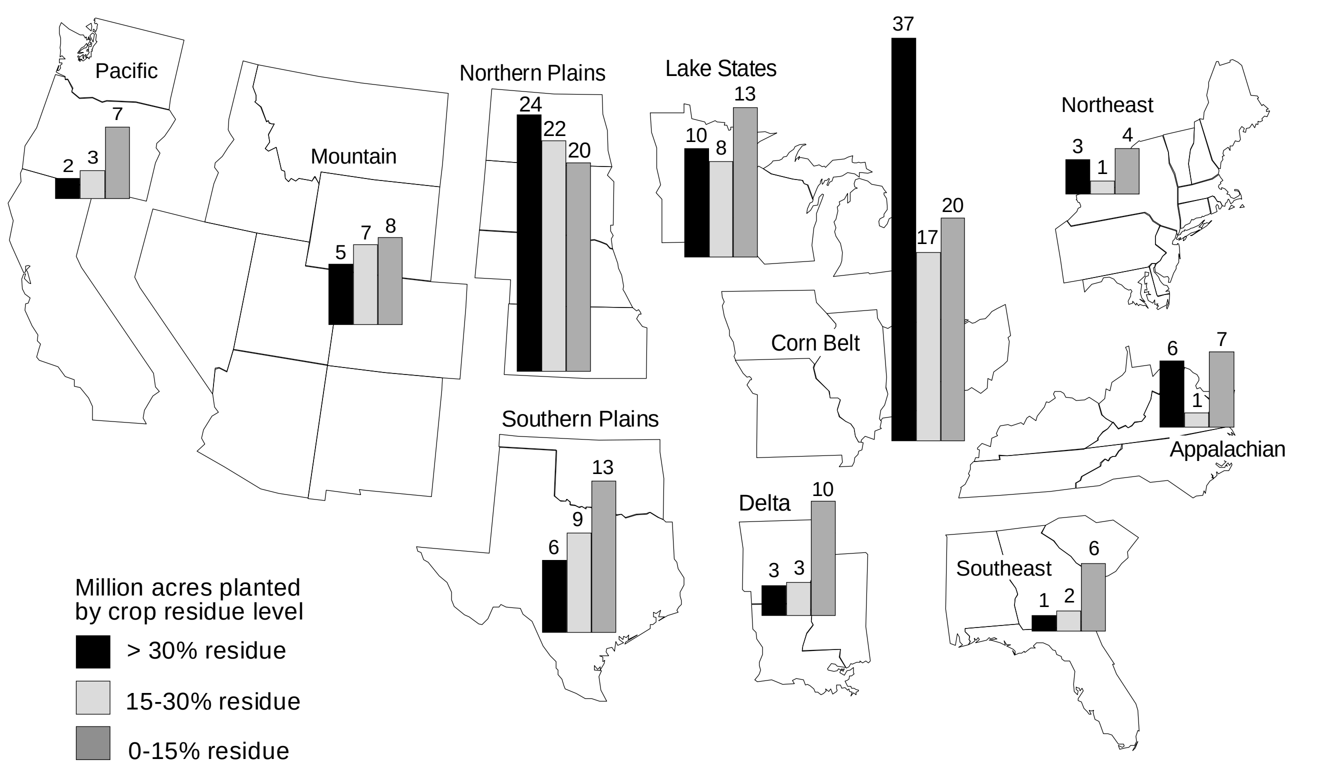


Source: Conservation Technology Information Center data.

The Corn Belt and Northern Plains had the most planted cropland in 1993 and accounted for nearly 63 percent of total conservation tillage acres (fig. 4.1.2). These regions, plus the Lake States, Mountain region, and Southern Plains, have substantial acreage with 15-30 percent residue cover. Much of this area (15-30 percent residue cover) has the potential to qualify as mulch till with increased surface residue from adoption of improved crop residue management.

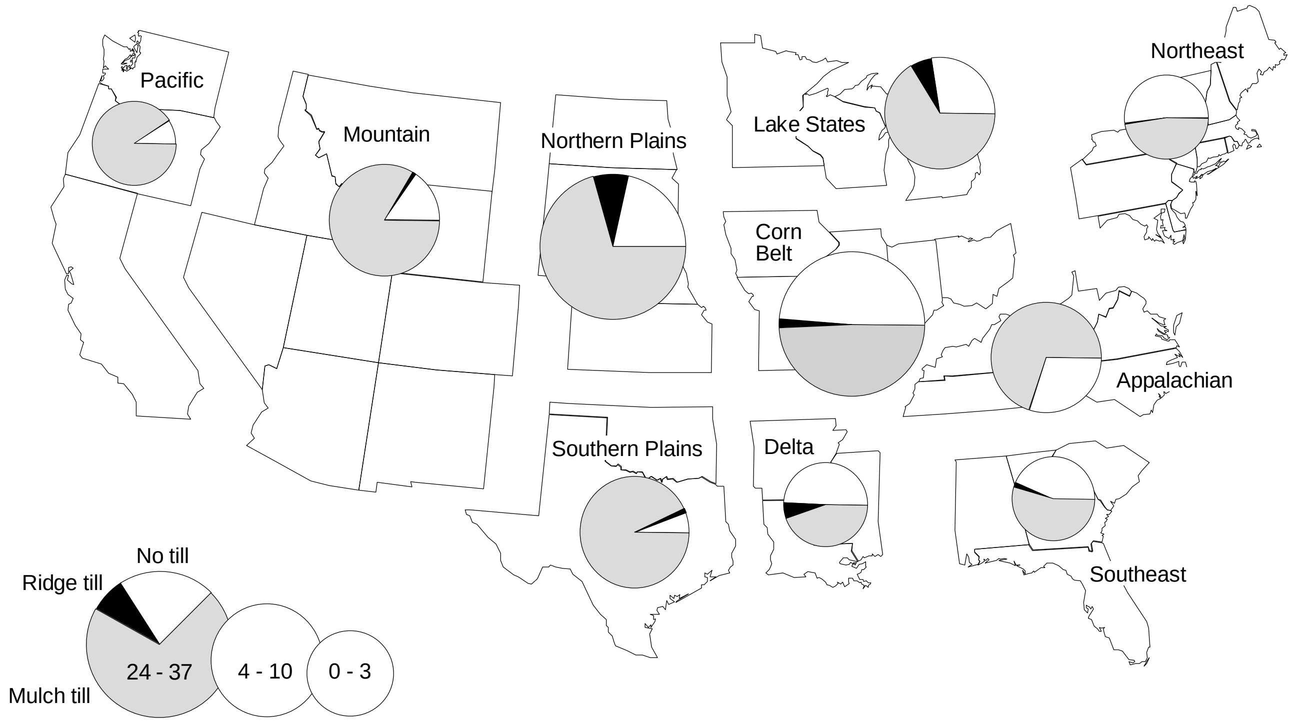
U.S. crop area planted with no-till has increased by about 2.5 times since 1989 to nearly 35 million acres in 1993. No-till's share of conservation tilled area is greater in the six eastern regions than elsewhere (fig. 4.1.3). Increased use of high-residue types of tillage has resulted in no-till and ridge till accounting for almost 40 percent (more than 38 million acres in

