Chapter 4.2 Soil Management and Conservation

Crop production depends largely on soil and is affected greatly by the quality of that soil. Soil quality also plays a role in the environmental effects of crop production. Traditional measures of soil quality include land capability and suitability, prime land, productivity, erodibility, and vulnerability to leach pesticides and nitrates. More comprehensive measures are needed that consider physical, chemical, and biological properties, and also economic factors. Soil management involves actions by land managers that affect soil quality and productivity and alter soil's effects on environmental quality. Examples of these actions include land use or cropping pattern, type and extent of tillage, amount of cover or residue left on the soil, and use of conservation buffers and structures.

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Why Manage Soil?

Soil, as a plant-growing medium, is the key resource in crop production. Soil supports the fundamental physical, chemical, and biological processes that must take place in order for plants to grow; it regulates water flow between infiltration, root-zone storage, deep percolation, and runoff; and it acts as a buffer between production inputs and the environment. Soil can also function as a "degrader" or "immobilizer" of agricultural chemicals, wastes, or other potential pollutants, and soil can mitigate climate change by sequestering carbon from the atmosphere (when the rate of organic matter production exceeds the rate of oxidation) (Kemper et al., 1997). How well soil performs these functions depends on soil quality.

A simple definition of soil quality is the capacity of soil to function (Karlen and Andrews, 2000). Soil quality refers to the attributes that characterize a particular soil. Important soil attributes are texture, structure, bulk density and rooting depth, permeability and water storage capacity, carbon content, organic matter and biological activity, pH, and electrical conductivity (National Research Council, 1993). Soil quality can be maintained or enhanced through the use of appropriate crop production technologies and related resource management systems. Inappropriate farming practices, on the other hand, can lead to soil degradation—loss of topsoil through erosion; loss of organic matter through oxidation; soil compaction; acidification; loss of nitrates, phosphorous, and pesticides; and accumulation of salts and trace elements. Inappropriate practices can also increase runoff of fertilizers and pesticides to surface and groundwater systems. Thus, soil degradation can have both direct and indirect negative effects on agricultural productivity and the environment. Even on high-quality soils, overuse of chemical inputs can result in soil toxicity and water pollution. Soil management, therefore, is an important component of all crop production systems because it can affect output levels as well as food quality and safety, environmental pollution, and global climate change.

Land and soil quality is not only important to agriculture but also to other plant and animal systems. These are all loosely defined as ecosystems, where agriculture is an agroecosystem. An ecosystem encompasses the functional links between soil, water, and air. Public concern about the environment has led to a changing concept of management from a single-resource, single-species management approach to multiple management approaches that involve the composition, structure, and function of entire ecosystems (CEQ, 1993). Soil quality can be defined as the capacity of soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health (Doran and Parkin, 1994). Similarly, the National Research Council (NRC) lists three functions of soil. The first is to provide the physical, chemical, and biological processes for plants to grow. The second is to store, regulate, and partition water flow through the environment. The third is to buffer environmental change by providing for the decomposition of organic wastes, nitrates, pesticides, and other substances that can become pollutants in water or air (NRC, 1993). The first function relates to the long-run maintenance of soil for crop production while the other two indicate the role of soil in maintaining environmental quality through the protection of water and air. Other researchers are expanding the emerging concepts of ecosystems and soil quality and their relationships to the environment (Björklund et al., 1999; Daily, Matson, and Vitousek, 1997; Daily et al., 1997; Groot, 1992).

How soil is managed also has significant offsite economic effects that are increasingly being evaluated and considered in policy and program decisionmaking (see Chapters 3.3, Wildlife Resources Conservation, and 6.4 Water Quality Programs, and Pretty et al., 2000).

Beneficial farm-level soil management practices are those designed to maintain the quality and long-term productivity of the soil and reduce potential environmental damages from crop production. These practices include rotational cropping, tillage and crop residue management, and various field/landscape scale engineering structures and buffer zones, e.g., grass waterways, terraces, contour-farming, strip-cropping, underground drainage outlets, and surface diversion and drainage channels. Also beneficial to soil are certain nutrient, pest, and irrigation practices (see Chapters 2.2, Irrigation Water Management, 4.3, Pest Management, and 4.4, Nutrient Management). For the most part, multiple practices in the right proportion must be used for best results, depending upon topographic and agro-climatic conditions. However, in any given context, the extent to which particular soil management technologies are carried out depends on site-specific technical, economic, and financial feasibility considerations, as well as farmer attitudes, perceptions, and resources. Also, to the extent that there are offsite negative impacts, land and soil management practices may be influenced by society's willingness or intolerance to accept those impacts (Ruhl, 2000).

Quality of Soils in U.S. Agriculture

Maintaining and improving the quality of the Nation's soils can increase farm productivity, minimize the use of nutrients and pesticides, improve water and air quality, and help sequester greenhouse gases. While the soil quality measures of land capability, productivity, and erodibility are well known, there is an increasing emphasis on measures, including economic measures, that incorporate dynamic soil properties more fully reflecting a soil's potential for long-term agricultural production without negative environmental impacts.

Developing economic measures of soil quality requires a better understanding of the multiple functions of soils and of the interaction between agricultural activities and soil quality. For example, productivity measures often reflect the private concerns surrounding soil quality. But other broader concerns, such as surface-water pollution from runoff, soil productivity for future generations, and the health of agricultural and rural ecosystems, may be of greater economic importance and need to be reflected in new measures of land and soil quality. Combining the many physical attributes of land and soil quality into meaningful indicators is difficult, as is assigning economic values to these indicators.

Traditional measures of quality

Land and soil quality has been viewed conceptually in two different ways (Jawson, 2001). First, there is the more traditional approach that focuses on inherent soil properties and the suitability of land for various uses such as crop production. Second, there is another more recent concept that focuses on the dynamic properties of soil and the effects of soil management. The former concept is more applicable for differentiating between soils while the latter is more useful for evaluating the effects of various practices on a particular soil (Karlen and Andrews, 2000; Karlen et al., 1997; Seybold et al., 1997). The term "soil quality" is used more often, but not always, to refer to the effects of soil management. The definitions used for soil quality, therefore, address the "capacity of the soil to function" (Doran and Parkin, 1994) or the "fitness for use" (Pierce and Larson, 1993; Acton and Gregorich, 1995; Jaenicke, 1998). These are dynamic concepts and relate to the influence of human use and management of soil. This concept is often termed soil health. The more traditional measurements of soil properties found in soil surveys (texture, structure, slope, color, etc.) focus on inherent properties of soil formation, which include vegetation and patent material (USDA, SCS, 1993).

Measures of soil quality such as capability and prime farmland are thought to reflect the inherent properties of soil in relation to crop production. Other soil quality criteria are needed for other uses of land. The potential capacity of a soil to function must be assessed before a soil's fitness for use can be measured (Mausbach, 1997). Measures of land and soil quality should also account for differences in scale, both spatial and temporal (Halvorson, Smith, and Papendick, 1997). Scale variation is important because soil quality changes over time and is different by region. To examine the relationships and services of land and soil in ecosystems, and of spatial and temporal differences, some researchers have explored other soil quality evaluation approaches. Gottfried, Wear, and Lee (1996) point out that no one evaluation approach may be suitable to achieve optimal land use. Söderbaum (1987) proposes "positional analysis" to replace conventional benefit-cost analysis. Some of the more traditional measures of land quality are discussed in the next six sections.

Land capability and suitability. Some measures of land quality are used to monitor the capability or suitability of land for a particular purpose, such as growing crops or trees, grazing animals, or nonagricultural uses. Data on two commonly used measures—land capability classes (LCC) and the prime farmland designation—have been collected in the National Resources Inventory (NRI), conducted by USDA's Natural Resources Conservation Service (NRCS) every 5 years (USDA, 1994, 1989b, and 2000). (See Appendix: Agricultural Resource Surveys and Data for a description of the NRI.)

Land capability classes (LCCs) range from I to VIII (USDA, 1973). Class I, about 7 percent of U.S. cropland, has no significant limitations for raising crops (table 4.2.1). Classes II and III make up just over three-fourths of U.S. cropland and are suited for cultivated crops but have limitations such as poor drainage, limited root zones, climatic restrictions, or erosion potential. Class IV is suitable for crops but only under selected cropping practices. Classes V, VI, and VII are best suited for pasture and range while Class VIII is suited only for wildlife habitat, recreation, and other nonagricultural uses (USDA, 1989a). Land capability classes I-III total 337 million acres, or 82 percent of U.S. cropland including land in the Conservation Reserve Program (CRP) but excluding Alaska (fig. 4.2.1, table 4.2.1).

Prime farmland. Another measure of land suitability is USDA prime farmland, which is based on physical and morphological soil characteristics such as depth of the water table in relation to the root zone, moisture-holding capacity, the degree of salinity, permeability, frequency of flooding, soil temperature, erodibility, and soil acidity. Land classified as prime farmland has the growing season, moisture supply, and soil quality needed to sustain high yields when treated and managed according to modern farming methods (USDA, 1989a). Prime farmland totals 222 million acres, or 54 percent of U.S. cropland, excluding Alaska (fig. 4.2.2, table 4.2.1).

These measures of land quality are often confused with the capability of land to produce economic returns. Land in capability classes I-III—prime farmland—does not necessarily have the highest value of crop production per acre (Vesterby and Krupa, 1993). Alternatively, lands earning high economic returns may not be classified as prime farmland or in LCC I-III. For example, prime and LCC are based on characteristics that reflect suitability for row crop production. Florida and Arizona have little prime farmland or land in LCC I-III, but these areas rank among the most economically productive in the Nation. (New irrigation will sometimes change a classification from nonprime to prime if other soil characteristics needed for a prime classification are present.)

Productivity. Soil productivity, which measures output per unit of input, is often the primary reason for monitoring soil erosion (or other degradation processes) and is itself a measure of soil quality. Productivity is often measured as crop yield per acre. Another indicator of land quality is the expected dollar returns per acre from production. Highest dollar values are in coastal areas where climate, soil, location, and irrigation favor production of high-value crops (fruits and vegetables), or where intensive livestock production takes place (fig. 4.2.3). The least productive lands, in terms of agricultural sales per acre, are in bands across the Northern and Central Plains. Productivity can reflect soil degradation if yields decline as soils become degraded and if input use increases to compensate for declines in soil quality. However, productivity may mask environmental or health components of soil quality; lands of poor physical quality (as measured by erosion, texture, and organic matter) can sometimes produce very high yields without large increases in input use (Vesterby and Krupa, 1993).

Erodibility. Highly erodible land (HEL) is a measure of soil quality of particular importance for USDA conservation policy (see Chapter 6.1, Conservation and Environmental Programs Overview). Because the estimated tons of wind- and water-eroded soil do not measure the erosion potential on particular soils, USDA uses the erodibility index (EI) to inventory and classify erosion potential and to determine conservation program eligibility. Highly erodible soils have the potential for erosion because of relatively unchanging physical

Table 4.2.1–Cropland and soil quality, selected measures, 1992 and 1997[1]

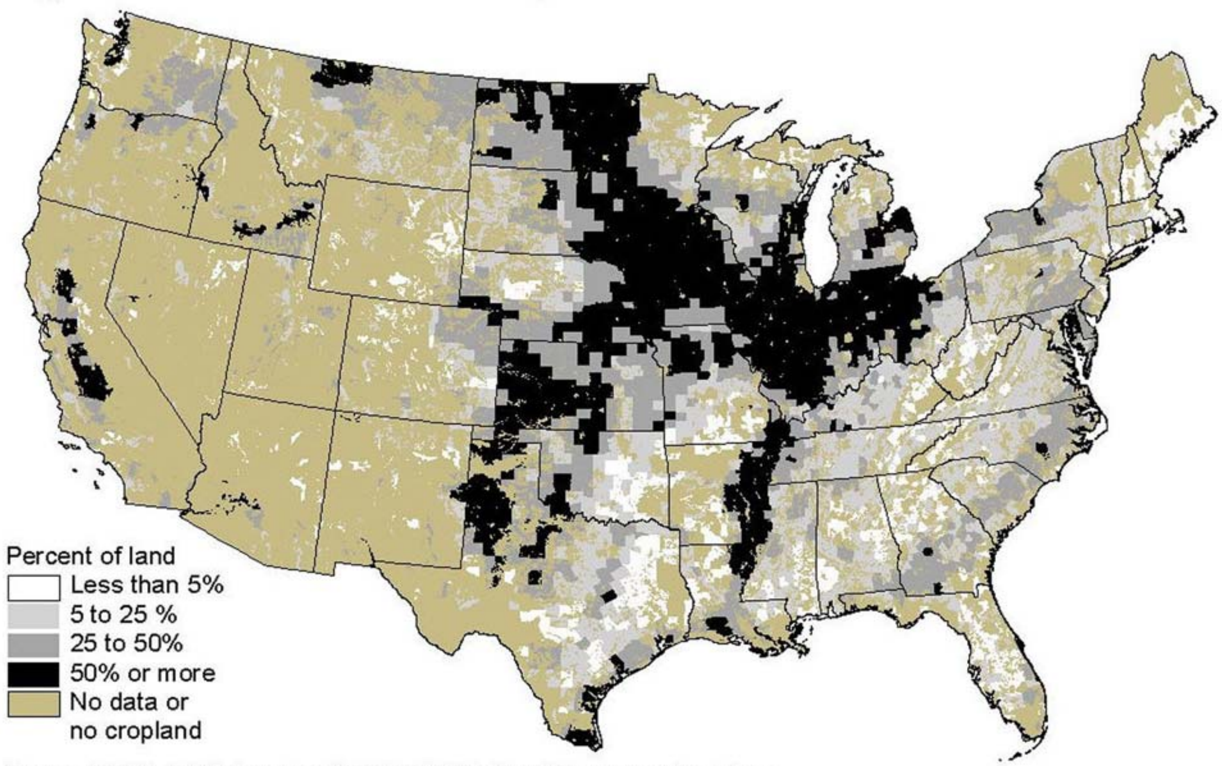
Measure	Cropland	CRP	Total	Cropland	CRP	Total
		1,000 acres			Percent of acres	
Land capability class in 1997						
I (highest land quality)	26,567	229	26,796	7	0.7	6.5
II	174,950	7,274	182,224	46.4	22.3	44.5
III	114,963	13,485	128,448	30.5	41.2	31.4
IV and above (lowest quality)	60,518	11,709	72,227	16.1	35.8	17.6
Total	376,998	32,697	409,695	100	100	100
Prime farmland in 1997	212,281	9,277	221,558	56.3	28.4	54.1
Erodibility in 1992:[2]						
Highly erodible from water only	51,924	na	na	13.5	na	na
Highly erodible from wind only	48,933	na	na	13	na	na
Highly erodible from both	3,516	na	na	0.9	na	na
Subtotal highly erodible	104,373	19,796	124,169	27.4	58.2	29.8
Not highly erodible	277,944	14,244	292,188	72.3	41.8	70.2
Total	382,317	34,040	416,357	100	100	100

[1]Includes cultivated and noncultivated cropland and land enrolled in the Conservation Reserve Program (CRP) in the contiguous States, Hawaii, and the U.S. Caribbean islands (less than 0.75 million acres).

[2]Highly erodible land has an erodibility index for sheet and rill erosion or for wind erosion of 8 or greater. Not available for 1997.

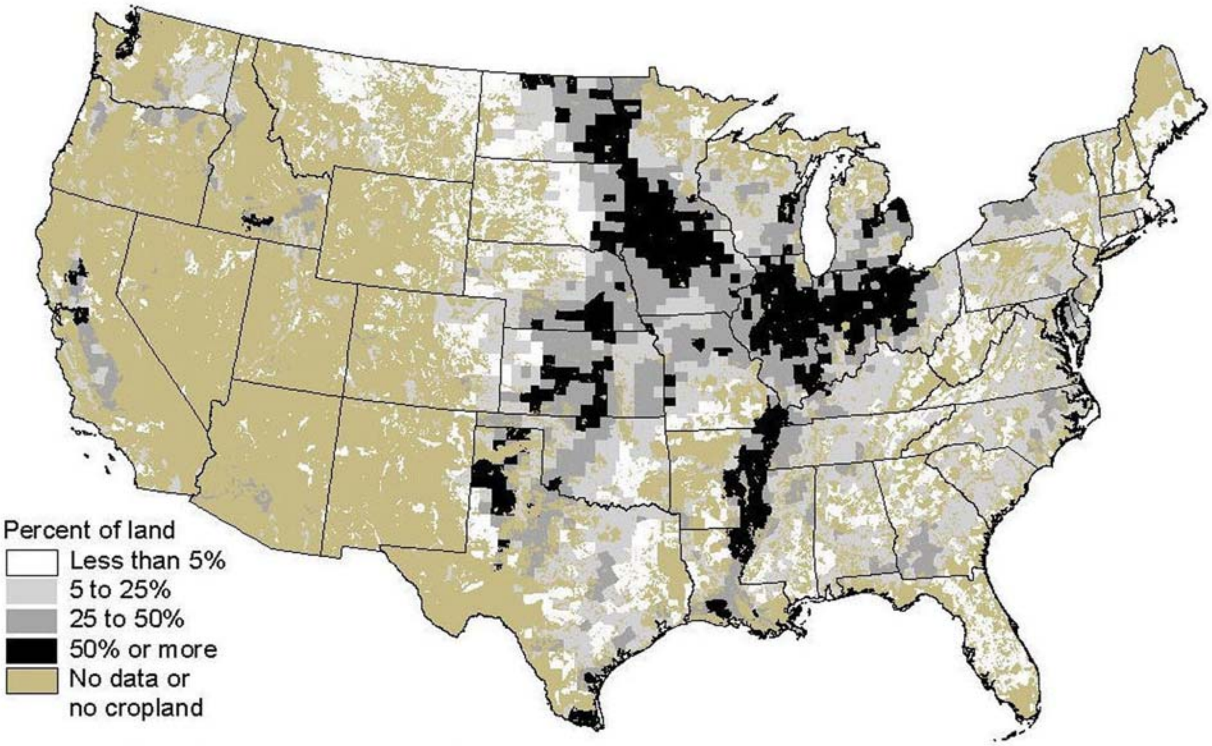
Source: USDA, ERS, based on NRCS 1992 and 1997 National Resources Inventory data

Figure 4.2.1 — Class I to III cropland distribution



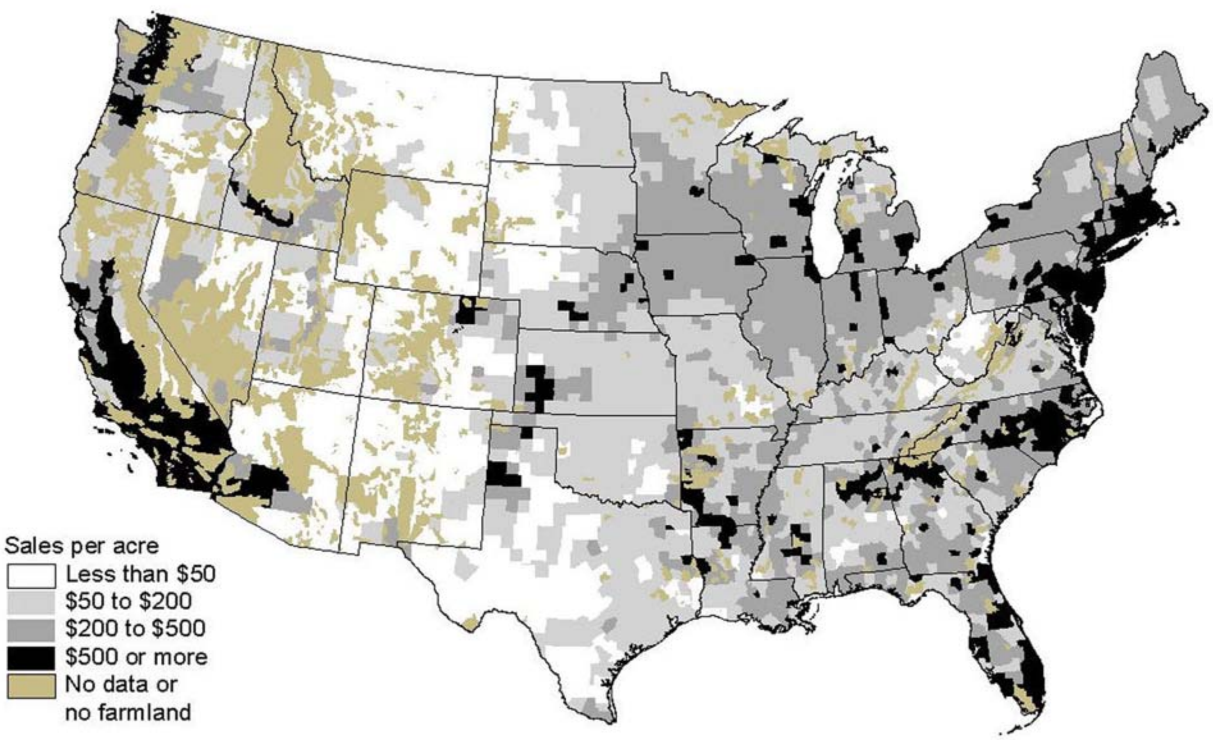
Source: USDA, ERS, based on NRCS 1997 National Resources Inventory