Figure 4.1.2
Crop residue levels on planted acreage by region, 1993



Source: Conservation Technology Information Center data.

Figure 4.1.3
Applied conservation tillage practices, 1993



Circle size represents conservation tillage area in million acres (range in ascending size).

Source: Conservation Technology Information Center data.

1993) of U.S. acreage with conservation tillage. This demonstrates a shift away from clean tillage (less than 15 percent residue) (table 4.1.1). High-residue types of tillage can leave as much as 70 percent or more of the soil surface covered with crop residues.

Tillage Systems Used on Major Crops

Conservation tillage was used mainly on corn, soybeans, and small grains in 1993. Almost 46 percent of the total acreage planted to corn and soybeans was conservation-tilled. Where double-cropping occurred, about 65 percent of soybean acreage, 48 percent of corn acreage, and 42 percent of sorghum acreage was farmed using conservation tillage systems. The widespread use of no-till with double-cropping captures several benefits such as timeliness in getting the second crop planted and limiting potential moisture losses from the germination zone in the seedbed. This allows greater flexibility in cropping sequence or rotation (Conservation Technology Information Center, 1993).

The 1988-93 Cropping Practices Surveys (see box, p. 127) provide additional detail on residue levels and tillage systems for major crops and producing States. Five tillage systems are estimated from survey data based on the use of specific tillage implements and their residue incorporation rates (Bull, 1993). These annual surveys indicate a decline in the use of conventional tillage both with and without the moldboard plow and an increase for all conservation tillage types (table 4.1.2, app. tables 4.1.1-4.1.5). Less than 10 percent of the surveyed area in major producing States used a moldboard plow in 1993, down from 19 percent in 1988 (fig. 4.1.4).

Corn

The three conservation tillage systems (mulch till, no-till, and ridge till) were used on 42 percent of the 1993 corn acreage, up from 21 percent in 1988 (table 4.1.2). The average amount of crop residue after planting increased accordingly from about 19 percent in 1988 to 29 percent in 1993. Mulch till, which fulfills the erosion protection requirements under many conservation compliance plans, is the most common type of conservation tillage used on corn. Its share of total corn acreage increased from 14 percent in 1988 to 24 percent in 1993. Acreage under

Table 4.1.2—Tillage systems used in field crop production in major producing States, 1988-95[1]

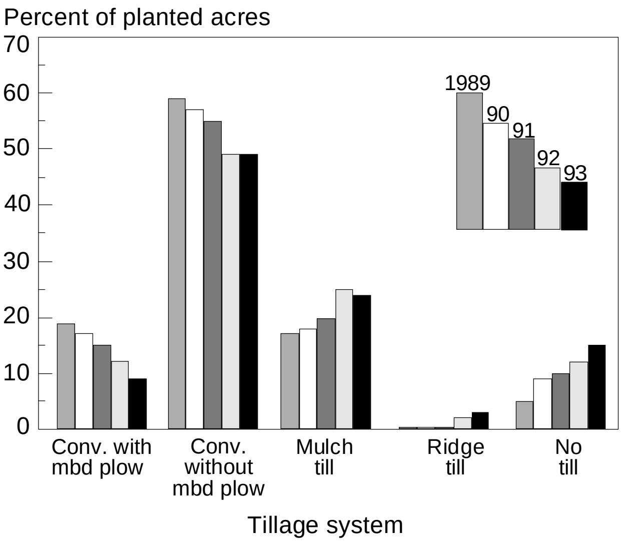
Item	Unit	1988	1989	1990	1991	1992	1993	1994	1995
Corn (10 States)	*1,000 acres*[2]	53,200	57,900	58,800	60,350	62,850	57,350	62,500	
Residue remaining after planting	*Percent*	19	19	22	24	27	29	30	
Tillage system:	*Percent of acres*								
Conv. with moldboard plow		20	19	17	15	12	9	8	
Conv. w/out moldboard plow		60	59	57	55	49	49	49	
Mulch till		14	17	18	20	25	24	23	
Ridge till		*	*	*	*	2	3	3	
No-till		7	5	9	10	12	15	17	
Northern soybeans (7 States)	*1,000 acres*[2]	36,550	37,750	36,400	38,850	38,150	42,500[3]	43,750[3]	
Residue remaining after planting	*Percent*	17	19	19	25	28	35	36	
Tillage system:	*Percent of acres*								
Conv. with moldboard plow		28	26	23	18	12	8	9	
Conv. w/out moldboard plow		55	51	51	48	47	44	38	
Mulch till		14	18	21	25	26	25	26	
Ridge till		*	*	*	*	1	1	1	
No-till		3	4	6	10	14	22	26	
Southern soybeans (7 States)	*1,000 acres*[2]	12,200	13,380	11,850	10,800	10,480	NA	NA	
Residue remaining after planting	*Percent*	14	15	19	17	18	NA	NA	
Tillage system:	*Percent of acres*								
Conv. with moldboard plow		3	4	4	3	3	NA	NA	
Conv. w/out moldboard plow		85	82	78	80	76	NA	NA	
Mulch till		5	5	7	6	8	NA	NA	
Ridge till		*	*	*	*	id	NA	NA	
No-till		7	10	12	11	14	NA	NA	
Upland cotton (6 States)	*1,000 acres*[2]	9,700	8,444	9,730	10,860	10,200	10,360	10,023	
Residue remaining after planting	*Percent*	2	2	3	3	3	2	3	
Tillage system:	*Percent of acres*								
Conv. with moldboard plow		28	15	14	21	12	16	10	
Conv. w/out moldboard plow		72	84	84	76	88	83	89	
Mulch till		id	id	1	1	id	**	**	
No-till		id	id	1	1	id	1	1	
Winter wheat (12-15 States)[4]	*1,000 acres*[2]	32,830	34,710	40,200	34,180	36,990	37,210	34,590	
Residue remaining after planting	*Percent*	17	17	18	17	19	18	18	
Tillage system:	*Percent of acres*								
Conv. with moldboard plow		15	16	12	12	11	6	8	
Conv. w/out moldboard plow		67	68	69	72	68	76	75	
Mulch till		16	15	17	13	18	14	12	
No-till		1	1	3	3	3	4	5	
Spring/durum wheat (4-5 States)[5]	*1,000 acres*[2]	12,280	19,580	18,900	16,500	19,550	18,900	19,700	
Residue remaining after planting	*Percent*	18	22	22	24	23	25	25	
Tillage system:	*Percent of acres*								
Conv. with moldboard plow		14	8	10	7	8	8	7	
Conv. w/out moldboard plow		63	60	63	59	60	57	57	
Mulch till		22	31	25	31	26	28	30	
No-till		1	1	2	3	6	7	6	
Total acres surveyed	*1,000 acres*[2]	156,760	171,764	175,880	171,040	178,220	166,320	170,563	
Tillage system:	*Percent of acres*								
Conv. with moldboard plow		19	17	15	14	11	8	8	
Conv. w/out moldboard plow		63	62	62	60	58	57	55	
Mulch till		13	17	17	19	21	21	21	
Ridge till		*	*	*	*	1	1	1	
No-till		5	4	6	7	9	13	15	

id = Insufficient data. * = Included in no-till for these years. ** = Less than 1 percent. NA = Not available.

[1] For the States included, see box "Cropping Practices Survey." For tillage system definitions, see box "Crop Residue Management System Definitions and Survey." [2] Preliminary. Planted acres, except for winter wheat (harvested). [3] Arkansas in 1993 and 1994 is included in Northern area. Previously, Arkansas was included with GA, KY, LA, MS, NC, and TN (not surveyed in 1993 and 1994) to comprise Southern area. [4] Winter wheat includes 15 States in 1988-89 and 1991-92; 12 States in 1990; and 13 States in 1993-95. [5] Spring wheat includes 5 States in 1988-89 and 4 States in 1990-95. Durum wheat includes only ND.

Source: USDA, ERS, Cropping Practices Survey data.

Figure 4.1.4
Corn tillage systems, 1989-93



Source: USDA, ERS, Cropping Practices Survey data.

no-till, which maintains the largest amount of crop residue on the soil surface, tripled from 1989 to 1993 and now accounts for almost one-third of all conservation tillage used on corn. Ridge-till systems are mostly used in Nebraska, Minnesota, and South Dakota and account for 3 percent of the total surveyed corn acreage.

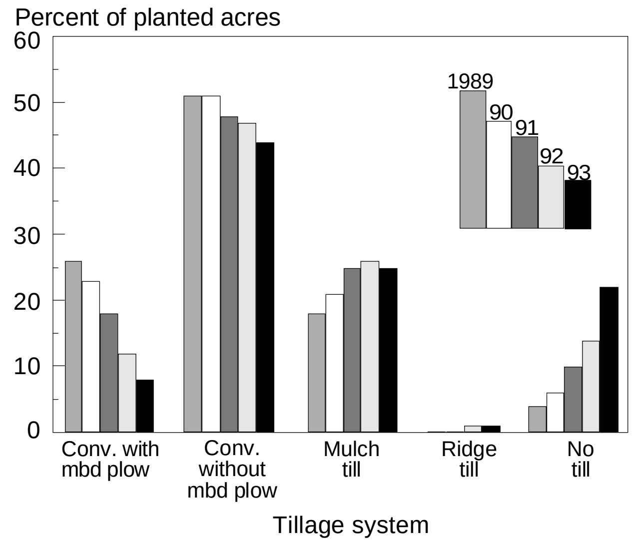
Soybeans

The increase in conservation tillage for Northern soybeans has been even faster than for corn. Nearly half of Northern soybeans are produced with conservation tillage methods (fig. 4.1.5, table 4.1.2). In 1989, less than 20 percent were produced using conservation tillage. The amount of crop residue increased from 17 percent in 1988 to 35 percent in 1993. Estimates of conservation tillage for Southern soybeans are not available for 1993 because most Southern soybean States were dropped from the Cropping Practices Survey. However, estimates through 1992 indicate that growth of conservation tillage systems in the Delta and Southeastern States has been much slower than in the Northern States (fig. 4.1.6).