Figure 4.2.2 — Prime farmland distribution



Source: USDA, ERS, based on NRCS 1997 National Resources Inventory

Figure 4.2.3 — County average agricultural sales per acre of land in farms



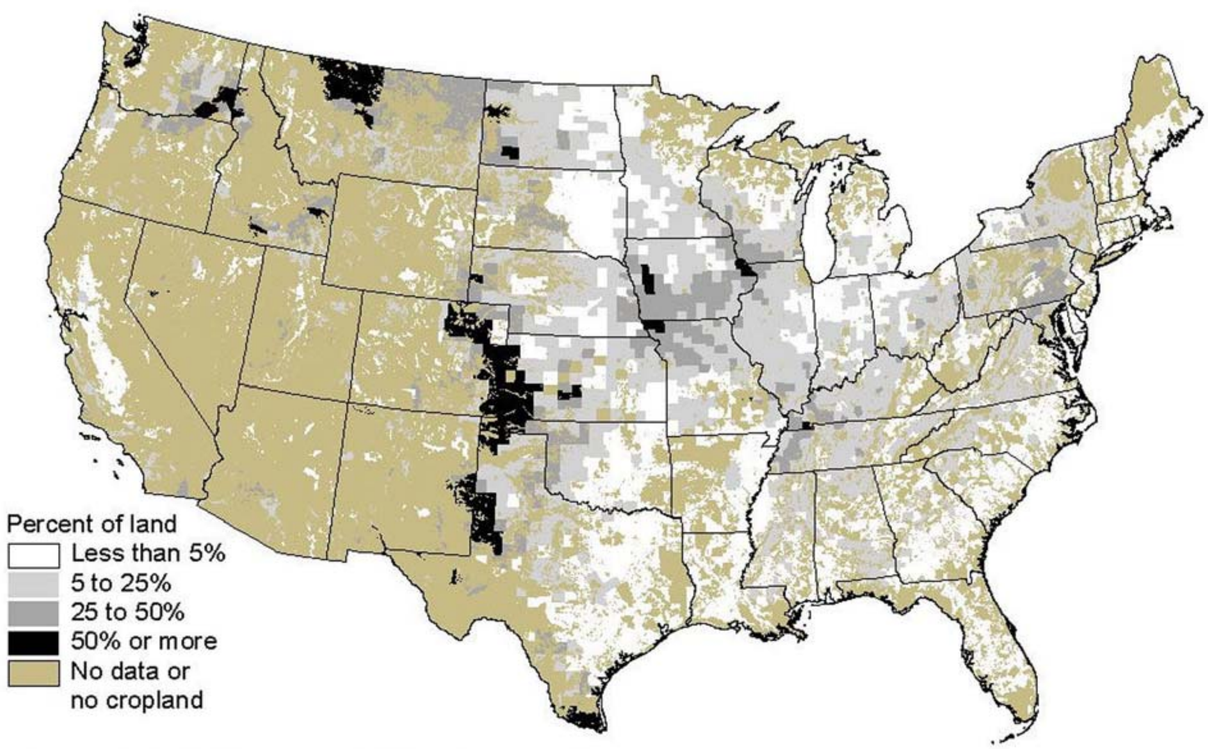
Source: USDA, NASS Census of Agriculture: total county sales of crops, livestock, and livestock products averaged over 1987, 1992, and 1997 Census years. Total farm sales reflect value of production from both cropland and grazing land, confined livestock and horticultural operations, access to markets, and availablility of irrigation water.

attributes. Associated with sheet and rill erosion are rainfall pattern, soil texture, and topography; associated with wind erosion are climatic and soil erodibility factors. Erosion rates can be reduced if hay or close-grown crops are grown, if tillage methods are used with appropriate crop residue management, and if conservation practices are employed. An assessment of erosion needs to consider both the physical potential for erosion and the erosion rate resulting from management choices.

Highly erodible lands are generally more vulnerable to soil quality problems, but soil may be productive if erosion is controlled. Eroding soils are usually considered to have lower quality than similar soils that are protected from erosion. Soil quality suffers on eroding soils, but simply controlling erosion does not necessarily translate to high-quality soils since compaction, acidity, salinization, and biological factors play a part in the quality of the soil (Mausbach, 1997).

The HEL determination is based on physical soil factors relating to sheet, rill and wind erosion. Soils are said to be highly erodible if the EI is greater than or equal to 8 ($EI \geq 8$). The EI is found by dividing the potential erosion (sheet and rill, or wind) by the soil-loss tolerance factor (T-level, the rate of soil erosion above which long-term soil productivity may be depleted) to reflect erosion potential relative to vulnerability to productivity loss (Heimlich and Bills, 1989; McCormack and Heimlich, 1985). USDA defines HEL as cropland with an erosion potential of at least eight times its T-level. According to the 1992 NRI, 124 million acres of cropland and CRP land are highly erodible from water, wind, or both (table 4.2.1). However, for purposes of administering the conservation compliance provision of the 1985, 1990, and 1996 Farm Acts (Nelson and Schertz, 1996), USDA's NRCS has classified 146 million acres as HEL. This includes some 22 million acres of other soils in fields that are primarily highly erodible soils (for more information see Chapter 6.4, Conservation Compliance). Highly erodible soils are found in all States (fig. 4.2.4).

Figure 4.2.4 — Highly erodible cropland, distribution



Source: USDA, ERS, based on NRCS 1997 National Resources Inventory

Erosion productivity loss. Another measure of productivity loss due to erosion converts total erosion from tons per acre per year to inches per year. The rate of expected soil loss in inches is divided into the topsoil depth (the "A" horizon) recorded in the Soil Interpretation Record (SOILS 5) (USDA, 1983). This is a measure of how many years it would take to remove the topsoil at the current rate of erosion (on the extreme assumption that all the eroded soil is removed from the field). Multiplying the inverse of this measure by the cash rental rate for cropland reflects the relative economic value of soil productivity loss due to erosion (USDA, 1997) (see box "Calculation of Erosion Productivity Loss"). Three factors are reflected in this measure: erosion rates, soil depth, and rental values of land. Low erosion rates on deep, long-lasting topsoil are given less weight, and highly productive (high rental rate) but vulnerable soils (thin topsoil, high erosion rate) are given more weight (fig. 4.2.5). This indicator shows five major concentrations of vulnerable soils; with the largest centered on Iowa, Illinois, and Missouri in the Corn Belt. This area's index values are largely driven by relatively high rental rates. While erosion rates are moderate in this area, the soil is more valuable relative to other regions such as the Plains States. A second concentration of vulnerable soils is in eastern North Dakota and western and south-central Minnesota. The third concentration is the eastern bluffs of the Mississippi River in western Kentucky, Tennessee, and along the eastern edge of the Mississippi Delta. A fourth concentration is the eastern edge of Colorado. The final concentration is a band of highly erodible and highly valued land in eastern Washington and Oregon around the Palouse and Central Plateau areas.

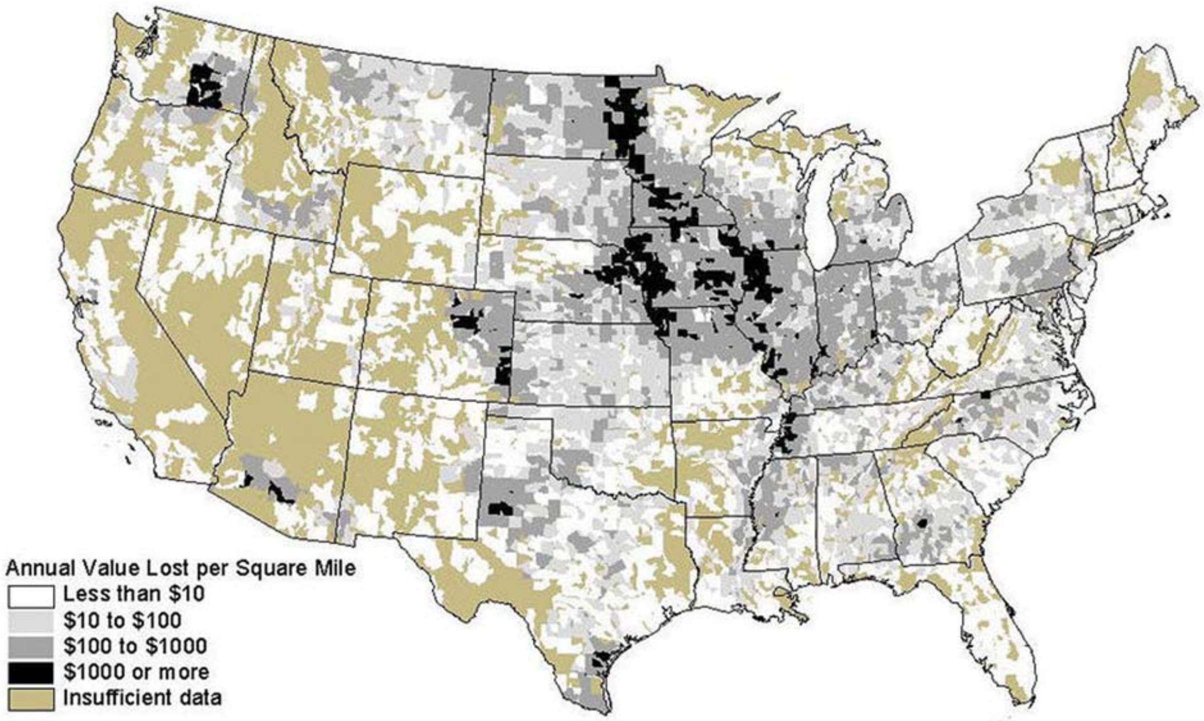
The major onsite effect of soil erosion is the impact on soil productivity. Research conducted in the 1980s has improved our understanding of the long-term relationship between erosion and productivity (AAEA, 1986). The 1987 Resources Conservation Appraisal (RCA) estimated that, under 1982 management conditions, agricultural productivity on the average would decline about 3 percent over the next 100 years due to soil erosion. Productivity loss would be concentrated on soils eroding at high tolerance values or on very fragile soils where even slight erosion can result in large declines in yields (USDA, 1989a). Soil erosion also contributes to off-farm damage when sediment enters streams, rivers, lakes, and other water bodies and damages municipal water systems, fills reservoirs and streams interfering with navigation, and contributes to flooding. The rate at which eroded soil enters water bodies is called the erosion/sediment delivery ratio and varies greatly depending on type of soil, slope, distance from water, and many other factors. Ribaudo (1986) estimated off-farm sediment damages at $2-$8 billion annually.

Vulnerability. Interest in soil erosion and its associated costs has been coupled with an increasing interest in the loss of nutrients, pesticides, and salts from farming systems to surface and ground water (National Research Council, 1993). For example, indices to assess the potential for groundwater contamination related to agricultural chemical use (Kellogg, Maizel, and Goss, 1992) incorporate variables that reflect the propensity of soils to leach pesticides and nitrates. The Ground Water Vulnerability Indices for Pesticides and Nitrogen are

Calculation of Erosion Productivity Loss

Erosion productivity loss (EPL) estimates in figure 4.2.5 take into account an erosion factor, depth of soil, and an economic factor. The formula is: ERL = (1/years of life) * rent. Years of life = inches of sheet, rill, and wind erosion per year/inches of topsoil in the "A" horizon. Rent = average rental rate for cropland in a specific county, based on U.S Census data. For example, suppose a soil is expected to erode at 0.1 inches per acre per year and the soil depth is 10 inches and the average rent is $20/acre. The soil would have 100 years of life. The erosion productivity loss is $20/100, or 20 cents/acre/year. Productivity loss is greater when soil depth is less, the erosion rate is greater, or average rent is higher.

Figure 4.2.5 — Distribution of annual value of soil lost to erosion



Source: USDA, ERS, based on NASS June Ag. Survey and NRCS 1997 National Resources Inventory data. Value is calculated as 1994-96 average rent divided by years of topsoil depth remaining at current erosion rates. Values for cropland soils with net losses are capitalized at a 7% discount rate and averaged over total area of each geographic unit to map the density of value lost.

functions of soil leaching potential, pesticide and nitrogen properties, precipitation, and chemical use. The Corn Belt, Southeast, and Lake States have large areas vulnerable to pesticide leaching and with high potential for nitrate leaching (see figs. 2.3.3 and 2.3.8 in Chapter 2.3, Water Quality Impacts of Agriculture).

Land capability classes, prime farmland, and highly erodible land designations are useful in determining how land might be used or the degree and location of erosion, but they are limited in that they exclude other important characteristics of soils and pertain mostly to cropland. Productivity measures, such as yields per acre, or profitability measures, such as cash rents, provide fairly direct indicators of the utility of land for production. Net income is another productivity measure for producers wishing to maximize the return on their land investments that can be used as an indicator of soil quality. But, such measures are limited to private interests and do not reflect the environmental vulnerability or degradation for alternative or future uses. Vulnerability indices are useful measures of potential environmental impacts and provide a needed link between soil characteristics and water quality. All these measures can provide policymakers and natural resource managers with information for beginning to design and target policies for resource management. But, as we broaden our understanding of land as a fundamental base for the environment, broader measures are needed to capture the multiple dimensions of soil and land quality.

Broadening the measures of soil quality

Among the first to suggest developing a broader concept of soil quality were Warkentin and Fletcher (1977). They stressed the importance of expanding the concept of soil definition to include more than just "pure soil." They noted that soil was being called upon for recycling and waste assimilation, aesthetics and leisure use, as well as food and fiber production. Larson and Pierce (1991) functionally defined soil quality and suggested ways to evaluate it with changes in management practices. Other researchers have expanded our knowledge of soil quality concepts and are developing methods of combining information on a variety of soil properties into soil quality indexes (Karlen and Andrews, 2000).

Instead of focusing on the capability to support specific activities, such as crop production, or a single soil degradation process, such as erosion or chemical leaching, researchers are focusing on how a broad range of physical, chemical, and biological properties determine soil quality. Physical properties include soil structure and aggregate stability, and wind and water erosion. Chemical properties include pH, total plant nutrients, and salinity. Biological properties include root microbial and other organism-driven processes such as respiration, mineralization, immobolization, and denitrification (Jawson, 2001).

Most definitions of soil quality include both environmental factors and measures of crop productivity. For example, soil quality has been defined as the ability of a soil to produce safe and nutritious crops in a sustained manner over the long term and to enhance human and animal health without impairing the natural resources base or harming the environment (Parr et al., 1992). Similarly, soil quality can be defined as the sustaining capacity of a soil to accept, store, and recycle water, minerals, and energy for production of crops at optimum levels while preserving a healthy environment (Arshad and Coen, 1992). The NRC (1993) recommends that the concept of soil quality should be the principle guiding the recommendations for use of conservation practices and the targeting of programs and resources. Currently, conservation compliance plans rely primarily on one soil quality indicator—soil erosion potential as measured by the EI.

A soil's quality is determined by many static and dynamic properties such as soil depth, water-holding capacity, bulk density, nutrient availability, organic matter, microbial biomass, carbon and nitrogen content, soil structure, water infiltration, and crop yield. Because of the correlation among these properties, a few key attributes can be selected as soil quality indicators (Olson, 1992; Hornsby and Brown, 1992; Alexander and McLaughlin, 1992; and Arshad and Coen, 1992). Parr et al. (1992) suggest a soil quality index that includes such factors as soil properties, productivity potential, environmental factors, health (human/animal), erodibility, biological diversity, food quality/safety, and management inputs. Many of these factors, such as food quality or biological diversity, are complex indicators themselves but may be important contributors to the full breadth of soil quality. And while the components of soil quality appear quite complex, some soil properties can be estimated without collecting detailed information of attributes. For example, Larson and Stewart (1992) use crop residue data and a simple regression model to estimate changes in soil organic matter for several U.S. soils.

Maintaining and improving soil quality

Soil quality is a function of many factors, including agroclimatic factors, hydrogeology, and cropping/production practices. Soil quality can be degraded through three processes: (1) physical degradation such as wind and water erosion and compaction; (2) chemical degradation such as toxification, salinization, and acidification; and (3) biological degradation, which includes declines in organic matter, carbon, and the activity and diversity of soil fauna (NRC, 1993). Slowing down or stopping these processes will help maintain soil quality. Reversing the processes will improve soil quality over time.

Physical degradation. Indicators of physical soil properties include bulk density, porosity, structure, roughness, and aggregate characteristics or soil tilth (Karlen et al., 1992). Erosion has long been considered the major agent of soil degradation worldwide (NRC, 1993). Another form of soil degradation is compaction, typically caused by heavy machinery and cattle trampling. Soil texture, compactive effort, soil moisture, and soil mineralogy are determining factors of vulnerability to compaction (Lewis, 2001). Compaction can make tillage costly, impede the emergence of seedlings, and decrease water infiltration, causing higher runoff of rainwater and increasing water erosion (World Resources Institute, 1992). Oskoui and Voorhees (1991) examined the effects of soil compaction on yield loss, energy costs, capital costs, timeliness costs, air pollution costs, and erosion costs. They estimated that the increased fuel cost due to compacted soil, alone, could be as high as $5.70/hectare ($2.31/acre).

Chemical degradation. While salinity problems are often associated with irrigation, they can also occur in dryland areas where rainfall is insufficient to leach salts from the soil. More than 48 million acres of cropland and pastureland are affected by varying degrees of salinity (USDA, 1989a). Irrigated areas are particularly subject to salinization because irrigation water contains dissolved salts, which become more concentrated in the soil as water is consumed by crops or lost by evaporation (USDA, 1989a). Crops such as corn, soybeans, rice, and some fruits and vegetables are quite sensitive to salinity and an increase in salinity can lead to a significant yield reduction.

Acidification, another chemical degradation process, can occur when bases (such as calcium, magnesium, potassium, and sodium) are leached from the soil. Aluminum toxicity is often a problem in acid soils, causing shallow rooting and susceptibility to drought (Foy et al., 1999). Pesticide toxicity also affects soil quality (NRC, 1993). Sorption rates and persistence, measured in half-life, determine pesticide impacts (Rao and Hornsby, 1989). Highly persistent pesticides are more subject to leaching and runoff, causing water quality problems (see Chapter 2.3 Water Quality Impacts of Agriculture). Pesticide toxicity effects are complex, but in general, higher quality soils tend to be more efficient at degrading pesticides through chemical and biological processes (NRC, 1993). Acidity may be reduced by the application of basic material, such as limestone. Acidic soil conditions can limit plant growth by supplying insufficient calcium or magnesium, altering the decomposition rates of organic matter, and reducing the amount of nitrogen fixed by legumes (NRC, 1993).

Biological degradation. Biological degradation affects the health of the soil and organic matter, which affects the physical and chemical properties of soils (NRC, 1993). Currently, little is known about how agricultural activities change a soil's biological properties, and what the potential cost is to the food and fiber system. A small fraction of the microbial portion of the soil has been isolated and characterized. It is estimated that less than 1 percent of all bacterial species are presently known and there may be up to 1 million different species on earth (ASM, 1994). The number of bacterial species in a gram of soil may exceed 10,000 (Torsvik and Daae, 1990).

Soil organisms contribute to the maintenance of soil quality and control many key processes such as decomposition of plant residue and organic material, nitrogen fixation, and nutrient availability (Kennedy and Papendick, 1995). Biological degradation is important because if the soil's food web is disrupted, the soil may not be able to cycle nutrients and transform harmful chemicals or substances to nontoxic waste or to combat plant pests and diseases (Mausbach, 1997). The assessment of soil health is thus important in determining the sustainability of land management systems (Doran, Sarrantonio, and Janke, 1996).

The microbial community is continually adapting to the environment, and can function as an indicator of changes in soil quality. Methods to assess soil microbial status need to be explored as indicators to further define and measure soil quality. Microbial populations can provide evidence of subtle changes in soil before organic matter or other parameters can measure it (Kennedy and Papendick, 1995).