Cotton

Nearly all cotton (99 percent in 1993) in the six major cotton States is produced using conventional tillage methods (fig. 4.1.7 and table 4.1.2). Although most land remains in conventional tillage, use of the moldboard plow has decreased to nearly half of the 1988 level. Some States require that farmers dispose of cotton plants after harvest to eliminate the winter

Figure 4.1.5
Northern soybean tillage systems, 1989-93

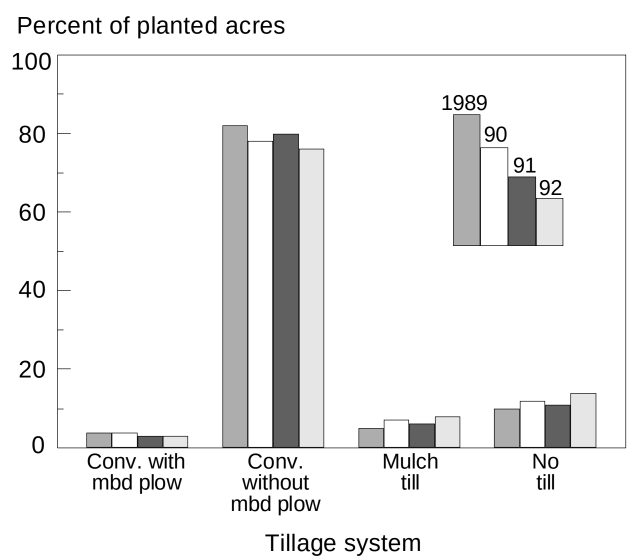


Source: USDA, ERS, Cropping Practices Survey data.

food source for bollworms and boll weevils. Using conventional tillage systems to dispose of cotton plants precludes current conservation tillage methods.

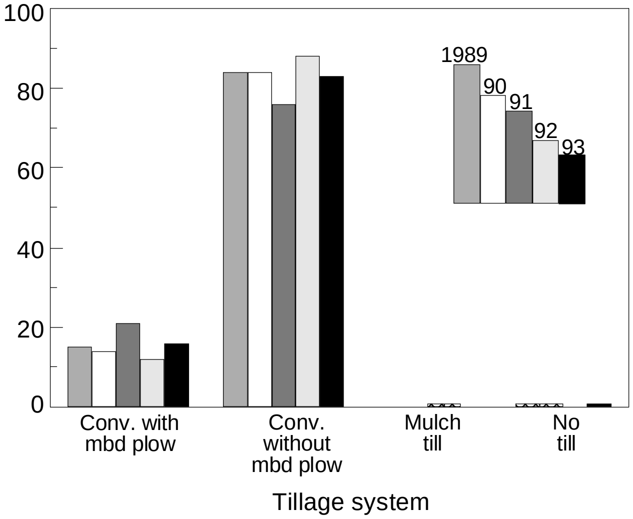
Research is being conducted on tillage and other cultural practices that provide both effective erosion and pest control on cotton. For example, "stale seed-bed" systems include (1) fall tillage to create beds, (2) a cover crop or natural vegetation growth over winter, and (3) spring time application of a burn down herbicide to kill the vegetation. The cotton is

Figure 4.1.6
Southern soybean tillage systems, 1989-92



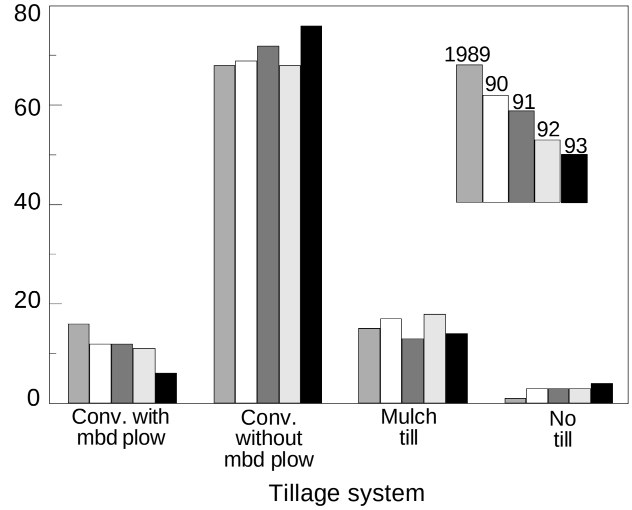
Source: USDA, ERS, Cropping Practices Survey data.

Figure 4.1.7
Cotton tillage systems, 1989-93



Source: USDA, ERS, Cropping Practices Survey data.

Figure 4.1.8
Winter wheat tillage systems, 1989-93



Source: USDA, ERS, Cropping Practices Survey data.

then directly seeded into the residue, similar to no-till systems.

Winter Wheat

Use of the moldboard plow in winter wheat has declined since 1988 (table 4.1.2). However, unlike corn and soybeans, most of this acreage was replaced with other conventional tillage systems (fig. 4.1.8). Conservation tillage was used on 18 percent of winter wheat in 1993, about the same as in 1988. Since the growing winter wheat crop covers the soil surface during critical erosion periods, no large increase in conservation tillage acreage is expected as remaining conservation compliance plans are implemented.

Tillage on Highly Erodible Land

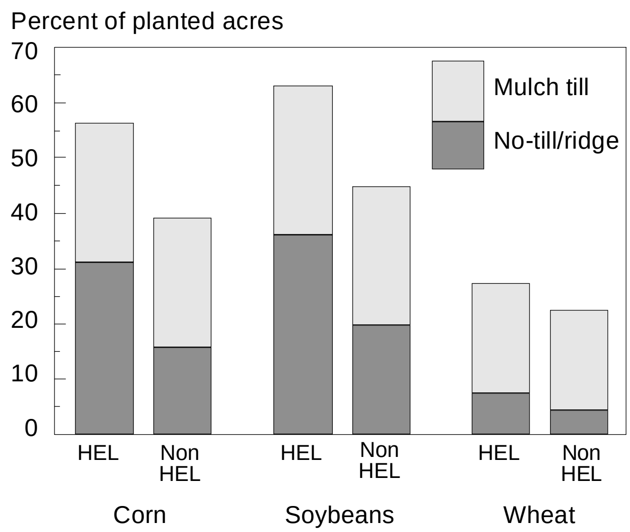
Tillage operations and amount of previous crop residue on the soil surface after planting are important indicators of soil erosion potential. To be eligible for most USDA program benefits, farmers must implement by 1995 an approved conservation plan on all highly erodible land (HEL). About 75 percent of the acreage in these plans includes some form of crop residue management.

The tillage trends on HEL are generally the same as for all land, but a larger share of HEL acreage uses conservation tillage, particularly no-till (fig. 4.1.9, table 4.1.3). Large reductions in moldboard plow use occurred for all crops on HEL except cotton.

About one-fifth of the 1993 corn acres in the Cropping Practices Survey were designated as HEL, 56 percent of which were planted using conservation tillage (table 4.1.3). The moldboard plow was used on only 7 percent of HEL acres in 1993, down from 16 percent in 1989. The share of HEL using no-till or ridge-till systems increased from 7 percent in 1989 to 31 percent in 1993.

About 63 percent of northern soybean HEL acres were planted using conservation tillage in 1993, up from 28 percent in 1989 (fig. 4.1.9). The increase in conservation tillage can primarily be attributed to the adoption of no-till. Tillage systems used on southern

Figure 4.1.9
Conservation tillage systems on highly erodible lands (HEL) versus non-HEL, 1993



Source: USDA, ERS, 1993 Cropping Practices Survey data.

Table 4.1.3—Tillage systems in field crop production, highly erodible and non-highly erodible lands[1]--continued

	Non-highly erodible						
Item	1989	1990	1991	1992	1993	1994	1995
Corn - planted acres (1,000)[2]	41,020	43,230	44,480	46,880	43,355	48,580	
(percent of total planted acres)	71	74	74	75	75	78	
Tillage system (percent of acres):							
Conv. with moldboard plow	19	18	15	12	9	9	
Conv. w/out moldboard plow	61	57	58	52	52	52	
Mulch till	15	18	18	24	23	23	
Ridge till	*	*	*	2	4	3	
No-till	5	8	9	10	12	13	
N. soybeans - planted ac. (1,000) [2,3]	29,193	27,450	29,930	29,680	33,625	34,800	
(percent of total planted acres)	77	75	77	78	79	80	
Tillage system (percent of acres):							
Conv. with moldboard plow	29	26	20	15	9	10	
Conv. w/out moldboard plow	49	49	48	48	46	44	
Mulch till	18	20	23	26	25	25	
Ridge till	*	*	*	1	1	1	
No-till	4	5	9	12	19	21	
S. soybeans - planted ac. (1,000)[2,3]	10,088	9,160	8,810	8,170	[3]	[3]	
(percent of total planted acres)	76	77	81	78	[3]	[3]	
Tillage system (percent of acres):							
Conv. with moldboard plow	2	3	2	3	[3]	[3]	
Conv. w/out moldboard plow	88	80	84	81	[3]	[3]	
Mulch till	4	8	6	8	[3]	[3]	
Ridge till	*	*	*	id	[3]	[3]	
No-till	6	9	8	8	[3]	[3]	
Cotton - planted acres (1,000)[2]	4,956	6,930	7,590	7,030	7,063	6.363	
(percent of total planted acres)	59	71	70	69	68	63	
Tillage system (percent of acres):							
Conv. with moldboard plow	9	10	17	7	9	9	
Conv. w/out moldboard plow	90	88	82	92	91	78	
Mulch till	id	1	1	id	id	10	
No-till	id	1	nr	nr	nr	3	
Winter wheat - harv. ac. (1,000)[2,4]	21,672	25,660	21,940	23,990	23,130	12,995	
(percent of total harvested acres)	62	64	64	65	62	64	
Tillage system (percent of acres):							
Conv. with moldboard plow	20	13	14	12	7	8	
Conv. w/out moldboard plow	66	70	72	70	78	78	
Mulch till	13	15	12	15	12	10	
No-till	1	2	2	3	3	3	
Spring wheat - planted ac. (1,000)[2,5]	12,557	12,010	10,800	13,960	13,055	12,910	
(percent of total planted acres)	76	76	80	80	77	75	
Tillage system (percent of acres):							
Conv. with moldboard plow	6	13	7	9	11	8	
Conv. w/out moldboard plow	64	64	61	59	55	59	
Mulch till	30	21	29	24	27	30	
No-till	id	2	3	8	7	4	
Durum wheat - planted ac. (1,000)[2,5]	2,217	2,505	2,345	1,970	1,670	2,155	
(percent of total planted acres)	71	81	78	90	86	86	
Tillage system (percent of acres):							
Conv. with moldboard plow	4	3	5	8	3	1	
Conv. w/out moldboard plow	49	62	53	50	54	60	
Mulch till	46	34	38	39	39	33	
No-till	1	1	4	3	4	6	
Total (1,000 acres)[2]	121,703	126,945	125,795	131,680	121,898	26,803	
(percent of total surveyed acres)	71	72	74	74	73	74	
Tillage system (percent of acres):							
Conv. with moldboard plow	18	16	14	11	9	9	
Conv. w/out moldboard plow	63	62	61	59	58	58	
Mulch till	16	17	18	21	21	21	
Ridge till	*	*	*	1	2	1	

Table 4.1.4—Herbicide use by tillage system in major producing States, 1990-93[1]