NRCS has recognized the importance of soil quality and has established the Soil Quality Institute to acquire and develop soil quality technology. In addition, many Federal programs address specific soil quality factors such as wind and water erosion and nutrient loss (see Chapter 6.1, Overview of Conservation Programs and Expenditures). USDA programs and other research are directed at conducting research on the relationship between farming practices and soil quality, developing new technologies and practices that conserve and protect soil resources, providing technical and financial assistance to adopt soil conserving practices, and protecting farmland through land retirement and conservation easements.

Government conservation programs and farmers' increased use of soil management and conservation practices have substantially reduced erosion and induced degradation of soil quality. In 1997, cropland sheet, rill, and wind erosion together averaged 5 tons/acre/year, down 44 percent from the late 1930s and 32 percent from 1982 (table 4.2.2). At the same time there has been a drop in cropland eroding above the tolerance level where it can lose productivity. In 1997, only 17 percent of cropland was above the tolerance level for sheet and rill erosion, down from 24 percent in 1982 (table 4.2.3). A similar drop also occurred in cropland with wind erosion above the tolerance level.

The following sections address conservation management systems that help maintain and improve the soil resource, bringing about multiple societal benefits such as cleaner water, cleaner air, and improved wildlife habitat.

Farmers' Use of Rotational Cropping Systems

Cropping systems which involve a rotation of crops (see box, "Cropping Pattern Definitions") can play significant roles in conserving soil, maintaining soil fertility, controlling pests, and reducing agriculture's

Cropping Pattern Definitions

The following definitions were applied to 3-year crop sequence data reported in the Cropping Practices and Agricultural Management Study surveys to identify a cropping pattern for each sample field. The data were limited to the current year's crop plus the crops planted the previous 2 years on the sample field.

Monoculture or continuous same crop—A crop sequence where the same crop is planted for 3 consecutive years. Small grains (wheat, oats, barley, flax, rye, etc.) or other close-grown crops may be planted in the fall as a cover crop. The rotation excludes soybeans double-cropped with winter wheat.

Corn/soybean rotation—A crop sequence that alternates between corn and soybeans.

Other row crops in rotation—A crop sequence, excluding continuous same crop, where only row crops (corn, sorghum, soybeans, cotton, peanuts, vegetables, etc.) are planted for 3 consecutive years. Small grains or close-grown crops may be planted in the fall as a cover crop.

Row crop/small grain rotation—A crop sequence where some combination of row crops and small grains are planted over the 3-year period. The rotation excludes soybeans double-cropped with winter wheat.

Rotation with meadow crops—A crop sequence that includes hay, pasture, or other use in 1 or more previous years. The rotation excludes any of the above rotations and any area that was idle or fallow in one of the previous years.

Idle or fallow in rotation—A crop sequence that includes idle, diverted, or fallowed land in 1 or more of the previous years.

Double-cropped soybeans and wheat—A crop sequence, limited to soybean and wheat acreage, where winter wheat is planted the previous fall, harvested the following summer, and then soybeans seeded and harvested.

Table 4.2.2—Estimated acreage and erosion in the contiguous United States, selected years, 1938-97

Item	1938	1967	1977	1982	1987	1992	1997
				Million acres			
Acreage:							
Cropland and CRP combined	398.8[1]	438.2	413.3	421	406.6	382.3	377
CRP land	-	-	-	-	3.8	34	32.7
Pasture	na	na	na	131.9	127.6	125.9	120
Range	na	na	na	408.9	402.8	398.9	406
Total erosion:				Billion tons/year			
Cropland and CRP combined–							
Sheet and rill	na	2.60[2]	1.93	1.69	1.52	1.21	1.06
Wind	na	na	na	1.38	1.4	0.95	0.84
Pasture–							
Sheet and rill[3]	na	na	na	1.45	1.28	1.26	1.08
Wind[3]	na	na	na	0.13	0.13	0.13	0.12
Range–							
Sheet and rill[3]	na	na	na	0.49	0.48	0.48	na
Wind[3]	na	na	na	1.92	1.77	1.76	na
Total cropland, pasture, range	na	na	na	7.12	6.46	5.76	na
Erosion per acre:				Tons/acre/year			
Cropland							
Sheet and rill	na	5.9	4.7	4	3.7	3.1	2.8
Wind	na	na	5.3	3.3	3.2	2.4	2.2
Subtotal	8.9[4]	na	na	7.3	6.9	5.5	5
CRP–							
Sheet and rill	-	-	-	-	2	0.6	0.4
Wind	-	-	-	-	6.8	0.7	0.3
Subtotal	-	-	-	-	8.8	1.3	0.7
Pasture–							
Sheet and rill	na	na	na	1.1	1	1	0.9
Wind	na	na	na	0.1	0.1	0.1	0.1
Range–							
Sheet and rill	na	na	na	1.2	1.2	1.2	na
Wind	na	na	na	4.7	4.4	4.4	na

na = not available.
[1] Based on 1939 census estimate of cropland.
[2] Kimberlin (1976), based on 1967 Conservation Needs Inventory.
[3] Based on multiplying published per acre erosion estimates times acreage.
[4] Based on dividing sum of sheet, rill, and wind erosion by total U.S. cropland acres.
Source: USDA, ERS, based on NRCS' National Resources Inventories of 1977, 1982, 1987, 1992, and 1997, except as noted.

negative effects on the environment. For example, row crops on erosive soils can be rotated with soil-conserving crops to reduce average annual loss of soil. Closely sown field grain crops such as wheat, barley, and oats, as well as hay and forage crops, provide additional vegetative cover to reduce soil erosion and add organic matter. In addition, these crops also compete with broadleaf weeds and may help control the weed infestation in subsequent crops since they are usually harvested before weeds reach maturity and produce seed.

Table 4.2.3—Changes in cropland eroding above and below the tolerance level, 1982-97

Erosion level relative to tolerance (T)	1982	1987	1992	1997	1982	1987	1992	1997
	Cropland area (million acres) [1]				Percent of cropland area[1]			
Sheet and rill erosion								
T level or less	319	316	310	312	76	78	81	83
Between T and 2T	54	49	42	40	13	12	11	11
Between 2Tand 3T	19	17	14	12	4	4	4	3
Over 3T	29	25	16	13	7	6	4	3
Total U.S.	421	407	382	377	100	100	100	100
Wind erosion								
T level or less	343	329	329	329	82	81	86	87
Between T and 2T	35	36	25	23	8	9	7	6
Between 2Tand 3T	18	17	11	10	4	4	3	3
Over 3T	25	25	15	15	6	6	4	4
Total U.S.	421	407	382	377	100	100	100	100

[1] Includes cultivated and noncultivated cropland. Estimates for 1987-97 exclude land in the Conservation Reserve Program, most of which had erosion below the T level in 1997 with conservation cover in place.
Source: USDA, ERS, based on NRCS National Resources Inventory data as reported in the 1997 Summary Report (revised December 2000).

Table 4.2.4—Cropping patterns on land in major field crops, major producing States, 1999 or latest year available

Cropping pattern	Corn in 1999	Soybeans in 1999	Cotton in 1999	Peanuts in 1999	Sunflowers in 1999	Winter wheat in 1998	Potatoes in 1997
	(15 States)	(17 States)	(10 States)	(4 States)	(3 States)	(18 States)	(3 States)
	Percent of total crop						
No rotation:							
Continuous same crop	16	8	61	-	-	38	2
Rotation with:							
Corn/soybeans	59	58	na	na	na	na	na
Other row crops	10	15	31	80	7	na	13
Wheat/soybeans double crop	na	6	na	na	na	2	na
Other row crops and small grains	2	6	2	1	72	31	45
Meadow	6	1	1	3	1	2	3
Fallow or idle	7	6	5	16	20	18	37
Other small grains	na	na	na	na	na	9	na
Subtotal rotation	84	92	39	100	100	62	98
Total	100	100	100	100	100	100	100
Fall cover crop	2	6	8	28	2	na	nd

na = not applicable. - = less than 0.5 percent. nd = no data
Source: USDA, ERS, 1998 and 1999 Agricultural Resource Management Study (ARMS) surveys.

Rotating crops helps break disease and insect cycles. Cover crops planted in the fall help reduce erosion from winter and spring storms, hold nutrients that might otherwise be lost, and increase carbon sequestration. Leguminous crops increase nitrogen levels in the soil.

This section reviews the extent to which farmers use rotational cropping and cover crops of various types, and how economic factors and policies and programs affect that use.

Extent of rotational cropping

Rotational cropping in some form dominates major crop production in the United States, with the exception of cotton (39 percent, table 4.2.4). In major growing States, 98 percent or more of peanut, sunflower, and potato acreage is in rotations, with soybeans and corn slightly lower at 92 and 84 percent, respectively.

Most rotational cropping of corn and soybeans is with each other, whereas that of cotton and peanuts is with other row crops. Row crop rotations help in disease control but are generally less soil-conserving than rotations that include small grains or meadow or hay crops. Only 4-8 percent of corn, soybean, cotton, or peanut acreage in 1999 was rotated with small grains or meadow.

Farmers rotate corn and soybeans on around 60 percent of the acreage in these crops. Because the corn crop leaves more residue after harvest than soybeans, a corn/soybean rotation reduces erosion more than does continuous soybeans, but less than continuous corn. A corn/soybean rotation has other advantages. It aids disease control on the corn and soybeans, while the soybeans fix nitrogen for use by the subsequent corn crop.

Winter wheat was rotated with a row crop and another small grain on 40 percent of the acreage in 1998. About one-fifth of winter wheat was rotated with fallow, using fallow to conserve moisture and reduce disease for the subsequent wheat crop. Two percent of winter wheat was double cropped with soybeans, a common practice in some Southern States.

About three-fourths of the sunflower acreage in 1999 and 45 percent of the potatoes in 1997 were in rotation with other row crops and small grains. An additional 1-6 percent of these crops was rotated with meadow or hay crops.

Trends in rotational cropping

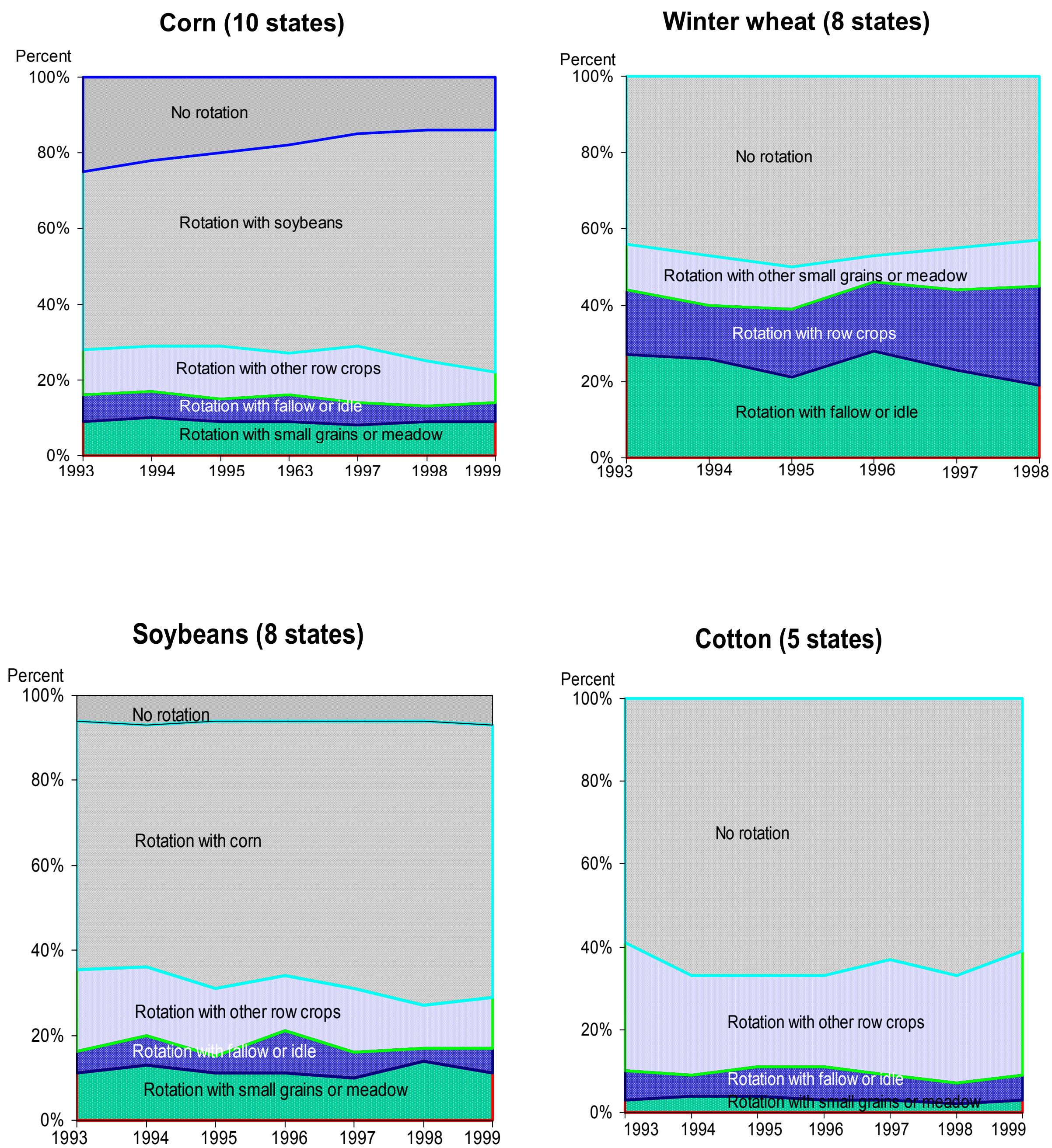
Rotating corn with other crops, particularly soybeans, has increased, based on time-series data available for major growing States (fig. 4.2.6). The increase for corn comes from greater rotation with soybeans. Corn farmers in 10 major corn growing States reported a corn/soybean rotation on 64 percent of the corn acreage in 1999, up from 47 percent in 1993. Rotational cropping of cotton in 1999 was up slightly from 1993.

Some shifts among rotational patterns are also noticeable for soybeans and winter wheat. Since 1993, relatively more soybean acreage in the eight major growing States is in rotation with corn while less is being rotated with other row crops. For winter wheat, the shift is toward more rotation with row crops and less rotation with fallow.

Use of cover crops

A cover crop of small grains, meadow, or hay planted in the fall after harvest of a row crop provides vegetative cover to reduce soil loss, hold nutrients, add organic matter to the soil, and sequester carbon. Except for winter wheat, the cover crop is usually not harvested, but is sometimes grazed by livestock. The highest relative use of

Figure 4.2.6--Trends in rotational cropping, 1993-99



Source: USDA, ERS, Cropping Practice Survey, 1993-95, and ARMS Surveys 1995-99 cover crops in major growing States occurred prior to planting peanuts, with over 28 percent of 1999 acreage benefiting from a 1998 fall planted cover crop (table 4.2.4). Prior cover crops also benefited 8 percent of cotton, 6 percent of soybean (mostly winter wheat/soybean double cropping), and 2 percent of corn and sunflower acreage. No data are available on cover crop planting prior to potatoes.

Economic factors affecting rotational cropping

The primary factor determining farmers' choice of a cropping pattern is the relative rate of return resulting from differences in yields, costs and returns, and government policy. Research shows higher yields usually result from crop rotations compared with those achieved with continuous cropping under similar conditions (Heichel, 1987; Power, 1987). Yields following legumes are often 10 to 20 percent higher than continuous grain regardless of the amount of fertilizer applied (NRC, 1989). Corn yields reported by farmers surveyed by USDA in 1990-96 averaged 4-18 bushels per acre higher on dryland in a corn-soybean rotation than on dryland in continuous corn (table 4.2.5). Corn following wheat, which is not a legume,

Table 4.2.5—Yields, costs, and returns to corn by cropping pattern and region, 1996

Region and cropping pattern	Average yield per acre	Average price per bushel	Gross receipts	Pre-harvest cost per acre	Returns above preharvest costs	Difference in returns
	1990-96	1996 [2]	1996 [3]	1996 [4]	1996	
	Bushels [1]		Dollars/acre			Percent
Dryland Areas						
Eastern Corn Belt						
Corn-corn	129	2.71	350	169	181	
Corn-soybean rotation	138	2.71	374	164	210	
Rotation effect	9		24	-5	29	16
Western Corn Belt						
Corn-corn	124	2.71	336	167	169	
Corn-soybean rotation	130	2.71	352	146	206	
Rotation effect	6		16	-21	37	22
Lake States						
Corn-corn	115	2.71	312	150	162	
Corn-soybean rotation	119	2.71	322	152	170	
Rotation effect	4		10	2	8	5
Plains States						
Corn-corn	82	2.71	222	121	101	
Corn-soybean	100	2.71	271	118	153	
Rotation effect	18		49	-3	52	51
Irrigated Areas						
Plains States						
Corn-corn	146	2.71	396	248	148	
Corn-soybean rotation	146	2.71	396	232	164	
Rotation effect	0		0	-16	16	11

[1] Estimated from Cropping Practices Surveys for 1990-96, see McBride (1999).
[2] U.S. average price, marketing year Sept. 1996-Aug. 1997.
[3] Average yield times the 1996 average U.S. price of $2.71 bushel.
[4] Estimated from the 1996 ARMS, see McBride (1999). Includes the pre-harvest costs of seed, fertilizer, chemicals, energy, labor, and capital.
Source: USDA, ERS, see table footnotes above.

produces greater yield than continuous corn when the same amount of fertilizer is applied (Power, 1987). Rotations that add organic matter can improve soil tilth and water-holding capacity, and in turn crop yields.

Crop rotations with legumes can reduce costs by increasing available soil nitrogen and reducing the need for commercial fertilizers. For example, a corn rotation with soybeans (a nitrogen-fixing legume) helps fix atmospheric nitrogen into nitrogen compounds, which become available for plant nutrition, thereby lessening the need for commercial fertilizer. Although most corn received commercial nitrogen applications in 1997, about 14 percent less nitrogen per treated acre was used on corn that was in rotation (mostly with soybeans) than on land in continuous corn (table 4.2.6). Finally, all rotations promote diversification and can provide an economic buffer against fluctuating prices of crops and production inputs and against the vagaries of weather, disease, and pest infestations.

Table 4.2.6—Chemical use under continuous same crop versus crop rotation, major producing States, 1997

Item	Corn (10 States)		Soybeans (19 States)		Cotton (12 States)		All wheat (16 States)	
	Continuous [1]	Rotation	Continuous	Rotation	Continuous	Rotation	Continuous	Rotation
Planted acres (million)	9.3	52.8	5.6	60.6	7.9	5.2	18.4	34.6
Percent	15	85	8	92	60	40	35	65
Acres treated with:			Percent of planted acres					
Nitrogen	98	99	13	20	86	95	85	86
Phosphate	84	83	22	28	64	76	53	68
Herbicides	97	97	96	98	95	99	40	75
Insecticides	69	24	2	2	75	81	10	1
Average application rate for:			Pounds of active ingredient per treated acre					
Nitrogen	147	127	16	22	84	84	65	67
Phosphate	37	62	40	51	45	47	31	33
Herbicides	2.4	2.9	1.3	1.3	2.4	2.3	0.3	0.7
Insecticides	0.7	0.7	0.4	0.5	2	1.4	0.4	0.4

[1] Continuous same crop.

Source: USDA, ERS, based on 1997 ARMS data. For the States included, see box on ARMS Survey.

Crop rotations can also reduce costs by helping control insects and diseases, particularly pests that attack plant roots (Brust and Stinner, 1991). Crop rotations aid in insect management by replacing a susceptible crop with a nonhost crop, thus disrupting pest cycles. For example, rotating corn with soybeans can reduce the number of corn rootworm larvae in the soil (although the effectiveness of this practice may be decreasing in some areas) and the need for insecticide treatment when in corn. In 1997, for example, only 24 percent of the corn acreage in rotations received insecticide treatments, compared with 69 percent of continuous corn (table 4.2.6). Cotton in rotation received 30 percent fewer pounds of insecticide per acre than did continuous cotton. Farmers treated only 1 percent of wheat in rotation with insecticide compared with 10 percent of continuous wheat. However, rotating wheat with row crops increases weed problems when in wheat. In 1997, three-fourths of wheat acreage in rotation was treated with herbicides compared with 40 percent of continuous wheat, and the average application per treated acre was also higher.

When corn is in rotation, especially with soybeans, higher average yields and lower chemical use result in higher average returns above pre-harvest cost compared with continuous corn. In 1996 returns to corn averaged 5 to 51 percent higher, depending on the region, when in rotation with soybeans than in continuous corn (table 4.2.5).

Similar results were found in Iowa, where corn-soybeans-corn yielded $40 per acre more than continuous corn (Duffy, 1996).

Regional differences such as climate, rainfall, and other conditions can affect farmers' decisions to rotate crops. Legumes in a rotation are most effective in humid and subhumid climates where they don't decrease sub-soil moisture for subsequent crops (Meisenbach, 1983; NRC,1989).

Policies and programs affecting cropping pattern use

Federal Government agricultural policies influence farmers' selection of crops and choice of management practices. Past commodity programs that restricted base acreage to one or two crops encouraged monoculture or continuous planting of the same crop. To reduce this effect, the 1990 Farm Act eliminated deficiency payments on 15 percent of participating crop base acres known as Normal Flex Acreage (NFA), regardless of the crop planted on them (with exception of dry beans and a few fruits and vegetables). As a result, many farmers "flexed" (shifted) out of monoculture or idled the marginal acreage. The extent of flexing out varied by type of crop base, depending on expected relative economic return. For example, oats appeared to be the least profitable program crop during 1991-94 as almost half of its NFA was flexed to another crop. The 1996 Farm Act allowed 100 percent flexing, with a few exceptions, and eliminated set-aside requirements. This allowed farmers to shift land previously dedicated to corn or cotton into other crops (usually soybeans) or rotations with other crops in response to changes in prices and loan deficiency payments (Lin et al., 2000).

Under the 1985 and subsequent Farm Acts, highly erodible land (HEL) used for crops required implementation of a conservation plan in order to be eligible for USDA farm program benefits (see Chapter 6.3, Conservation Compliance, for more detail). Rotating the more erosive row crops with less erosive crops such as small grains and hay or pasture, is a key part of some conservation plans for HEL, usually in combination with crop residue use and conservation tillage (see table 6.3.3 in Chapter 6.3, Conservation Compliance). In major corn-growing States, rotations of corn with small grains, hay, or pasture were more prevalent on HEL (13 percent) than on non-HEL (6 percent) in 1997 (table 4.2.7). Such greater frequencies were not apparent for other major crops. More winter and spring wheat on HEL was in a rotation with fallow or idle (32 and 60 percent, respectively) than on non-HEL (17-19 percent), probably reflecting moisture conservation needs more than soil conservation.

Farmers' Use of Crop Residue Management

Crop residue management (CRM) maintains additional crop residue on the soil surface through fewer and/or less intensive tillage operations. CRM is generally cost-effective in protecting soil and water resources and can lead to higher farm economic returns by reducing fuel, machinery, and labor costs while maintaining or increasing crop yields. CRM systems include reduced tillage, conservation tillage (no-till, ridge-till, and mulch-till), and the use of cover crops and other conservation practices that leave sufficient residue to protect the soil surface from the erosive effects of wind and water (see box, "Crop Residue Management and Tillage Definitions"). This section discusses reasons for managing residue on the soil surface, describes extent of CRM use, and reviews economic, policy, and other factors that affect CRM adoption.

Why manage residue?

Historically, crop residues were removed from farm fields for livestock bedding and feed. Any residues that remained on the soil surface after harvest were burned off to control pests, plowed under, or tilled into the soil. Culturally, some farmers take pride in having their fields "clean" of residue and intensively tilled to obtain a smooth surface in preparation for planting. More recently, farmers have adopted CRM practices—with

Table 4.2.7—Cropping patterns on HEL and non-HEL, major producing States, 1997

Category	Corn (10 States)	Soybeans (19 States)	Cotton (12 States)	Winter wheat (14 States)	Spring wheat (4 States)	Durum wheat (ND)	Total 6 crops
Planted acres (1,000) [1]	62,150	66,215	13,080	35,065	18,100	2,700	197,310
Erodibility:				Percent of planted acres			
Highly erodible land (HEL)	20	17	22	33	23	22	22
Non-HEL	80	83	78	67	77	78	78
Total	100	100	100	100	100	100	100
Three-year crop sequence on HEL:				*Percent of HEL planted acres*			
Continuous same crop	20	3	64	22	Id	id	16
Continuous row crops	61	74	29	na	na	na	40
Continuous small grains	na	na	na	14	32	6	8
Row crop/small grains [2]	2	8	2	28	7	2	11
Idle or fallow in rotation	6	12	2	32	60	32	20
Hay/other crop rotations	11	2	3	4	1	id	5
Total HEL	100	100	100	100	100	100	100
Three-year crop sequence on non-HEL:				Percent of non-HEL planted acres			
Continuous same crop	14	10	61	48	id	id	19
Continuous row crops	74	68	31	na	na	na	51
Continuous small grains	na	na	a	6	41	59	5
Row crop/small grains [2]	2	14	1	8	37	4	13
Idle or fallow in rotation	6	6	6	17	19	37	9
Hay/other crop rotations	4	2	1	1	3	id	3
Total non-HEL	100	100	100	100	100	100	100

na = not applicable. id = insufficient data. Percentages may not add to 100 due to rounding.
[1] For the States included, see box on “ARMS Survey.”
[2] Includes double-cropped with wheat or soybeans.
Source: USDA, ERS, based on 1997 ARMS data.

government encouragement—because of new knowledge about the benefits of leaving greater residue on the soil surface and the advent of improved planters, chemical weed control, etc. CRM can benefit society through an improved environment, and 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. Public and private interests support cooperative efforts to address the barriers to realizing greater benefits from CRM practices. For example, recent advances in planting equipment permit seeding new crops through heavier surface residue into untilled soil and even directly into killed sod. Major benefits of CRM can include the following:

Reduced soil erosion. Tillage systems that leave substantial amounts of crop residue evenly distributed over the soil surface reduce wind erosion and the kinetic energy impact of rainfall, increase water infiltration and moisture retention, and reduce surface sediment and water runoff (Edwards, 1995). Several field studies (Baker and Johnson, 1979; Glenn and Angle, 1987; Hall et al., 1984; Sander et al., 1989) conducted on small watersheds under natural rainfall on highly erodible land (14-percent slope) have compared erosion rates among tillage systems. Compared with the moldboard plow, no-till reduces soil erosion by as much as 90 percent and mulch-till and ridge-till by up to 70 percent.

Cleaner surface runoff. Surface residues help 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). Increased organic matter in the top layer of soil results in cleaner runoff by reducing contaminants such as sediment and adsorbed or dissolved chemicals, and thus benefits water quality in lakes and streams (Onstad and Voorhees, 1987; CTIC, 1996). Studies under field conditions indicate that while the quantity of water runoff from no-till fields was variable depending on the frequency and intensity of rainfall, clean-tilled soil surfaces produce substantially more runoff (Edwards, 1995). Runoff from no-till and mulch-till fields averaged about 30 and 40 percent of the amounts from moldboard-plowed fields (Baker and Johnson, 1979; Glenn and Angle, 1987; Hall et al., 1984; Sander et al., 1989). Average herbicide runoff losses from treated fields with no-till and mulch-till systems for all products and all years were about 30 percent of the runoff levels from moldboard-plowed fields (Fawcett et al., 1994). Under normal production conditions, the presence of increased crop residue reduces the volume of contaminants associated with runoff to surface waters by constraining sediment losses and enhancing infiltration (Edwards, 1995; Fawcett, 1987).

Higher Soil Moisture and Water Infiltration. Crop residues on the soil surface slow water runoff by creating tiny dams, reducing surface crust formation, and enhancing infiltration (Edwards, 1995). The channels (macropores) created by earthworms and old plant roots, when left intact with no-till, improve infiltration to help reduce or eliminate field runoff. This raises the prospect of increased water infiltration carrying agricultural chemicals into the groundwater in specific situations (see box, "Effects of CRM on Groundwater Quality"). Combined with reduced water evaporation from the top few inches of soil and with improved soil characteristics, the higher level of soil moisture can contribute to higher crop yields in many cropping and climatic situations (CTIC, 1996). However, in some areas, soil moisture levels can also be too high for optimal crop growth or leave soils too cool and wet at planting time, thereby reducing yields.

Improved long-term soil productivity. Less intensive tillage reduces breakdown of crop residue and loss of soil organic matter. Also with less tilling, net carbon sequestration may improve to build soil organic matter, enhance biological (including earthworm) activity, and maintain long-term productivity. Conservation tillage, particularly no-till, improves soil structure by increasing soil particle aggregation (small soil clumps), aiding water movement through the soil so plants expend less energy to establish roots. No-till also reduces soil compaction through fewer trips over the field and reduced weight and horsepower requirements (CTIC, 1996).

Reduced release of carbon dioxide and air pollution. Intensive tillage contributes to the conversion of soil carbon to carbon dioxide, which in the atmosphere can combine or react with other gases to affect global warming (Pretty et al., 2000). Increased crop residue and reduced tillage enhance the level of naturally occurring carbon in the soil and may contribute to lower carbon dioxide emissions (Lal, et al., 1998). In addition, CRM requires fewer trips across the field and less horsepower, which reduces fossil fuel emissions. Crop residues reduce wind erosion and the generation of dust-caused air pollution (CTIC, 1996).

National and regional CRM use

According to the CTIC National Crop Residue Management Survey, U.S. farmers practiced CRM on about 173 million acres in 2000, or 58 percent of planted acreage, up from 142 million acres in 1989 (table 4.2.8). The conservation tillage component of CRM accounted for 36 percent of U.S. planted crop acreage in 2000, compared with 26 percent in 1989. Most of the growth in conservation tillage since 1989 has come from expanded adoption of no-till (fig. 4.2.7), which can leave as much as 70 percent or more of the soil surface covered with crop residue. U.S. crop area planted with no-till more than tripled from 14 to 52 million acres between 1989 and 2000, increasing from 5 to over 17 percent of planted acres. Some of the rise in no-till use

Table 4.2.8--National use of various tillage systems, 1989-2000[1]

Item and tillage system [2]	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	2000
Area planted with:						Million acres					
No-till	14.1	16.9	20.6	28.1	34.8	39.0	40.9	42.9	46.0	47.8	52.2
Ridge-till	2.7	3.0	3.2	3.4	3.5	3.6	3.4	3.4	3.8	3.5	3.3
Mulch-till	54.9	53.3	55.3	57.3	58.9	56.8	54.6	57.5	60.0	57.9	52.6
Total conservation tillage	71.7	73.2	79.1	88.7	97.1	99.3	98.9	103.8	109.8	109.2	108.1
Reduced-till	70.6	71.0	72.3	73.4	73.2	73.1	70.1	74.8	77.3	78.1	65.2
Total crop residue management	142.4	144.2	151.4	162.1	170.3	172.5	169.0	178.6	187.1	187.3	173.3
Intensive-till	137.3	136.7	129.8	120.8	107.9	111.4	109.7	111.6	107.6	106.1	124.4
Total area planted [3]	279.6	280.9	281.2	282.9	278.1	283.9	278.7	290.2	294.7	293.3	297.7
Percentage of area with:						Percent					
No-till	5.1	6.0	7.3	9.9	12.5	13.7	14.7	14.8	15.6	16.3	17.5
Ridge-till	1.0	1.1	1.1	1.2	1.2	1.3	1.2	1.2	1.3	1.2	1.1
Mulch-till	19.6	19.0	19.7	20.2	21.2	20.0	19.6	19.8	20.4	19.7	17.7
Total conservation tillage	25.6	26.1	28.1	31.4	34.9	35.0	35.5	35.8	37.3	37.2	36.3
Reduced-till	25.3	25.3	25.7	25.9	26.3	25.8	25.2	25.8	26.2	26.6	21.9
Total crop residue management	50.9	51.3	53.9	57.3	61.2	60.7	60.6	61.5	63.5	63.8	58.2
Intensive-till	49.1	48.7	46.1	42.7	38.8	39.3	39.4	38.5	36.5	36.2	41.8
Total area planted	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] Data not available for 1999. In 2000, more accurate measurement of remaining residue may account for the drop in acreage in reduced-till and total crop residue management, and the increase in intensive-till.

[2] For tillage system definitions, see box "Crop Residue Management and Tillage Definitions."

[3] Excudes pasture, fallow, annual conservation use, and Conservation Reserve Program acres.

Source: USDA, ERS, based on National Crop Residue Management Survey data from the Conservation Technology Information Center (CTIC).

Crop Residue Management and Tillage Definitions

Unmanaged	Crop Residue Management (CRM)			
Intensive or conventional tillage	Reduced tillage	Conservation tillage		
		Mulch-till	Ridge-till	No-till
Moldboard plow or other intensive tillage used	No use of moldboard plow and intensity of tillage reduced	Further decrease in tillage intensity (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—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. Where soil erosion by wind is the primary concern, 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.

Intensive or 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 with a moldboard plow and/or other intensive tillage. Weed control is accomplished with herbicides and/or cultivation.

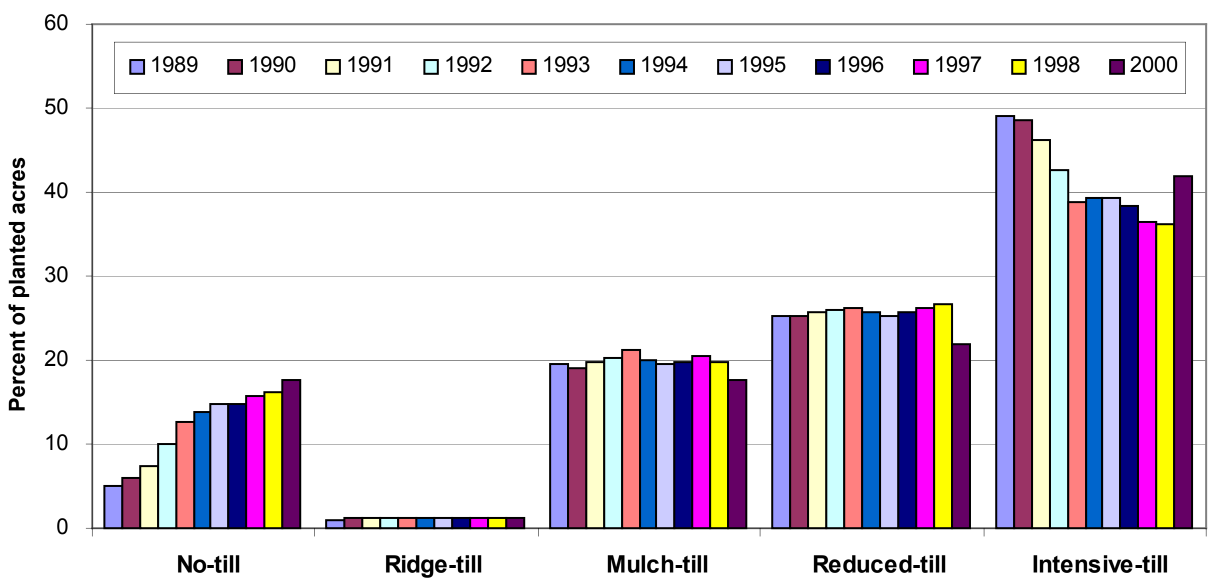
Source: USDA, ERS, based on Bull, 1993, and CTIC, 1996.

occurred as farmers implemented conservation compliance plans in order to remain eligible for farm program benefits under the 1985 Food Security Act and subsequent farm legislation. Also, some of the expansion in no-till usage since 1998 likely came from farmers switching from mulch-till.

With implementation of new and improved data collection procedures in the Conservation Tillage Information Center (CTIC) survey for 2000, acreage identified as reduced till dropped substantially from 1998 (data not collected in 1999). At least part of this decline in reduced-till acreage likely came from the more accurate procedures that classified as intensive-till some land that would have been previously placed in the reduced-till category.

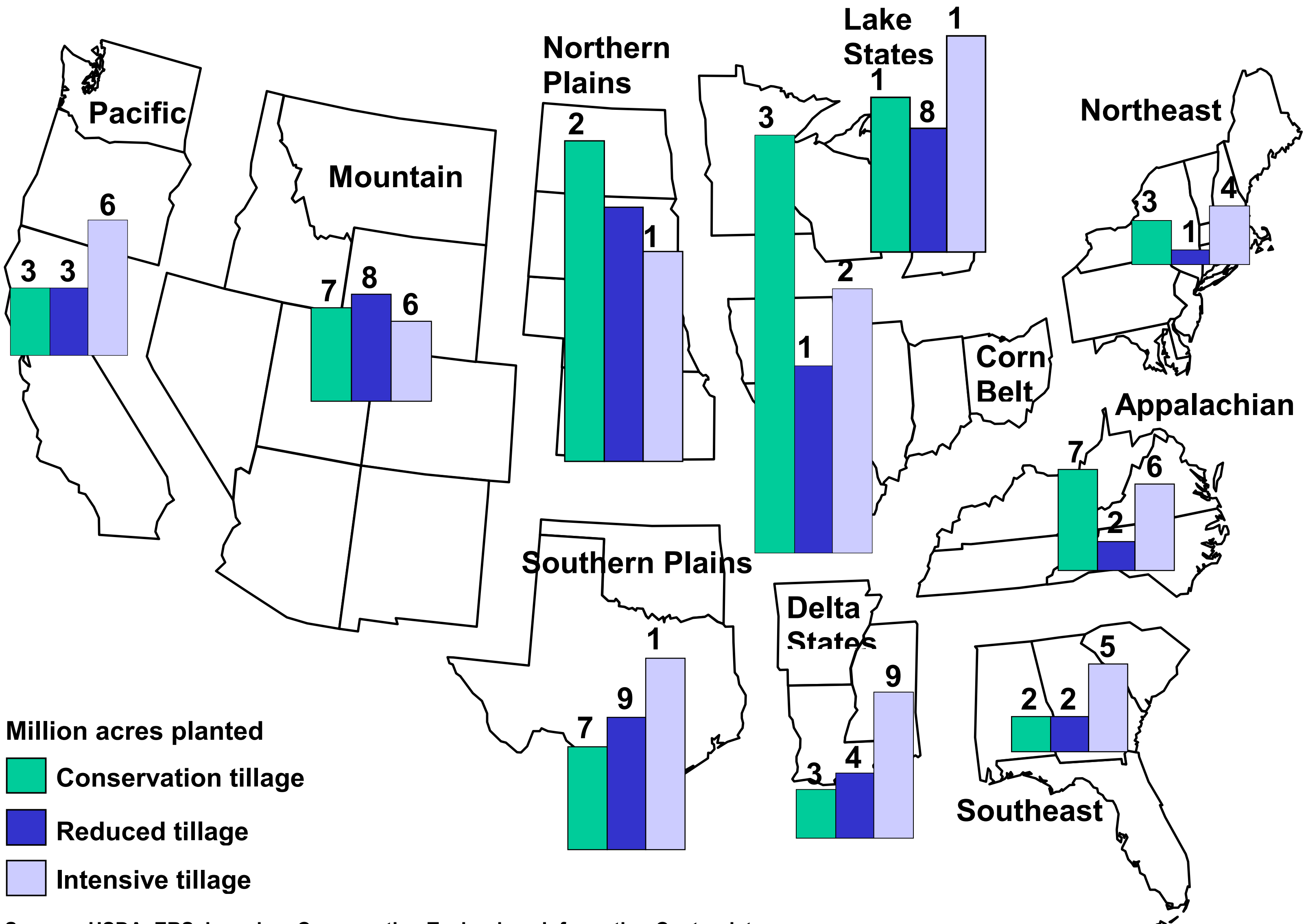
The Corn Belt and Northern Plains regions, with 51 percent of the Nation's planted cropland, accounted for over 60 percent of total conservation tillage acres in 1998 (fig. 4.2.8). These regions, plus the Lake States, Mountain region, and Southern Plains, also have substantial acreage with reduced till (15-30 percent residue cover) which, with improved crop residue management, has the potential to qualify as conservation tillage (which requires 30 percent or more surface residue cover). No-till's share of conservation tilled area is greater in the six eastern regions than elsewhere (fig. 4.2.9). Over 1989-98, the percent of acres planted with no-till showed an increase for most years in nearly all regions (fig. 4.2.10).