Item	Conv.		Conservation		
	With mbd. plow	W/out mbd. plow	Mulch till	No-till	Ridge till
Corn:[2]					
Acreage treated	*Percent of planted acres treated*				
1990	90	96	94	96	100
1991	91	96	97	96	94
1992	95	97	97	99	98
1993	92	98	98	99	98
Amount applied	*Pounds a.i. per treated acre*				
1990	3.03	3.37	3.01	3.27	2.47
1991	2.73	2.98	3.05	3.25	2.11
1992	2.69	3.05	2.92	3.30	2.19
1993	2.48	2.99	2.82	3.42	1.87
Northern soybeans:[3]					
Acreage treated	*Percent of planted acres treated*				
1990	97	97	95	94	100
1991	95	97	98	94	100
1992	99	99	99	98	100
1993	97	97	98	98	100
Amount applied	*Pounds a.i. per treated acre*				
1990	1.57	1.32	1.35	2.21	1.14
1991	1.30	1.23	1.28	1.52	1.00
1992	1.13	1.14	1.09	1.33	0.72
1993	1.09	1.04	0.95	1.40	1.21
Southern soybeans:[4]					
Acreage treated	*Percent of planted acres treated*				
1990	89	93	90	96	nr
1991	86	92	92	95	nr
1992	78	95	97	98	nr
Amount applied	*Pounds a.i. per treated acre*				
1990	1.21	1.19	1.05	1.94	nr
1991	1.21	1.12	0.89	1.99	nr
1992	1.37	1.16	1.15	1.40	nr
Winter wheat:[5]					
Acreage treated	*Percent of planted acres treated*				
1991	40	27	22	36	n/a
1992	48	34	23	28	n/a
1993	53	43	40	43	n/a
Amount applied	*Pounds a.i. per treated acre*				
1991	0.23	0.31	0.37	0.68	n/a
1992	0.30	0.33	0.35	0.35	n/a
1993	0.38	0.32	0.42	0.48	n/a

nr = none reported. n/a = not applicable

[1] For the States included, see box "Cropping Practices Survey." For tillage system definitions, see box "Crop Residue Management System Definitions and Survey." [2]See app. table 4.1.6 for more detail and test results on significance of differences in amounts applied. [3]See appendix table 4.1.7 for more detail and test results on significance of differences in amounts applied. [4]See appendix table 4.1.8 for more detail and test results on significance of differences in amounts applied. [5]See appendix table 4.1.9 for more detail.

Source: USDA, ERS, Cropping Practices Survey data.

soybean HEL acreage changed only slightly from 1988 to 1992; however, over half the reported acreage used conservation tillage in 1992.

Over one-third of the 1993 winter wheat was harvested from HEL. One-fourth of this acreage used conservation tillage systems, compared with 15 percent of non-HEL.

Pesticide and Fertilizer Use Under Different Tillage Systems

While conservation tillage systems reduce soil erosion and may enhance productivity, the effect on fertilizer and pesticide use is less certain. The Cropping Practices Surveys (CPS, see box) from 1990 to 1993 provide some information about the quantities of pesticide and fertilizer applied with different tillage systems. These relationships, however, are not conclusive.

In general, the CPS data indicate that users of no-till systems applied more herbicide and less insecticide per acre than other tillage systems (tables 4.1.4-4.1.5). Mulch-till system users, however, often applied less herbicide than conventional systems not using the

Table 4.1.5—Corn acres treated with insecticide by tillage system in major producing States, 1990-93[1]

Item	Conv.		Conservation		
	With mbd. plow	W/out mbd. plow	Mulch till	No-till	Ridge till
Planted acres treated:	*Percent*				
1990	35	32	37	31	48
1991	29	30	35	27	63
1992	28	28	32	25	60
1993	27	26	32	22	58
Number of treatments:	*Number*				
1990	1.04	1.10	1.12	1.05	1.27
1991	1.05	1.10	1.13	1.17	1.88
1992	1.01	1.06	1.11	1.08	1.48
1993	1.06	1.04	1.06	1.01	1.18
Amount applied:	*Pounds a.i. per treated acre*				
1990	1.16	1.12	1.11	0.95	1.34
1991	1.00	1.10	1.12	0.87	1.11
1992	1.08	0.93	1.00	0.83	0.90
1993	1.10	0.96	0.92	0.75	1.13

[1] For the States included, see box "Cropping Practices Survey." For tillage system definitions, see box "Crop Residue Management System Definitions and Survey." For more detail, see appendix table 4.1.6.

Source: USDA, ERS, Cropping Practices Survey data.

moldboard plow. Ridge till, while not widely used, generally used the least herbicide. The differences in quantity of pesticide applied between tillage systems were usually small and often were not statistically significant.

These results suggest that conservation tillage systems do not consistently use more total pesticides than conventional tillage systems. Higher use might be true for a specific crop, tillage system, or particular year. Crop rotation, moisture availability and timing, nonchemical pest management practices, and other factors influencing pest populations also affect pesticide use in annual crop production.

The per-acre quantity of pesticide used on corn and soybeans declined between 1990 and 1993. This is true across most tillage systems for most years. More recent pesticide products often use lower application rates.

A farmer's conversion to no-till may increase weed problems in the first few years. New adopters often use more herbicide and combination mixes in response to this problem (Bull and others, 1993). Because much of the current no-till acreage is new, this could obscure a long-term downward trend in pesticide use.

Research on long-term no-till suggests fewer weed problems and less need for herbicides. With annual tillage, both new weed seeds on the surface and dormant seeds deeper in the soil are brought into the germination zone and provide a continual source of weeds (Martin and Wicks, 1992). Continuous no-till without row cultivations eliminates this weed seed mixing and increases surface mulch. Therefore, weed problems are expected to decrease after several years of continuous no-till.

Corn

No-till corn, except in 1990, received a higher rate of herbicide application than did any other tillage system (table 4.1.4 and app. table 4.1.6). Ridge till,

Cropping Practices Survey

The Cropping Practices Surveys collect annual data on fertilizer and pesticide use, tillage systems, crop sequence, and information on other inputs and cultural practices. Fertilizer information has been reported from these surveys since 1964. In the mid-1980's, pesticide use, tillage operations, and prior crop questions were added to the survey. Integrated pest management and nutrient management questions have recently been included.