Figure 4.2.7--National trends in tillage systems, 1989-2000



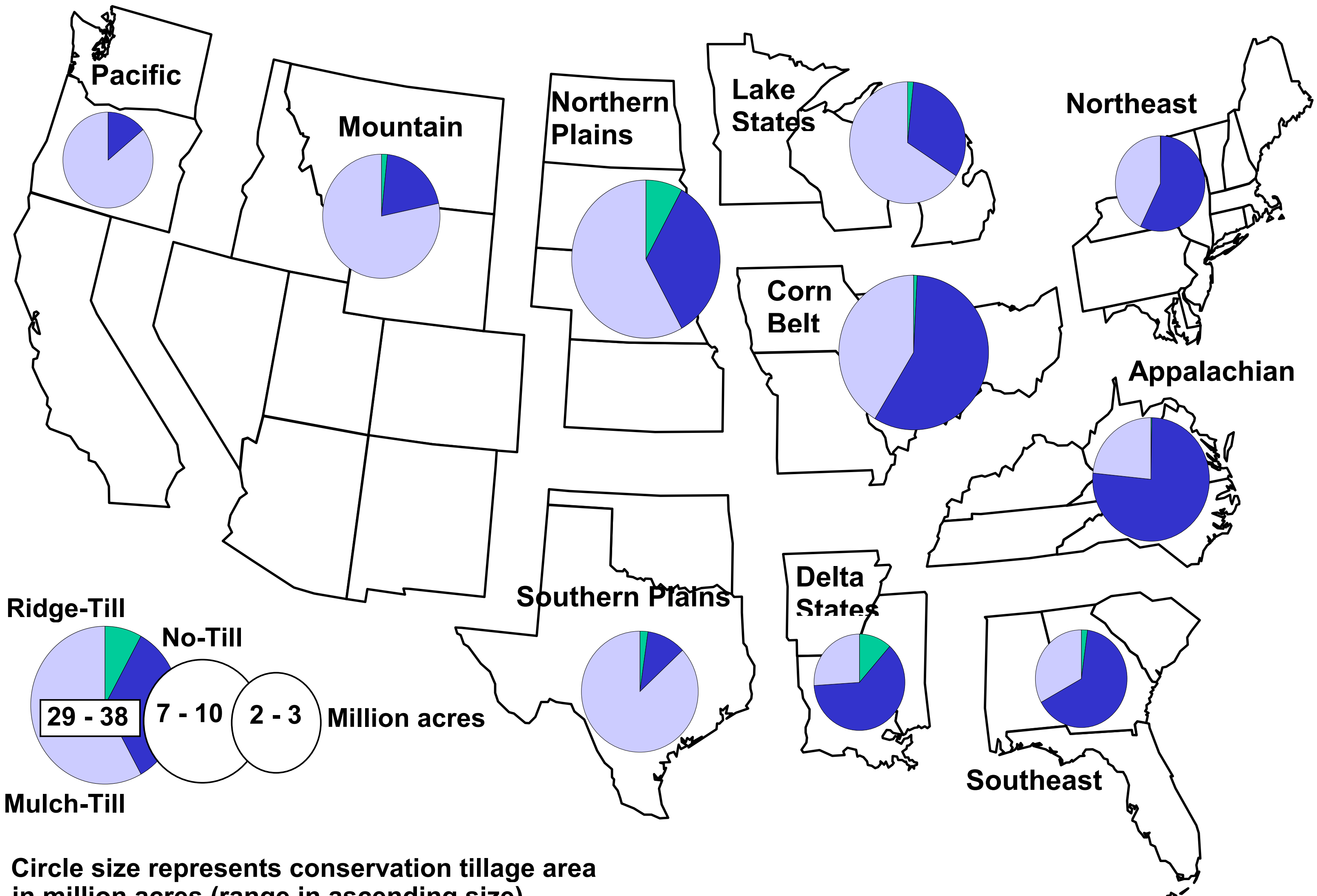
Source: USDA, ERS, based on Conservation Technology Information Center data.

Figure 4.2.8–Regional use of tillage systems, 1998



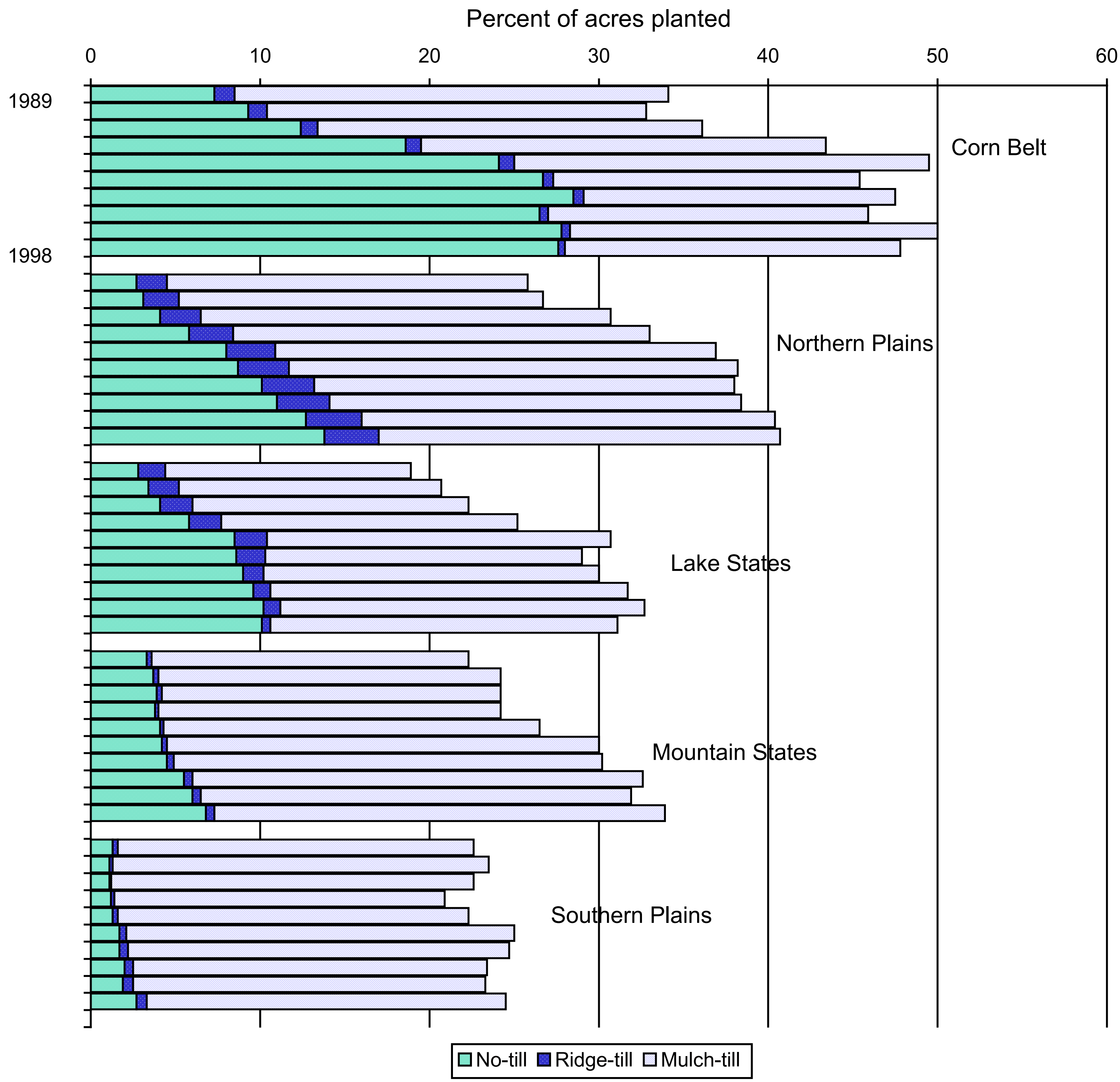
Source: USDA, ERS, based on Conservation Technology Information Center data.

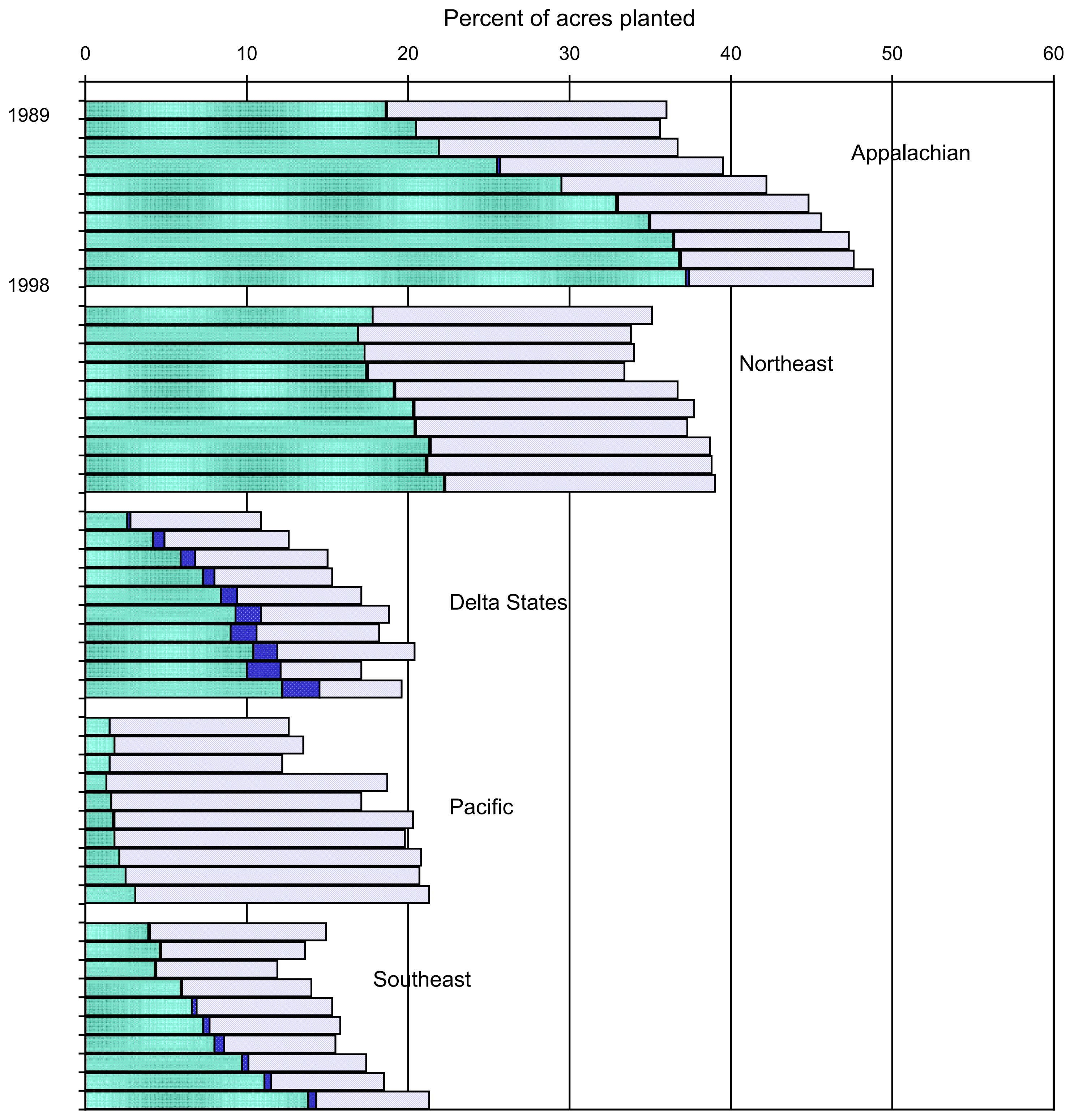
Figure 4.2.9–Regional use of conservation tillage by type, 1998



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

Figure 4.2.10--Conservation tillage adoption by Farm Production Region, 1989-98





Source: USDA, ERS, based on CTIC

Effects of CRM on Groundwater Quality

Greater infiltration of water under crop residue management (CRM) raises concerns about whether there are greater adverse effects on groundwater than with intensive tillage. The issue continues to be researched, but the difficulty of tracking a pesticide once it has been applied complicates attempts to find an answer. While conservation tillage systems can change weed and insect problems and the kinds of herbicides and insecticides used, average pounds of pesticides applied does not change greatly when farmers convert to conservation tillage (Fawcett, 1987; Fawcett et al., 1994; Hanthorn and Duffy, 1983). Analyses of tillage systems generally conclude that appropriate conservation tillage systems are no more likely to degrade water quality through chemical contamination than are intensive or conventional tillage systems, and do not increase the risk of undesirable impacts from pesticides on human health and aquatic life (Baker, 1980; Baker, 1987; Baker et al., 1987; Baker and Laflen, 1979; Edwards et al., 1993; Fawcett et al., 1994; Melvin, 1995; Wagenet, 1987). For a specific site, the effects depend on a complex set of factors besides the infiltration rate, including properties of the chemicals applied, quantities applied, timing of application, method of application, and a variety of site specific factors (climatic, hydrologic, geologic, soil, and topographic) (Onstad and Voorhees, 1987; Wagenet, 1987). Also, one has to consider what the cropping pattern and chemical use would be in the absence of CRM. In any situation, some of the factors may contribute to lesser effect and others to greater effect, with detailed analysis required to determine the net result. Some observations on these factors follow.

The potential for higher infiltration with conservation tillage creates an opportunity for groundwater degradation in some circumstances, such as for highly permeable sandy soils over shallow groundwater aquifers (Baker, 1987; CTIC, 1996; Wauchope, 1987). However, increased infiltration also normally dilutes the concentration of contaminants in the percolate to ground water (Bengtson et al., 1989; USDA, ERS, 1993).

A recent report reviews and summarizes the findings of more than 30 North American studies of pesticide transport into subsurface agricultural drains (Kladivko and Brown, 2001). The presence of a subsurface drainage system generally increases the volume of infiltration and consequently decreases the volume of surface runoff water and sediment compared to similar soils where subsurface drainage systems are not installed. These findings suggest that when considering pesticide contamination of surface waters, the highest priority should be placed on managing surface pesticide runoff. The evidence indicates that surface runoff contributions are usually the most significant of the pesticide inputs to surface water, with subsurface drains adding relatively small amounts. The presence of subsurface drainage decreases surface runoff losses of sorbed compounds such as pesticides, because of lower runoff volumes and often also because of lower concentrations in the runoff resulting from the delayed initiation of runoff. Pesticide concentrations and mass losses are usually much lower in subsurface drainage than in surface runoff, often by an order of magnitude. However, increased infiltration has the potential to increase losses of more mobile compounds such as nitrate-nitrogen through subsurface drainage system discharge water.

Management practices involving tillage systems or crop rotations appear to have only minor impact on the concentrations and losses of pesticides in tile drainflow (Kladivko and Brown, 2001). Rainfall timing, duration, intensity, and volumes relative to pesticide application timing and amount, in combination with soil type, seem to be the most important factors in determining pesticide transport to subsurface drains. In the medium- and fine-textured soils where subsurface drainage is common, the dominant mechanism for pesticide transport to the drain tiles is most likely preferential flow during rainfall/drainage events occurring soon after pesticide application. The longer-term studies show that concentrations and mass losses in subsurface drains are highly variable from year to year, depending on weather patterns.

The fate of applied chemicals is particularly dependent on the respective properties of the active ingredients, such as their adsorption, persistence, solubility, and volatility (Dick and Daniel, 1987; Fawcett, 1987; Melvin, 1995; Wauchope et al., 1992). Chemicals with high water solubility and low adsorption characteristics are highly mobile and possess the potential for loss through surface runoff or subsurface drainage (leachate) (Moldenhauer et al., 1995; USDA, ERS, 1993).
(continued)

Effects of CRM on Groundwater Quality (continued)

Pesticides that are strongly adsorbed to soil, sediment particles, or organic matter are protected from chemical or biological degradation and volatilization while adsorbed to these materials. Pesticides that are tightly held will not readily leach to ground water and will be found in surface-water runoff only under erosive conditions where the particles to which they are attached are washed off the fields. The soil adsorption property is a major factor affecting the pollution potential of a particular pesticide (Melvin, 1995; Wauchope et al., 1992; Weber and Warren, 1993).

The behavior of chemical compounds in the environment is also influenced by the application method. For example, whether a pesticide is applied to foliage or the soil or is incorporated into the soil makes a big difference in how easily the application deposits can be dislodged by rain, and thus leached into the soil or transported in surface runoff. Soil incorporation physically lowers the susceptibility of a pesticide to volatilization and thereby increases its persistence (Wauchope et al., 1992).

Early pre-plant (EPP) herbicides are applied several weeks or months prior to crop planting. Their advantages include prevention of weed establishment, elimination of the need for burndown treatments at planting, reduction in the potential for herbicide carryover from one crop season to the next, and the spreading out of labor related to planting. However, there are disadvantages to EPP herbicides particularly on sloping or highly erodible cropland. Occasional heavy rains on unprotected sloping fields can cause soil erosion and high rates of surface runoff even with no-till systems, and chemicals (attached to soil particles or dissolved in runoff water) could enter waterways. Use of EPP herbicides should be avoided on sandy soils or other soil types with high leaching potential (CTIC, 1996). Pre-plant/pre-emergence herbicides depend on rainfall to trigger the active ingredients soon after application. Once in the soil, they must be mobile and persistent for a sufficient period of time to make contact with and destroy weed seedlings throughout the expected weed germination period. These enhanced mobility and persistence properties also facilitate the migration of such chemicals in the environment through surface-water runoff or percolation to ground water.

Burndown herbicides, more important in no-till systems, are nonselective and are used before or just after planting but prior to crop emergence. Post-emergence herbicides are successful in controlling problem weeds or escapees well into the growing season without damaging the crop or reducing yield potential and are generally unaffected by soil type or amount of crop residue on the surface. However, post-emergent application does depend on proper timing and correct identification of the target weeds. Post-emergence and burndown herbicides frequently have short-lived or no residual soil effects (CTIC, 1996). They are generally less mobile and less persistent than pre-emergence herbicides and, therefore, less likely to migrate from their target. Pesticides applied to plant foliage, for instance, leave pesticide deposits that are highly vulnerable to photolysis and other degradation processes that reduce persistence and the potential for water pollution (Wauchope et al., 1992). For example, glyphosate and paraquat, although highly soluble, are strongly adsorbed to the targeted material or the soil and rapidly converted to relatively harmless degradation products that reduce their potential for contaminating ground water (Melvin, 1995; Moldenhauer et al., 1995).

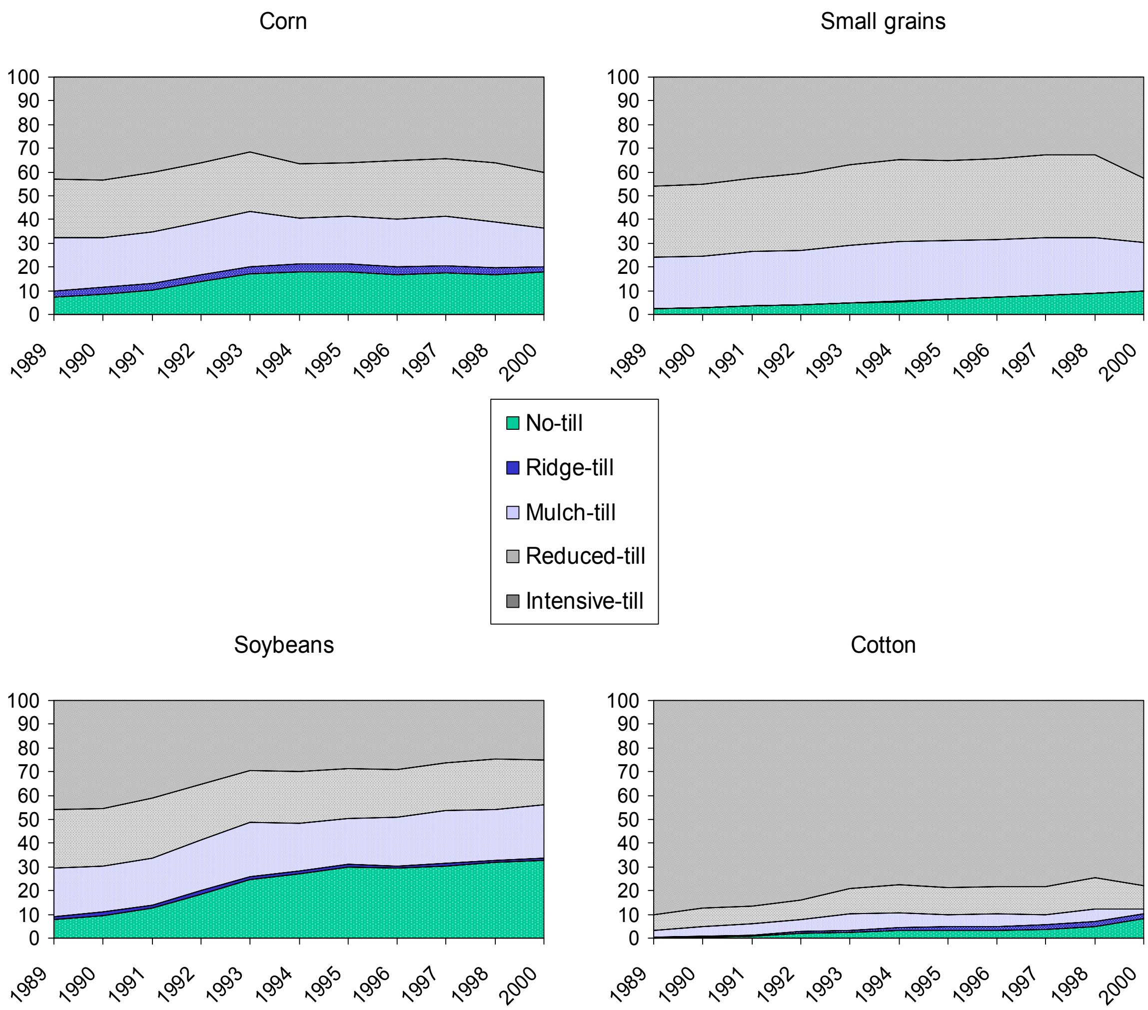
The difference in chemical properties among classes of herbicides is important when considering the environmental impacts of herbicide use among tillage systems. Tillage systems that employ herbicides with lower mobility and shorter persistence are preferable from a water-quality standpoint to tillage systems that require herbicides with greater mobility and longer persistence (Melvin, 1995; Wauchope et al., 1992).

The inherent toxicity of the active ingredients and their degradation, the impact of these products on nontarget species, and their mobility and persistence in soil and water determine their relative impact on the environment. In addition, a specific active ingredient can be converted by environmental processes including hydrolysis, photolysis, and other processes into an important degradation product with different chemical properties (Wauchope et al., 1992). Tillage systems employing newer pesticides that are highly toxic to targeted species but are used at much lower rates may be more environmentally desirable. For a given chemical, the amount of active ingredient being dissipated into the environment is generally proportionate to the amount applied; as a result, lower application rates translate into reduced exposure of nontarget species to the side effects of these chemicals (Wauchope et al., 1992).

CRM use on major crops

Farmers apply conservation tillage mainly to corn, soybeans, and small grains. CTIC data for 2000, which include all States, show that over 56 percent of the soybean acreage, 36 percent of the corn, and 30 percent of the small grains were conservation-tilled (table 4.2.9). This contrasts with only 12 percent of cotton acreage. Also, the CTIC data indicate that use of no-till has expanded more rapidly than other forms of conservation tillage for all four crops (fig. 4.2.11). Sandretto and Bull (1996) found that conservation tillage was used relatively more on double-cropped fields than on single-cropped fields. 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 4.2.11--Tillage trends on major crops



Other sources of data on CRM use on major crops are the 1988-95 Cropping Practices Surveys (CPS) and 1996-99 Agricultural Resource Management Study (ARMS). These surveys provide more detailed data than does CTIC on residue levels and tillage systems, but only for the major producing States (for more discussion of these surveys, see Appendix: Agricultural Resource Surveys and Data). The advantages of the CPS and ARMS for analysis of CRM come from linking CRM practices to other relevant details about the farm production system, such as the type of tillage equipment used, the number of trips made over a field, and farm chemical use. These annual surveys of major producing States indicate a decline in the use of the moldboard plow and other intensive tillage systems and an increase in the use of all types of conservation tillage for most of the major field crops. Only 11 percent or less of the surveyed area in any major field crop was moldboard plowed in 1997-99, down from 22 percent in 1988 (table 4.2.10). The reduction in use of the moldboard plow and the increase in CRM use resulted in average residue levels after planting increasing for all major crops.

Economic incentives for CRM adoption

The trend toward adoption of conservation tillage and a corresponding decline in intensive tillage has been stimulated by the prospect of higher economic returns with conservation tillage and by public policies and programs promoting conservation tillage for its conservation benefits. Higher economic returns with CRM result primarily from increased or stable crop yields and an overall reduction in input costs, with both heavily dependent on characteristics of the resource base and appropriate management (Clark et al., 1994).

Differences in yield. Yield response with soil-conserving tillage systems varies with location, site-specific soil characteristics, climate, cropping patterns, and level of management skills. 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 intensive tillage (Hudson and Bradley, 1995; CTIC, 1996). Experienced no-till farmers claim greater yields from increased infiltration and improved soil properties such as reduced erosion and soil compaction, increased soil organic matter and earthworm activity, and improved soil structure in 4-7 years from when the system becomes established (CTIC, 1996). A mulch-till system may be more appropriate where soil characteristics vary greatly within a field, where pre-plant incorporated herbicides are used for weed control, or where equipment or management limitations preclude the use of no-till or ridge-till (CTIC, 1996).

The benefits from improved moisture retention in the root zone—that derive from reduced water runoff, increased infiltration, and suppressed evaporation from the soil surface—usually increase crop yields, especially under dry conditions. In some areas of the northern Great Plains, these benefits permit a change in the cropping pattern to reduce the frequency of moisture-conserving fallow periods (Clark et al., 1994). Increased crop residue on the soil surface tends to keep soils cooler, wetter, and less aerated (Mengel et al., 1992). These characteristics under cool, wet planting conditions, especially in some Northern States, have been blamed for delayed plantings, uneven stands, and lower corn yields (Griffith et al., 1988). However, with hot, dry weather later in the growing season, the effects of increased organic matter, improved moisture retention and permeability, and reduced nutrient losses from erosion all benefit crop yields.

The crop grown in the previous year can have a great influence on the success of conservation tillage systems, especially no-till. The kind, amount, and distribution of previous crop residue can influence soil temperature, seed germination, and early growth. Lower seed germination and lack of early growth sometimes result due to placing seed under or near decaying residue from the same crop or a closely related species (Griffith et al., 1992; CTIC, 1996). No-till, mulch-till, and even intensive tillage systems are more likely to be successful with crop rotation than with monoculture. Ridge-till is best suited to row crops, and therefore is often used with monoculture (Bull and Sandretto, 1995).

Table 4.2.9—Tillage systems used on major crops, contiguous 48 States, 1989-2000

Crop and year[1]	No-till	Ridge-till	Mulch-till	Reduced-till	Intensive-till
			Percent		
Corn					
1989	7.4	2.4	22.4	24.6	43.2
1990	8.7	2.6	21.0	24.4	43.3
1991	10.2	2.8	21.9	25.1	40.1
1992	13.8	2.8	22.3	25.1	35.9
1993	17.1	3.1	23.2	25.0	31.6
1994	18.2	3.1	19.3	23.1	36.4
1995	18.1	3.1	20.1	22.6	36.2
1996	17.0	3.0	20.3	24.3	35.5
1997	17.5	3.1	20.9	24.2	34.3
1998	16.6	2.9	19.5	25.0	36.0
2000	17.9	2.1	16.5	23.2	40.3
Soybeans					
1989	7.7	1.2	20.7	24.5	45.9
1990	9.6	1.4	19.4	24.2	45.4
1991	12.6	1.4	19.8	25.1	41.1
1992	18.5	1.4	21.5	23.2	35.5
1993	24.7	1.3	22.7	21.7	29.5
1994	27.2	1.2	19.8	21.7	30.1
1995	30.0	1.0	19.4	20.8	28.8
1996	29.7	0.8	20.2	20.3	28.9
1997	30.5	1.0	22.1	20.2	26.2
1998	31.9	0.9	21.3	21.4	24.6
2000	32.8	0.9	22.4	18.8	25.1
Small Grains					
1989	2.6	0.0	21.6	30.0	45.8
1990	3.0	0.0	21.4	30.4	45.1
1991	3.7	0.0	22.9	30.9	42.4
1992	4.1	0.0	23.0	32.3	40.5
1993	5.0	0.0	24.2	34.0	36.8
1994	5.5	0.1	25.3	34.2	34.9
1995	6.6	0.0	24.6	33.7	35.0
1996	7.5	0.0	24.0	34.1	34.4
1997	8.3	0.1	23.8	35.0	32.9
1998	8.9	0.1	23.5	34.7	32.8
2000	9.8	0.1	20.5	27.1	42.5
Cotton					
1989	0.2	0.1	2.9	6.5	90.3
1990	0.4	0.4	4.0	8.0	87.2
1991	0.7	0.6	4.8	7.6	86.2
1992	2.0	0.7	4.9	8.3	84.0
1993	2.6	0.8	6.7	10.8	79.2
1994	3.2	1.2	6.3	11.8	77.5
1995	3.4	1.4	5.1	11.6	78.4
1996	3.4	1.4	5.4	11.5	78.2
1997	3.7	2.0	4.1	11.8	78.5
1998	4.9	2.2	5.3	13.1	74.5
2000	8.0	2.2	2.2	9.7	77.9

Numbers may not add due to rounding. [1] No data were gathered in 1999
Source: USDA, ERS, based on CTIC data.

Table 4.2.10—Moldboard plow use and residue remaining after planting, major crops, 1988 and 1997-99

Crop	Use of moldboard plow		Residue remaining after planting[1]	
	1988	1997-99[2]	1988	1997-99[2]
	Percent of crop		Percent residue cover remaining	
Corn (10 States)	20	6	19	26
Soybeans (11States)	22	5	16	37
Cotton (6 States)	28	11	2	6
Winter wheat (10 States)	15	9	17	19
Spring & durum wheat (ND,SD)	14	10	18	25

1 Averaged over all tillage systems.
2 1999 for corn and soybeans; 1997 for other crops.
Source: USDA, ERS, based on data from Cropping Practices Surveys and ARMS.

Crop yields can be significantly affected by pest populations, which frequently change under different tillage systems. Maintaining or increasing yields when changing tillage systems requires skillful use of the various means of pest control, including crop variety selection, pesticide application, cultivation, cover crops, crop rotation, scouting, and other integrated pest management practices (for more detail, see box, "Weed Control and Tillage" and Chapter 4.3*,* Pest Management).

*Differences in pesticide use***.** Pesticide use on major crops differs among 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. Factors other than tillage that affect pest populations may have greater impact on pesticide use than type of tillage (Bull et al., 1993).

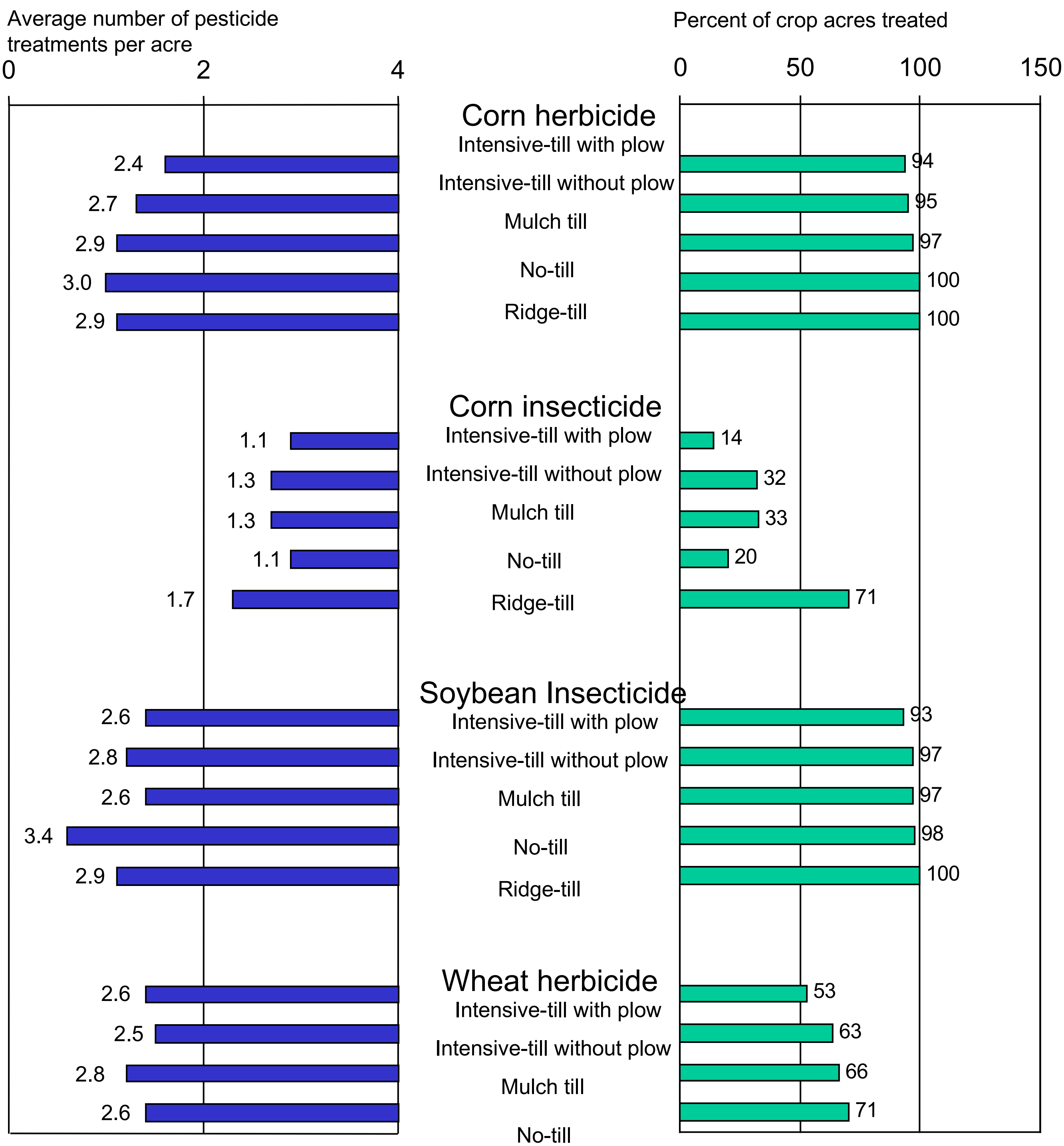
In 1997, nearly all **corn** acres under all tillage systems were treated with herbicides (fig. 4.2.12). The overall application (pounds per acre treated) averaged highest for no-till and lowest for moldboard plowed, but great variation existed among surveyed fields in each tillage system (fig. 4.2.13). Analyses of 1994 survey data shows that differences among tillage systems were greater in the active ingredients applied than in the overall average amount applied per treated acre (USDA, 1997, pp. 164-166). Of the 11 most commonly used herbicides on corn, 2 were applied most frequently in 1994 with intensive-till, 3 with mulch-till, 4 with no-till, and 2 with ridge-till. A comparison between no-tilled and intensively tilled corn acreage shows that 6 of the 11 most commonly used herbicides were more frequently used with intensive-till and 5 were more frequently used with no-till.

Farmers in 1997 applied corn insecticide to 71 percent of ridge-till acres, compared with one-third or less of acres under other tillage systems (fig 4.2.12). No-till acres averaged fewer acre treatments of insecticide than ridge-till, and about the same as intensive tillage with plow. No fungicide use was reported on surveyed corn acreage.

Most **soybean** acres under all tillage systems were treated with herbicides (fig. 4.2.12). Few or none were treated with insecticides or fungicides. A greater variety of herbicides was used on soybeans than on corn or wheat (USDA, 1997, p.165). Differences in the specific herbicide active ingredients applied existed among tillage systems, but the overall average amounts applied per treated acre were similar. Of the 18 most commonly applied herbicides on soybeans, 5 were applied most frequently with intensive-till, 9 with no-till, and 4 with ridge-till.

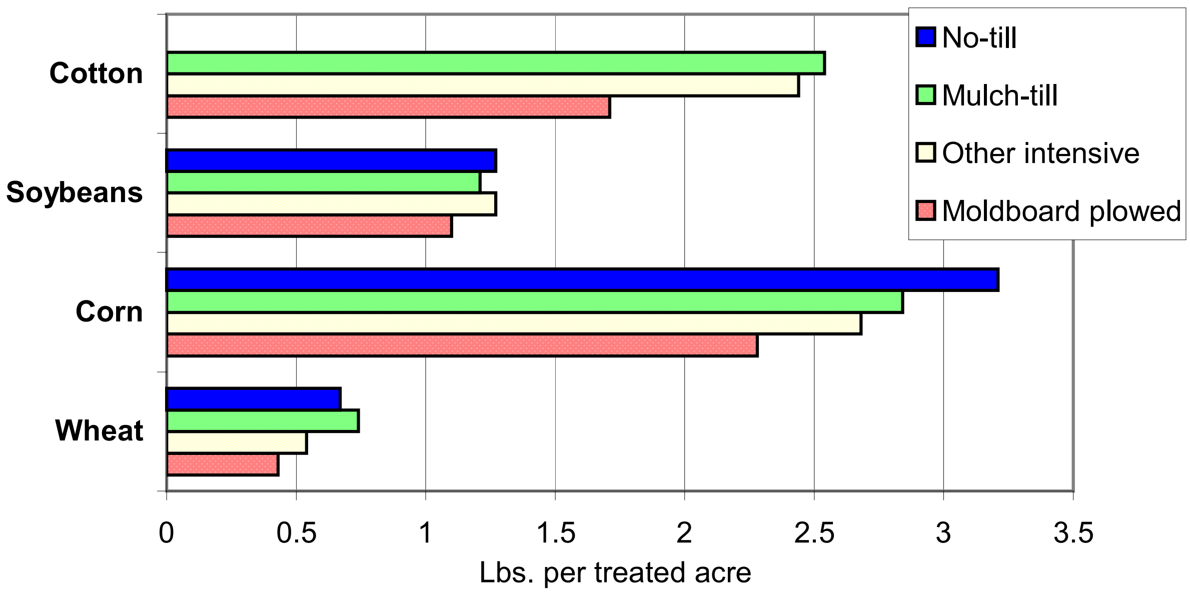
A smaller share of **wheat** acreage than corn or soybeans in 1997 was treated with herbicides, ranging down from 71 percent of no-till acreage to 53 percent of acres intensively tilled with plow (fig. 4.2.12). Also the average amount of herbicide applied per treated acre was lower for wheat than for corn or soybeans. Application rates averaged higher on mulch-till and no-till acres than on land intensively tilled with plow (fig. 4.2.13).

Figure 4.2.12 – Pesticide use by tillage system, 1997



Source: USDA, ERS, 1997 ARMS, and Padgitt (2000)

Figure 4.2.13—Average herbicide application, 1997



Source: USDA, ERS, based on ARMS survey data.

Impacts on production costs. Choice of tillage system affects machinery, chemical, fuel, and labor costs. In general, decreasing the intensity of tillage or reducing the number of operations results in lower machinery, fuel, and labor costs. These 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 (CTIC, 1996 and Siemens and Doster, 1992). The cost of pesticides with alternative tillage systems is not simply related to the total quantity of all pesticides 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 applied at a much lower rate but are often more expensive. This complicates the comparison of costs among tillage systems (Bull et al., 1993).

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 financial management, improved marketing, or other activities to improve farm profitability (Sandretto and Bull, 1996). Making fewer trips over the field also means that equipment lasts longer 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 capital, 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 lowers fuel and maintenance costs. Fuel costs, like labor costs, can drop nearly 60 percent per acre by some estimates (Monson and Wollenhaupt, 1995; Weersink et al., 1992). When fuel prices increase, conservation tillage practices become relatively more profitable.

Several studies report that on a range of soil types, higher residue tillage systems such as no-till and ridge-till result in greater economic returns for a given crop than lower residue systems. Even in some northern areas with heavy wet soils where no-till yields have sometimes been slightly lower, net returns have often been better because per-acre costs were lower (Doster et al., 1994; Fox et al., 1991). For corn production, McBride (1999) found the potential benefits of reduced and conservation tillage to be largest for dryland production in the Plains States, probably due to moisture conservation (table 4.2.11). Reduced-till, mulch-till, and no-till all had lower costs and higher returns than intensive tillage in the four major producing regions studied, except on irrigated land. With no-till in the Lake States and Corn Belt, lower costs more than offset slightly lower average yields to produce returns 4-13 percent higher than intensive tillage.

Adoption of conservation tillage may increase net returns on the entire farming operation even if returns for a particular crop on a farm do not. For example, a tillage system that requires substantially less labor per acre and reduces returns per acre slightly but that permits application of the labor savings to more acres could result in larger total returns (Sandretto and Bull, 1996).