The 1993 surveys included corn, cotton, soybeans, wheat, and potatoes and represented about 167 million acres. This area includes the acreage in major producing States, which account for about 80 percent of the total U.S. acreage for these crops. Because of priority data needs and available survey funds, the number of crops and States and types of data have varied from year to year. Crops and States surveyed for data on tillage systems and crop sequence include:

Corn:	IL, IN, IA, MI, MN, MO, NE, OH, SD, and WI
Soybeans:	Northern: IL, IN, IA, MN, MO, NE, and OH. Also AR in 1993; Southern, 1988-92: AR, GA, KY, LA, MS, NC, and TN
Cotton:	AR, AZ, CA, LA, MS, and TX
Winter wheat:	CO, IL, KS, MO, MT, NE, OH, OK, TX, and WA. Also AR, CA, ID, IN, and OR in 1988-89; AR and SD in 1990; AR, ID, IN, OR, and SD in 1991-92; and ID, OR, and SD in 1993
Spring wheat:	MN, MT, ND, and SD. Also ID in 1988-89
Durum wheat:	ND.

The sample consists of fields containing a random acre selected through a stratified sampling procedure. Respondents are asked to provide field-level information for the fields containing the sample acre. The operator of the selected sample field is asked to report 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 identifies whether the field has been designated as highly erodible land (HEL) by the Soil Conservation Service and whether the farm unit participates in Federal price support programs.

representing less than 3 percent of the acreage, used the lowest amount of herbicides. Acreage tilled with the moldboard plow used slightly less herbicide than mulch till or conventional tillage without the moldboard plow. Reported differences in herbicides applied per acre were not always statistically significant. Other elements, such as weather, soil type, tillage system experience, and inherent weed problems, could be more influential factors than tillage type.

About the same herbicide ingredients were used on all tillage types (Bull, 1991). Atrazine, alachlor, cyanazine, and metolachlor accounted for over 80 percent of active ingredients (a.i.) applied with any tillage system (NASS, 1993). EPTC was frequently used with conventional and mulch tillage. Because EPTC must be incorporated into the soil to prevent loss by volatilization, it is not normally used with no-till or ridge till.

In contrast to herbicide use, insecticide use on corn was consistently less per treated acre under no-till than under other tillage systems (table 4.1.5). None of the differences were significant, probably due to the small sample size (low incidence of insecticide use).

The CPS indicates lower nitrogen application rates on land using the moldboard plow. This appears to be offset by the greater incidence of manure application (app. table 4.1.7). The greater use of nitrogen and lesser applications of phosphate and potash with ridge till are probably related to higher fertilization on soils with higher yield potential, higher incidence of irrigation, and continuous corn cropping where ridge till is most prevalent. Nitrogen management (including rate, timing, and placement) has been found to be more crucial for controlling nitrate loss through leaching than the type of tillage system (Baker and others, 1987).

Soybeans

No-till soybeans in both northern and southern regions received higher herbicide application rates than any other tillage systems (table 4.1.4 and app. tables 4.1.7-4.1.8). Differences among other tillage systems were small and not consistent between years. Like corn, other factors in addition to tillage determine herbicide treatments for soybeans.

Unlike corn, the type of a.i. applied did vary across tillage systems in soybean production. Trifluralin was the most widely used a.i. in both conventional tillage systems and mulch tillage. Trifluralin is applied before planting and incorporated into the soil with a tillage tool (see box, "Crop Residue Management System Definitions").

For no-till and ridge-till systems, no single a.i. or combination mix was dominant in the northern region before 1990. Since 1990, imazethapyr has become the most widely used a.i. in northern no-till soybeans. Imazethapyr can be applied preplant incorporated, preemergence, or postemergence. It controls many broadleaf weeds and certain grasses. For southern soybeans, the most commonly used a.i. with no-till were glyphosate and fluazifop. Glyphosate is applied before the soybeans emerge to kill existing vegetation and fluazifop is a postemergence treatment.

It is, therefore, not appropriate to compare only the total quantity of herbicide applied between no-till and another tillage system. The a.i. content and properties such as leaching potential and persistence would be quite different.

Pesticides other than herbicides are not frequently applied to soybeans under any crop residue management system. Insecticides were applied to less than 3 percent of soybean acres across all tillage systems. Fungicide applications were made on less than 1 percent of soybean acres. Almost 25 percent of soybean acreage is planted with seed that has been treated with an insecticide and/or fungicide.

The incidence of fertilizer use is much less for soybeans than for corn (app. tables 4.1.6-4.1.8). The application rates show some variation between tillage systems and between years. Southern soybeans tended to use more fertilizer for no-till than for the other systems, while northern soybeans showed no consistent differences. Many southern no-till soybeans are double-cropped and, therefore, require more fertilizer.

Cotton

Cotton acreage is nearly 99 percent conventionally tilled. Differences in fertilizer and pesticide use reflect regional differences rather than differences caused by tillage system. Parts of Texas, Arizona, and California have "plow-down" laws requiring that the cotton plant be disposed of to eliminate the overwinter food source for bollworms and boll weevils.

Winter Wheat

The percentage of winter wheat acreage treated with herbicides is greater for conventional tillage with the moldboard plow than for other tillage systems (table

4.1.4 and app. table 4.1.9). Herbicide use per acre is greatest for no-till and is associated with a greater number of treatments. Glyphosate and 2,4-D were used more extensively with no-till. This may indicate an initial burndown treatment that did not always eliminate the need for subsequent treatments.

Winter wheat also showed some variation in fertilizer use across years and tillage systems (app. table 4.1.9). However, as with corn and soybeans, this was probably related more to regional differences (including soil and rotations) than to differences in tillage systems.