Policies and programs promoting CRM adoption

Conservation compliance provisions of the 1985 Food Security Act gave farmers an additional incentive to adopt CRM on highly erodible land (HEL). Under the program, farmers who produce crops on HEL and fail to implement an approved conservation plan forfeit eligibility for most USDA farm program benefits. Crop residue management (including conservation tillage) is a key component in the conservation plans for around 75 percent of the cultivated HEL subject to compliance (see Chapter 6.3, Compliance Provisions for Soil and Wetland Conservation). The 1990 and 1996 Farm Acts further strengthened the Federal role of protecting soil and water resources. Besides increasing penalties for noncompliance, the Acts established other programs that offer incentives to adopt practices such as CRM to improve water quality or control erosion (see Chapter 6.1, Overview of Conservation and Environmental Programs).

In 1991, USDA developed the Crop Residue Management Action Plan to assist producers with highly erodible cropland in implementing conservation systems that met the requirements of their approved conservation plans by the 1995 deadline. The plan increased the timely delivery of information, provided technical assistance to help land users install conservation systems, helped producers better understand the conservation provisions of farm legislation, and assisted them in maintaining their conservation plans and thus their eligibility for USDA program benefits. Crop Residue Management (CRM) alliances were established at the National, State, and local levels. The 20 State alliances, some of which remain active, included USDA agencies, agricultural supply industries, farm media, grower associations, commodity groups, conservation and environmental organizations, universities, et al., interested in promoting the conservation of soil and water resources. USDA continues to provide assistance to farmers to meet conservation compliance requirements.

Weed Control and Tillage

Crop yields can be significantly affected by weeds. Traditional tools for controlling weeds have included crop rotations, crop or cover crop competition, and row crop cultivation. Each of these tools can play an important role in combination with modern pesticides to achieve effective pest control. These tools combined with scouting comprise the core of what has become known as integrated pest management (IPM). IPM is a systematic way of controlling pests (weeds, insects, and diseases) using a variety of techniques. The results from an effective IPM program often include higher profits due to savings from reduced pesticide applications and improved protection of the environment (CTIC, 1996).

Weed control problems vary among tillage systems because the nature of the weed population changes. An understanding of the response of weed species to tillage systems is essential in designing effective weed management programs (Martin, 1995). Actively tilling the soil before planting (and cultivating during the growing season for row crops) helps provide weed control in conjunction with herbicides. However, tillage also brings up dormant weed seeds and prepares a seedbed not only for the crop, but for weed seeds as well (Monson and Wollenhaupt, 1995). Tillage can also expand the perennial weed problem of some species by spreading their rhizomes and tubers (Kinsella, 1993). A challenge with no-till in some areas involves a gradual shift from annual weeds to several hard-to-control perennial weeds, including woody species and volunteer trees after 7-10 years (CTIC, 1996).

Mechanical cultivation for weed control is only feasible on the share of the cropland acreage planted with a row planter. The reported Cropping Practices Survey incidence of mechanical cultivation was fairly consistent across tillage systems except for higher use with ridge-till and considerably lower (one-third to one-half of the share of acres treated for other tillage systems) use with no-till. Ridge-till systems normally use mechanical cultivations during the season to rebuild and maintain the ridges in addition to controlling weeds.

Crop rotation can be an important tool for weed control because certain weeds are easier or more economical to control in one crop than another. For example, perennial grasses that are difficult to control in corn can be managed effectively in broadleaf crops such as cotton and soybeans (CTIC, 1996). Conversely, some broadleaf weeds are much easier to control in corn than in soybeans. A competitive crop that can achieve early shading of weeds can greatly improve weed control. The success of this system depends on obtaining a quick-closing crop canopy to shade emerging weeds and good stand establishment since skips allow some weeds to escape. Cover crops can accomplish this goal by reducing the amount of sunlight that reaches emerging weed seedlings (CTIC, 1996). In addition, crop rotations can often reduce the area needing treatment with pesticides and also decrease reliance on annual applications of the same pesticide; the latter pattern can increase pesticide resistant species and reduce pesticide effectiveness.

Herbicide effectiveness depends on spraying at the right stage of growth and of plant stress, and under favorable weather conditions. Recommendations on the type and combination of herbicides and method of application for efficient weed control vary among tillage systems. The effective use of post-emergence herbicides most commonly employed in high residue situations requires careful and regular scouting and better knowledge of weed identification to facilitate appropriate herbicide selection. Herbicide application rates for ridge tillage were consistently lower than for other systems due to more prevalent banding, which uses smaller amounts of chemicals and more mechanical cultivation. Because no-till employs limited (or no) mechanical tillage, proper application of herbicides is essential for effective weed control. In addition, during the transition to higher residue systems, farmers often tend to increase slightly the amount of herbicide used as a risk aversion measure. The reported Cropping Practices Survey increase by no-till users in herbicide application (by weight) is due in part to the inclusion of an additional "burndown" herbicide treatment prior to planting as a substitute for mechanical weed control. However, successful no-till users find that herbicide costs generally decrease and become competitive with intensive tillage systems in 3-5 years (CTIC, 1996). Also, different management skills are required to control weeds with no-till or other high-residue tillage systems than with intensive tillage systems (CTIC, 1996). Crop residue management systems do not necessarily increase agricultural chemical requirements or application costs.

The trend toward precision farming means that increasingly agricultural chemicals, including fertilizers and pesticides, will be carefully managed in a manner tailored to the site-specific conditions and the problems to be corrected. Improved input management is necessary to ensure economic viability, maintain long-term productivity, and protect environmental quality.

Table 4.2.11—Average corn yields, costs, and returns under reduced tillage systems compared with intensive tillage, 1996

Region and tillage system	Difference in average yield 1990-96 [1]	Difference in gross receipts [2]	Difference in preharvest costs per acre [3]	Difference in returns above preharvest costs [4]	
	Bushels/acre	-------------------Dollars per acre		------------------	Percent
Dryland					
Eastern Corn Belt					
Reduced-till	10	27	-16	43	24
Mulch-till	8	21	-24	45	26
No-till	-3	-8	-30	22	13
Western Corn Belt					
Reduced-till	2	5	-4	9	5
Mulch-till	4	11	-8	19	10
No-till	-4	-11	-18	7	4
Lake States					
Reduced-till	1	2	-22	24	16
Mulch-till	3	8	-33	41	29
No-till	-2	-6	-22	16	11
Plains States					
Reduced-till	17	47	-9	58	66
Mulch-till	16	44	-30	74	84
No-till	23	68	-33	101	115
Irrigated land					
Plains States					
Reduced-till	-6	-16	--	-16	-10
Mulch-till	-6	-16	30	-46	-28
No-till	-5	-13	-9	-4	-2

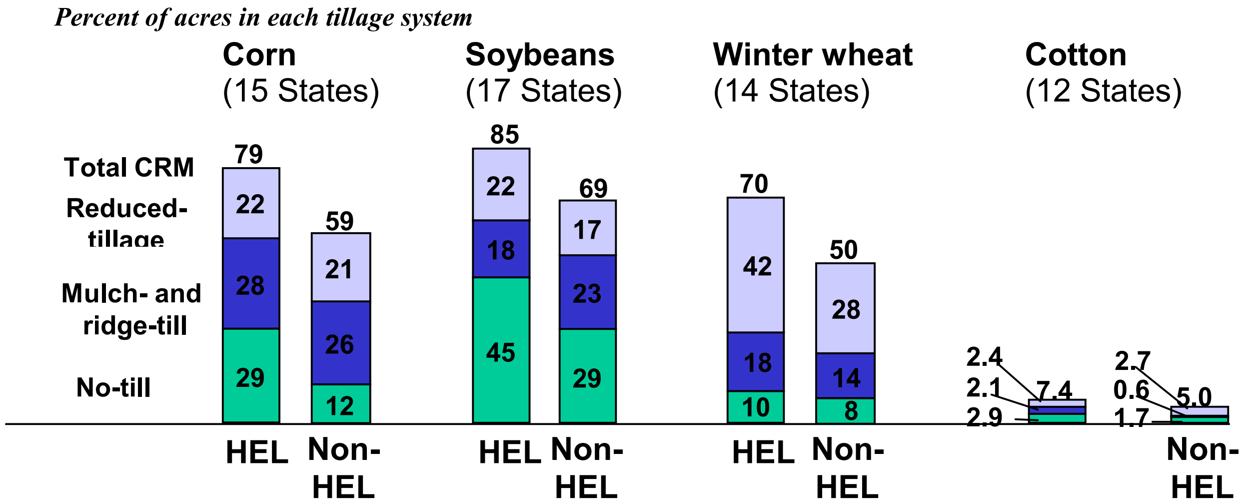
[1] Estimated from Cropping Practices Surveys for 1990-96, see McBride (1999).
[2] Difference in average yield times the 1996 average U.S. corn price of $2.71 bushel.
[3] Difference in cost between the reduced tillage system and intensive tillage, estimated from the ARMS, see McBride (1999). Cost includes the pre-harvest costs of seed, fertilizer, chemicals, energy, labor, and capital.
[4] Difference in gross receipts minus the difference in pre-harvest costs.
Source: USDA, ERS, and McBride (1999).

The use of conservation tillage on non-HEL indicates that all producers are motivated by the potential of conservation tillage systems to reduce costs, improve efficiency, and/or increase soil productivity. Also, once a producer implements conservation tillage on HEL to meet compliance requirements, using the same equipment and techniques on non-HEL makes good economic sense.

Adoption of CRM practices, especially no-till, has been greater on HEL than on non-HEL (fig. 4.2.14). In 1999, for example, CRM was used on nearly 79 percent of HEL corn acreage in major growing States, compared with 59 percent use on non-HEL. Most of the higher use was due to no-till adoption. On winter wheat, use of reduced-till, which adds some additional residue to protect the soil, was substantially higher on HEL than non-HEL in 1997, 42 percent compared with 28 percent. However, mulch-till and no-till use were only a few percentage points higher on HEL wheat.

In passing the 1996 Farm Act, Congress reaffirmed its preference for dealing with agricultural resource problems using voluntary approaches. The Act continued the Conservation Compliance Program and gave

Figure 4.2.14-Crop residue management on HEL and non-HEL



HEL = Highly erodible land

Source: USDA, ERS, based on ARMS Surveys of 1997 and 1999.

farmers greater flexibility in meeting requirements. The Act also established the Environmental Quality Incentives Program (EQIP) to replace previous financial and technical assistance programs and to better target assistance to areas most needing actions to improve or preserve environmental quality. While half of EQIP funding is directed to environmental practices related to livestock production, the other half is for other conservation improvements. Directing the program toward management practices favoring crop residue management would increase adoption. Crop residue management, including conservation tillage, is a particularly 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 needs. The cost-savings from reduced fuel, labor, machinery, and time requirements, while usually maintaining or increasing crop yields, may provide economic incentives to overcome noneconomic barriers to greater adoption of CRM. (For more information on programs, see Chapter 6.1, Overview of Conservation and Environmental Programs, and Chapter 6.3, Compliance Provisions for Soil and Wetland Conservation).

Barriers to CRM adoption

Given the conservation and potential economic advantages of conservation tillage systems, and the promotion that has occurred, why haven't the systems been adopted on more than 37 percent of U.S. cropland? First, adoption is the final step in a process that begins with becoming aware, moves to gaining information, then to trial, and finally to adoption. A number of farmers may be in the reduced tillage transition stage between intensive tillage and conservation tillage, or are currently trying conservation tillage on part of their land. Second, there are particular soils and climatic or cropping situations where conservation tillage systems have not yet demonstrated that they can consistently produce good economic results. In these areas, most farmers are waiting for the development of improved systems. Further limiting factors include the need for additional management skill and capital investment in new equipment, economic risk involved in changing systems, negative attitudes and perceptions against new practices, and, in some cases, institutional constraints.

Some farmers' attitudes against adoption of new technologies, including conservation tillage, derive from a reluctance to change from methods of production that have proven to be successful in their own experience. The superiority of new techniques has to be demonstrated to a sufficient extent to offset exposure to the risks inherent in making a change from traditional methods. The perceived risks are critical because unusual weather or pest problems may be accepted as a normal occurrence with traditional methods but poor results related to weather or pests may be blamed on the new tillage system if they occur during the transition period. Consequently, the new technique may be unfairly discredited in the area for a long time if initial attempts are perceived to result in failure. Cultural and institutional factors can also constrain adoption. Some farmers or even whole communities demonstrate strong preferences for clean tilled fields as a sign of "good" management. The banker and/or landlord may be reluctant to permit a change in the way the land is farmed, especially if they perceive more potential risk to crop yields and net returns during the transition.

Farmers are aware that a series of challenges exist with higher residue levels. These may include different (but not necessarily more serious) disease, insect, or weed problems; difficulties with more residue on the surface in proper seed, fertilizer, and pesticide placement; and, under certain conditions, particularly cool wet seasons, lower corn yields (CTIC, 1996). In addition, the land must be properly prepared for no-till. Previous compaction and fertility problems need to be corrected first. The transition period can be very difficult as the farmer wrestles with learning how to adapt the new tillage system to his unique situation, especially if unusual weather or pest problems arise during the transition. Long-term benefits such as improved soil quality may take years to be realized. However, in many situations, innovative farmers have found solutions to most of these problems or through experience have learned how to reduce their impact to tolerable levels until more acceptable solutions can be devised.

Farmers often face significant tradeoffs when choosing the most appropriate tillage system for their conditions. Higher residue systems generally allow less opportunity to correct mistakes or adjust to changed circumstances once the season is underway. Conservation tillage practices, with their higher levels of crop residue, usually require more attention to proper timing and placement of nutrients and pesticides, and in carrying out tillage operations. Nutrient management can become more complex with crop residue management because of higher residue levels and reduced options with regard to method and timing of nutrient applications. No-till, in particular, can complicate manure application and may also contribute to nutrient stratification within the soil profile from repeated surface nutrient applications without any mechanical incorporation. This is not necessarily a problem because with higher residue levels evaporation is reduced and more water is maintained near the surface, fostering the growth of feeder roots near the surface where the nutrients are concentrated (Monson and Wollenhaupt, 1995). Also, new equipment is available that permits deep banding of nutrients with minimal soil/residue disturbance. In some instances, increased application of specific nutrients and the use of specialized equipment for proper fertilizer placement may be necessary, contributing to higher costs.

Farmers' Use of Conservation Buffers and Structures

Soil and water conservation structures and buffer zones can significantly reduce erosion caused by rainfall and water runoff. These structures allow for surface water to be captured on site or slowed and diverted from the field via erosion-resistant waterways, channels, or outlets. While crop rotation and tillage practices may also be used to help control erosion, they may not provide sufficient control of runoff water after heavy rains. Therefore, engineering structures and buffer zones are often important components of farm soil management systems.

National and regional use of buffers and structures

Despite regional variation, ARMS data show some similarity of soil conserving structures used in conjunction with a particular cropping sequence (table 4.2.12). On land in continuous corn, for example, grassed waterways are used by more farmers than any other structure, except in the Southeast States, where the practice is second to underground outlets. In the Lake States and Corn Belt Regions, more than 20 percent of farms implemented contour farming and underground outlets. In the Plains States and Southeast States Regions, the frequency of corn farmers using various soil-conserving structures is lower than in other regions, most likely because of fewer problems with water-based erosion.

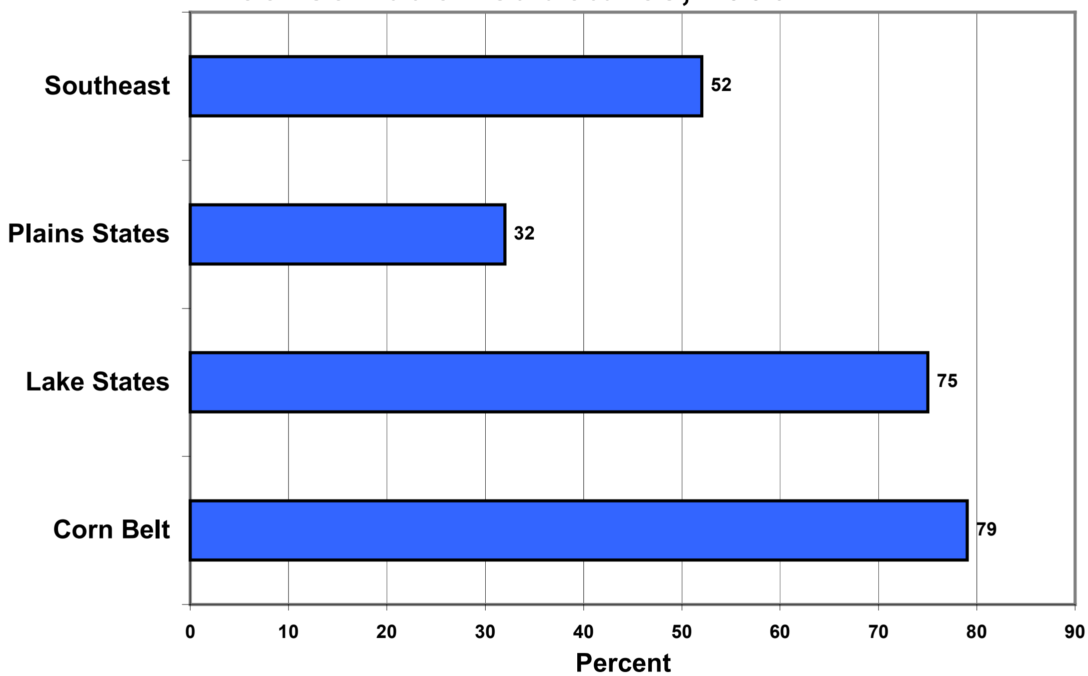
The use of one or more structures for soil and water conservation varies significantly across production regions (fig. 4.2.15). The adoption rate is higher in the Corn Belt (79 percent) and Lake States (75 percent) than it is in the Southeast (52 percent) and Plains States (32 percent). The adoption rate in the Plains States, the only region where more than half the planted corn for grain acreage is not serviced by at least one soil and water conservation structure, is notably lower than it is in the other three regions. Soil and climatic variation are likely responsible for much of the adoption rate differences.

Table 4.2.12—Corn farms using various soil conserving structures, by cropping pattern and region, 1996

Region and structure	Continuous Corn	Corn Soy-Corn	Soy-Soy-Corn	Fallow Corn-Corn	Fallow Soy-Corn	Fallow-Fallow Corn
			Percent of farms			
Lake States Region						
Grassed waterways	42	22	-	20	-	44
Terraces	6	-	-	2	-	1
Contour farming	24	4	-	19	-	8
Strip cropping	36	2	-	25	22	24
Underground outlets	21	80	97	11	17	5
Other drainage	15	6	1	2	-	2
Corn Belt Region						
Grassed waterways	53	26	42	77	24	76
Terraces	26	8	25	-	6	-
Contour farming	38	12	27	61	6	52
Strip cropping	5	1	-	-	6	-
Underground outlets	45	59	49	16	42	36
Other drainage	21	13	15	-	-	2
Plains States Region						
Grassed waterways	8	15	13	32	71	11
Terraces	2	11	13	32	-	15
Contour farming	3	11	13	32	-	7
Strip cropping	1	4	-	-	-	6
Underground outlets	2	10	-	-	-	-
Other drainage	7	1-	-	38	71	13
Southeast States Region						
Grassed waterways	11	27	20	15	71	4
Terraces	-	14	-	-	-	-
Contour farming	-	39	-	-	-	3
Strip cropping	5	3	13	-	-	-
Underground outlets	13	24	18	-	-	-
Other drainage	3	35	5	-	-	-

- = less than 0.5 percent or insufficient data to make an estimate.
Source: USDA, ERS, based on the 1996 ARMS.

Figure 4.2.15--Corn acres with one or more conservation structures, 1996[1]



[1] Conservation structures include grassed waterways, terraces, contour farming, and strip cropping.

Source: USDA, ERS, based on ARMS data.

Economic and program factors affecting adoption of conservation structures

USDA programs since the 1930s have provided cost-sharing and technical assistance as incentives for implementation or installation of conservation buffers, structures, and practices (see Chapter 6.1, Overview of Conservation and Environmental Programs, for more discussion of past and current programs). While 1997-98 program efforts to conserve soil were directed heavily toward management type practices, including grass cover establishment and crop residue management, some land continues to be served by installation of terraces, sediment control structures, and other structural measures (table 4.2.13).

Characteristics of Conservation Adopters

What factors or characteristics influence farmers to adopt conservation tillage or other conservation practices? Policymakers can use this information to better design conservation policies and programs. A number of studies provide insights (for example see Soule, Tegene, and Wiebe, 2000; Rahm and Huffman, 1984; Norris and Batie, 1987; Belknap and Saupe, 1988; Gould, Saupe and Klemme, 1989; Fuglie and Klotz, 1994; Ervin and Ervin, 1982; Lynne, Shonkwiler and Rola, 1988; Featherstone and Goodwin, 1993; and Young and Shortle, 1984). Although these past studies examined different practices in different parts of the country at different points in time and did not use the same set of explanatory factors, a few general findings stand out. Farmers that operate larger acreages were more likely to adopt conservation tillage than their smaller counterparts. The age and education of the operator, land ownership, perception of an erosion problem, and increased contact with providers of conservation services (such as NRCS and extension personnel) were all positively related to adoption.