Mechanical Cultivations

Mechanical weed control cultivations may be used as a pest control alternative to herbicides. However, these cultivations do have disadvantages. Cultivation interrupts the buildup of organic matter and the activity of earthworms and microorganisms. It also tends to till the soil, which brings up dormant weed seeds and stirs up seeds near the surface and loosens soil particles, which can then be dislodged by wind and water erosion.

The percentage of no-tilled corn acres that received mechanical weed control cultivations was much less than for other tillage systems (table 4.1.6 and app. table 4.1.6). Of the cultivated acres, the number of cultivations averaged 1.2-1.5 for all tillage systems except for ridge till, at 1.7-1.8. Ridge-till systems normally use mechanical cultivations during the season to maintain the ridges in addition to controlling weeds.

Mechanical cultivation for weed control on soybeans is feasible only on those planted with a row planter.

Environmental Effects of Conservation Tillage

Conservation tillage systems reduce soil erosion, water runoff, and the potential for surface water contamination from agricultural pollutants. Under normal circumstances, the potential for ground water contamination is no greater than for other tillage systems. A change to conservation tillage systems to meet USDA program goals should contribute to a net decrease in total potential water quality degradation.

Tillage practices that leave substantial amounts of crop residue evenly distributed over the soil surface defend against the potential of rainfall's kinetic energy to generate sediment and increase water runoff. Several field studies (Baker and Johnson, 1979; Glenn and Angle, 1987; Hall and others, 1984; Sander and others, 1989) conducted under natural rainfall on highly erodible land (14 percent slope) have compared erosion rates between tillage systems. Compared with moldboard plowing, no-till generally reduced soil erosion by more than 90 percent, mulch till and ridge till by about 70 percent.

Increased surface residues also filter out and trap sediment and sediment-adsorbed chemicals (fertilizers and pesticides) and result in cleaner runoff (Onstad and Voorhees, 1987). The increased organic matter associated with crop residue management intercepts these chemicals and holds them in place until they are used by the crop or degrade into harmless components (Dick and Daniel, 1987; Helling, 1987; Wagenet, 1987). The presence of increased crop residue usually reduces the volume of contaminants entering surface waters by constraining runoff (including dissolved chemicals and sediment) and enhancing infiltration (Baker, 1987; Fawcett, 1987; Wauchope,1987).

Enhanced water infiltration associated with greater surface residue provides additional soil moisture to benefit crops during low rainfall periods, but raises concerns about potential leaching of nitrates and pesticides to shallow ground water (Baker, 1987; Wauchope,1987). However, increased volume of infiltration normally dilutes the concentration level of contaminants in the percolate to groundwater. Scientific evidence suggests that, under normal climatic and hydrologic conditions, conservation tillage systems are no more likely to degrade ground water quality than other tillage systems (Baker, 1980; Baker, 1987; Edwards and others, 1993; Fawcett and others, 1994; Wagenet, 1987).

While conservation tillage systems often require different herbicide treatments, all tillage systems use a broad spectrum of herbicides for weed control. Many factors, including the type of chemical applied, application methods and timing, soil properties, weather, and the crop residue effects on compaction and macropores, can affect the fate of applied nutrients and pesticides (Bull and others, 1993). Chemicals applied prior to heavy rainfall events and that have high water solubility, low adsorption to soil, and resistance to degradation are most likely to impair water quality (Dick and Daniel, 1987; Fawcett, 1987; Wauchope and others, 1992; Weber and Warren, 1993).

About 75 percent of soybean acreage is row-planted. This percentage is consistent across tillage systems except for ridge till, which must be row-planted.

Mechanical weed control cultivations on the acres that were row-planted and cultivated averaged about 1.5 times for the northern soybean area across all tillage systems, with ridge till being higher in some years (table 4.1.6 and app. table 4.1.7). The southern soybean area averaged about 2 cultivations for all tillage systems. A smaller percentage of no-tilled acres were cultivated than for other tillage systems.

Table 4.1.6—Weed control cultivation by crop and tillage system in major producing States, 1990-93[1]

Item	Conv.		Conservation		
	With mbd. plow	W/out mbd. plow	Mulch till	No-till	Ridge till
Corn:					
Acreage cultivated	*Percent of planted acres*				
1990	74	73	69	29	97
1991	69	71	70	31	100
1992	76	77	78	32	100
1993	65	57	55	21	92
Average cultivations	*Number*				
1990	1.4	1.3	1.3	1.5	1.8
1991	1.3	1.3	1.2	1.3	1.7
1992	1.4	1.2	1.3	1.2	1.8
1993	1.3	1.2	1.2	1.2	1.7
Northern soybeans:					
Acreage cultivated	*Percent of row planted acres*				
1990	89	86	85	26	100
1991	87	83	87	15	84
1992	86	79	81	22	96
1993	74	62	63	13	66
Average cultivations	*Number*				
1990	1.6	1.6	1.4	1.5	1.8
1991	1.5	1.4	1.4	1.6	2.5
1992	1.5	1.3	1.3	1.5	1.4
1993	1.3	1.4	1.3	1.4	1.2
Southern soybeans:					
Acreage cultivated	*Percent of row planted acres*				
1990	79	75	60	11	nr
1991	71	74	43	16	nr
1992	78	75	45	10	nr
Average cultivations	*Number*				
1990	2.1	2.2	2.2	2.2	nr
1991	2.0	2.3	1.8	1.7	nr
1992	2.2	2.3	1.9	1.9	nr

nr = none reported.

[1] For the States included, see box "Cropping Practices Survey." For tillage system definitions, see box "Crop Residue Management System Definitions and Survey." For more detail, see appendix tables 4.1.6-4.1.8

Source: USDA, ERS, Cropping Practices Survey data.

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