Table 4.2.13—Major practices implemented under USDA conservation programs, fiscal years 1988-1998

Practice and program		1988	1990	1992	1994	1995	1996	1997	1998
		Thousand acres treated							
Grass cover establishment:	ACP1	650	580	590	710	380	330	130	na
	CRP2	7,360.00	3,020.00	790	0	0	400.6	3,685.80	2,348.20
Grass cover improvement:	ACP	1,370.00	960	1,000.00	1,250.00	880	550	510	na
	CRP	470	170	90	0	0	89.3	0	2,100.30
Tree planting:	ACP	160	120	120	130	200	80	150	na
	CRP	500	190	100	0	0	79.4	1,057.50	145.7
	FIP3	160	150	160	190	140	105.7	0	0
Wildlife habitat establishment:	ACP	71.1	61.7	30.5	25.2	17.9	10.3	9.6	na
	CRP	390	650	10	0	0	5.6	0	874.5
Wetland conservation/rest: 4	ACP	24.1	18.9	16.8	11.5	6.7	5.7	4.7	na
	CRP	1.5	293.5	1.3	0	0	0	832.5	303.1
	WRP/EWRP5	0	0	43.4	105.7	159.6	48.9	129.3	211.9
	Water Bank	63.5	74.6	114.3	69	8.3	0	0	0
Riparian buffers or filter strips:	ACP	0	0	0	0.2	0.3	0.2	0.7	na
	CRP	15.2	8.9	1	0	0	34.5	52.4	262.5
Cropland protective cover:	ACP	750	580	650	410	20	0	0	na
Conservation tillage/residue:	ACP	450	430	560	530	210	40	40	na
	EQIP6							1,200.00	
Strip cropping systems:	ACP	140	150	100	70	50	30	130	na
Integrated crop management:	ACP	0	30	280	380	340	360	310	na
Nutrient management:	WQP	na	na	1,410.00	na	na	na	na	na
	EQIP							1,900.00	
Pesticide management:	WQP	na	na	910	na	na	na	na	na
	EQIP							1,200.00	
		Thousand acres served							
Grazing land protection:	ACP	3,600.00	4,720.00	3,660.00	2,680.00	2,130.00	1,790.00	1,750.00	na
	EQIP							3,200.00	
Irrigation water conservation:	ACP	820	690	690	850	520	390	370	na
	EQIP							400	
Terraces and diversions:	ACP	1,070.00	620	750	800	650	270	320	na
Water impoundments:	ACP	270	220	140	120	90	0	90	na
Sediment control structure:	ACP	250	210	200	190	160	120	110	na
Sod waterways:	ACP	220	180	200	260	160	120	100	na
		Number							
Agricultural waste systems:	ACP	1,947	2,348	3,844	4,116	3,132	2,258	3,153	na
	EQIP							103,000	

1 ACP = Agricultural Conservation Program. Became part of EQIP in 1998. 2 CRP = Conservation Reserve Program.
3 FIP= Forestry Incentives Program. 4 Includes wetlands and associated upland buffer areas. 5 WRP/EWRP = Wetland Reserve/ Emergency Wetland Reserve Program. 6 EQIP = Environmental Quality Incentives Program. Program was initiated in 1997.
na = not available. Blanks indicate that the program was not yet in operation.
Source: USDA, ERS, based on annual reports and other data for various programs.

Recent analysis of the ARMS survey data of corn producers in 1996 and soybean producers in 1997 also examined factors associated with adoption of conservation tillage and three types of structures—grassed waterways, strip cropping, or contour farming. Three factors were positively correlated with conservation tillage adoption for both corn and soybean producers—farm size, the percentage of the farm in corn or soybeans, and the field's designation as highly erodible land (HEL) (table 4.2.14). Farm program participation was also an important explanatory factor for soybean producers but not for corn producers. Younger and more highly educated corn farmers were more likely to adopt conservation tillage, but age and education were not important factors for soybean producers. Less likely to use conservation tillage were corn producers with limited resources, retired or residential/lifestyle, cash-rented land, and improved drainage.

For the adoption of the three structural practices, the designation of the sampled field as highly HEL was the only significant explanatory factor for soybean producers (table 4.2.14). HEL was also a significant and positive factor affecting adoption for corn producers, as was average annual precipitation. Negative influences on adoption by corn producers included farm size, the operator's age, the percent of the farm in corn or soybeans, and average annual temperature. Both cash-renters and share-renters were less likely to adopt conservation practices on corn land than were owner-operators. In addition, among corn producers, limited-resource, retired and residential/lifestyle farmers were less likely to adopt one of the conservation practices than were large family farmers.

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Table 4.2.14—Factors associated with the use conservation practices on corn and soybeans

Variable	Definition	Corn, 1996 Tillage	Corn, 1996 Structures[1]	Soybeans, 1997 Tillage	Soybeans, 1997 Structures1
		Association (- = negative; + = positive)[2]			
Farm size	Acres operated by the farmer	+	-	+	
Operator's age	Farm operator's age in years	-		-	
College education	Farm operator had some college education	+			
Program participation	Farm operator participated in government programs if he/she received any government payments			+	
LRRR farmer[3]	Small farm operators defined as limited-resource, retired, or residential/lifestyle farmers	-	-		
Corn-soy ratio	Percentage of the farm operation planted to corn or soybeans	+	-	+	
HEL designation	Field under study was classified as highly erodible by NRCS	+	+	+	+
Improved drainage	Field under study had some type of improved drainage	-			
Cash-renter	Field under study was operated by a renter under a cash lease	-	-		
Share-renter	Field under study was operated by a renter under a share lease		-		
Urban proximity	An index of population weighted by the inverse of distance squared				
Precipitation	30-year average annual precipitation		+		
Temperature	30-year average temperature		-		

[1] Conservation structures include grassed waterways, contour farming, and strip cropping.
[2] Only statistically significant associations at the 90 percent level are indicated, with a + indicating a positive correlation and – a negative one.
[3] LRRR=limited-resource, retired, or residential/lifestyle farmer.
Source: USDA, ERS, based on ARMS data, and Soule, et al. (2000).

References

Acton, D.F., and L.J. Gregorich (1995). "Understanding Soil Health," *The Health of Our Soils: Toward Sustainable Agriculture in Canada,* Acton and Gregorich (eds.). Center for Land and Biological Resources Research, Research Branch, Agriculture and Agri-Food Canada, Ottawa, Ontario.

Alexander, E.B. and J.C. McLaughlin (1992). "Soil Porosity as an Indicator of Forest and Rangeland Soil Condition (Compaction) and Relative Productivity," *Proceedings of the Soil Quality Standards Symposium, San Antonio, Texas, Oct. 1990*. Watershed and Air Management Report No. W0-WSA-2. U.S. Dept. Agr., U.S. Forest Service.

American Agricultural Economics Association Task Force (1986). *Soil Erosion and Soil Conservation Policy in the United States*. Occasional Paper No. 2, Iowa State University, Ames, IA.

American Society for Microbiology (1994). *Microbial Diversity Research Priorities*. Washington, DC.

Arshad, M.A., and G.M. Coen (1992). "Characterization of Soil Quality: Physical and Chemical Criteria," *American Journal of Alternative Agriculture*, Vol. 7, Numbers 1 and 2.

Baker, J. L. (1980). "Agricultural Areas as Nonpoint Sources of Pollution." in M. R. Overcash and J. M. Davidson [eds.] *Environmental Impact of Nonpoint Source Pollutio*n. Ann Arbor Science Publications, Inc., Ann Arbor, MI, pp. 275-310.

Baker, J. L. (1987). "Hydrologic Effects of Conservation Tillage and Their Importance to Water Quality," in T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash [eds.], *Effects of Conservation Tillage on Ground-water Quality: Nitrates and Pesticide*s. Lewis Pub., Chelsea, MI, pp. 113-124.

Baker, J. L. and H. P. Johnson (1979). *The Effect of Tillage System on Pesticides in Runoff from Small Watersheds*. Transactions of the American Society of Agricultural Engineers, 22: 554-559.

Baker, J. L. and J. M. Laflen (1979). "Runoff Losses of Surface-applied Herbicides as Affected by Wheel Tracks and Incorporation," *Journal of Environmental Qualit*y, 8: 602-607.

Baker, J. L., T. J. Logan, J. M. Davidson, and M. R. Overcash (1987). "Summary and Conclusions," in T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash [eds.] , *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticide*s. Lewis Pub., Chelsea, MI, pp. 277-281.

Belknap, J. and W. Saupe (1988). "Farm Family Resources and the Adoption of No-Plow Tillage in Southwestern Wisconsin." *North Central Journal of Agricultural Economics,* 10 (January):13-24.

Bengtson, R. L., L. M. Southwick, G. H. Willis, and C. E. Carter (1989*). The Influence of Subsurface Drainage Practices on Herbicide Loss.* Paper 89-2130. American Society of Agricultural Engineers, St. Joseph, MI.

Bennett, H. H., and W. C. Lowdermilk. (1938). "General Aspects of the Soil Erosion Problems," *Soil and Men: Yearbook of Agriculture, 1938*. U.S. Dept. of Agr., pp. 581-608.

Björklund, Johanna, Karin E. Limburg, and Torbjörn Rydberg (1999). "Impact of production intensity on the ability of the agricultural landscape to generate ecosystem services: An example from Sweden," *Ecological Economics* 29(1999) 269-291.

Brust, G.E., and B.R. Stinner (1991). "Crop Rotation for Insect, Plant Pathogen, and Weed Control," *CRP Handbook of Pest Management in Agriculture*, David Pimentel (ed.), Second Edition, Volume 1. CRC Press Inc. pp.217-230.

Bull, Len. (1993). *Residue and Tillage Systems for Field Crops*, U.S. Dept. Agr., Econ. Res. Serv., Staff Report No. AGES 9310, July.

Bull, Len, and Carmen Sandretto (1995). "The Economics of Agricultural Tillage Systems," *Farming for a Better Environment: A*

White Paper. Soil and Water Conservation Society, Ankeny, IA, pp. 35-37.

Bull, Len, Herman Delvo, Carmen Sandretto, and Bill Lindamood (1993). "Analysis of Pesticide Use by Tillage System in 1990, 1991 and 1992 Corn and Soybeans." *Agricultural Resources: Inputs Situation and Outlook Report,* AR-32, U.S. Dept. Agr., Econ. Res. Serv., October.

Clark, Richard T., James B. Johnson, and Jennifer Brundson (1994). "Economics of Residue Management," in *Crop Residue Management to Reduce Erosion and Improve Soil Quality: Northern Great Plains Region.* W.C. Moldenhauer and A.L. Black, (eds.) U.S. Dept. Agr., Agr. Res. Serv., Conservation Research Report No. 38.

Conservation Technology Information Center (1996). *A Checklist for U.S. Farmers*, West Lafayette, IN.

Council on Environmental Quality (CEQ) (1993). *Environmental Quality*. Twenty-fourth annual report. Executive Office of the President of the United States.

Daily, G.C., S. Alexander, P.R. Ehrlich, L. Goulder, J. Lubchenco, P.A. Matson, H.A. Mooney, S. Postel, S.H. Schneider, D. Tilman, and G.M. Woodwell (1997). "Ecosystem Services: Benefits Supplied to Human Societies by Natural Ecosystems," *Issues in Ecology*. No. 2. Spring. pp. 1-16.

Daily, G.C., P.A. Matson, and P. Vitousek (1997). "Ecosystem Services Supplied by Soil," in *Nature's Services, Societal Dependence on Natural Ecosystems*. G.C. Daily (ed.), Island Press. pp.113-32.

Dick, W. A. and T. C. Daniel (1987). "Soil Chemical and Biological Properties as Affected by Conservation Tillage: Environmental Implications," in T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash (eds.), *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*. Lewis Pub., Chelsea, MI, pp. 125-147.

Doran, J.W., and T.B. Parkin (1994). "Defining and Assessing Soil Quality," in *Defining Soil Quality for a Sustainable Environment*, D.C. Coleman, D.F. Bezdicek, and B.A. Stewart (eds.), SSSA Spec. Pub. No. 35, Madison, WI.

Doran, J.W., M. Sarrantonio, and R. Janke (1996). "Strategies to Promote Soil Quality and Health," *The Soil Quality Concept*. The Soil Quality Institute. U.S. Dept. of Agr., Natural Resources Conservation Service. Oct.

Doster, D.H., T. W. Pritchard, D. R. Griffith, and S. D. Parsons (1994). *Tillage Economics, One Planter Farms*. ID-191. Purdue University Cooperative Extension Service.

Duffy, Michael (1996). Personal conversation on Sept. 30, 1996. Department of Economics, Iowa State University, 560 Heady Hall, Ames, IA 50011.

Edwards, William M. (1995). "Effects of Tillage and Residue Management on Water for Crops," in *Crop Residue Management to Reduce Erosion and Improve Soil Quality: Appalachia and Northeast Region,* R.L. Blevins and W.C. Moldenhauer (eds.), U.S. Dept. Agr., Agr. Res. Serv., Conservation Research Report No. 41.

Edwards, William M., M. J. Shipitalo, L. B. Owens, and W. A. Dick (1993). "Factors Affecting Preferential Flow of Water and Atrazine Through Earthworm Burrows Under Continuous No-till Corn," *Journal of Environmental Quality*. Vol. 22, No. 3.

Ervin, C. A., and D.E. Ervin (1982). "Factors Affecting the Use of Soil Conservation Practices: Hypotheses, Evidence and Policy Implications." *Land Economics* 58 (August):277-291.

Fawcett, Richard S. (1987). "Overview of Pest Management for Conservation Tillage Systems," in T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash (eds.), *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*. Lewis Pub., Chelsea, MI, pp. 19-37.

Fawcett, Richard S., Dennis P. Tierney, Brian R. Christensen (1994). "Impact of Conservation Tillage on Reducing Runoff of Pesticides into Surface Waters." *Journal of Soil and Water Conservation*. Vol. 49, No. 2.

Featherstone, A.M. and B.K. Goodwin (1993). "Factors Influencing a Farmer's Decision to Invest in Long-Term Conservation Practices: Hypotheses, Evidence and Policy Implications." *Land Economics 69(February):67-81*.

Fox, G., A. Weersink, G. Sarwar, S. Duff, and B. Deen (1991). "Comparative Economics of Alternative Agricultural Production Systems: A Review." *Northeastern Journal of Agricultural and Resource Economics.* Vol. 30, No. 1.

Foy, C.D., A.M. Sadeghi, J.C. Ritchie, D.T. Krizek, J.R. Davis, and W.D. Kemper (1999). "Aluminum Toxicity and High Bulk Density: Role in Limiting Shoot and Root Growth of Selected Aluminum Indicator Plants and Eastern Gamagrass in an Acid Soil," *Tektran*. U.S. Dept. Agr., Agr. Res. Serv. May.

Fuglie, K.O. and C.A. Klotz (1994). "Adoption of Conservation Tillage in the Lower Susquehanna Basin." Paper presented at the NEARWA meetings, July 27-29, 1994.

Glenn, S. and J. S. Angle (1987). "Atrazine and Simazine in Runoff from Conventional and No-Till Corn Watersheds." *Agricultural Ecosystems and Environmen*t, 18: 273-280.

Gottfried, R., D. Wear, and R. Lee (1996). "Institutional solutions to market failure on the landscape scale." *Ecological Economics* 18(1996)133-140. Elsevier.

Gould, B.W., W.E. Saupe and R.M. Klemme (1989). "Conservation Tillage: The Role of Farm and Operator Characteristics and the Perception of Soil Erosion," *Land Economics* 65 (May 1989):167-182.

Griffith, D. R., E. J. Kladivko, J. V. Mannering, T. D. West, and S. D. Parsons (1988). "Long Term Tillage and Rotation Effects on Corn Growth and Yield on High and Low Organic Matter, Poorly Drained Soils*." Agronomy Journal* No. 4, pp. 599-605.

Griffith, D.R., J.F. Moncrief, D.J. Eckert, J.B. Swan, and D.D. Breitbach (1992). "Crop Response to Tillage Systems." *Journal of the American Society of Agricultural Engineers*, 22: 554-559.

Groot, Rudolf S. de (1992). *Functions of Nature, Evaluation of Nature in Environmental Planning, Management and Decision Making.* Wolters-Noordhoff. Netherlands.

Hall, J. K., N. L. Hartwig, and L. D. Hoffman (1984). "Cyanazine Losses in Runoff from No-Tillage Corn in 'Living' and Dead Mulches vs. Unmulched, Conventional Tillage." *Journal of Environmental Quality*, 13: 105-110.

Halvorson, Johnathan J., Jeffrey L. Smith, and R.I. Papendick (1997). "Issues of Scale for Evaluating Soil Quality." *Journal of Soil and Water Conservation,* 52(1). Jan/Feb.

Hanthorn, M. and M. Duffy (1983). *Corn and Soybean Pest Management Practices for Alternative Tillage Strategies*. Publication No. IOS-2, U.S. Dept. Agr., Econ. Res. Serv., Washington, DC

Heichel, G.H (1987). "Legumes as a source of nitrogen in conservation tillage system," in *The Role of Legumes in Conservation Tillage System*, J.F. Power (ed.), Ankeny, IA: Soil Conservation Society of America. pp. 29-35.

Heimlich, R., and N. Bills (1989). *Productivity and Erodibility of U.S. Cropland*. AER-604. U.S. Dept. Agr., Econ. Res. Serv.

Helling, C. S. (1987). "Effect of Conservation Tillage on Pesticide Dissipation." In T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash (eds.), *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*. Lewis Pub., Chelsea, MI, pp. 179-187.

Hornsby, A.G., and R.G. Brown (1992). "Soil Parameters Significant to Pesticide Fate*." Proceedings of the Soil Quality Standards Symposium*, San Antonio, TX, Oct. 1990. Watershed and Air Management Report No. W0-WSA-2. U.S. Dept. Agr., U.S. Forest Service.

Hudson, E. H. and J. F. Bradley (1995). "Economics of Surface-Residue Management, Southeast Region." *Crop Residue Management* *to Reduce Erosion and Improve Soil Quality: Southeast Region,* U.S. Dept. Agr., Agr. Res. Serv., Conservation Research Report No. 39.

Jawson, Michael D. (2001). Technical Review (personal correspondence). U.S. Dept. Agr., Agr. Res. Serv. May.

Jaenicke, Edward. C. (1998). *From the Ground Up, Exploring Soil Quality's Contribution to Environmental Health*. Policy Studies Report No. 10, Henry Wallace Institute for Alternative Agriculture, Greenbelt, MD. Oct.

Karlen, Douglas L., and Susan S. Andrews (2000). "The soil quality concept: A tool for evaluating sustainability," *DIAS Report No. 38, Plant Production*. Proceedings from NJF seminar 310, S. Elmholt, B. Stenberg, A. Grønlund, and V. Nuutinen, eds. Danish Institute of Agricultural Sciences. Tjele, Denmark. pp.15-26. Dec.

Karlen, D.L., N.S. Eash, and P.W. Unger (1992). "Soil and crop management effects on soil quality indicators." *American Journal of Alternative Agriculture*, Vol. 7, Nos. 1 and 2., pp. 48-55.

Karlen, D.L., M.J. Mausbach, J.W. Doran, R.G. Cline, R.F. Harris, and G.E. Schuman (1997). "Soil Quality: A Concept, Definition, and Framework for Evaluation." *Soil Science Society of America Journal 61(1)*.

Kellogg, Robert L., Margaret Stewart Maizel, and Don W. Goss (1992). *Agricultural Chemical Use and Ground Water Quality: Are There Potential Problem Areas?* U.S. Dept. Agr., Soil Conservation Service, Economic Research Service, Cooperative State Research Service, and National Center for Resource Innovations, Dec.

Kemper, W.D., E.E. Alberts, C.D. Foy, R.B. Clark, J.C. Ritchie and R.W. Zobel (1997). "*Aerenchyma*, acid tolerance, and associative nitrogen fixation enhance carbon sequestration in soil," in: R. Lal, J. M. Kimble, R.F. Follett and B.A. Stewart (eds.), *Management of Carbon Sequestration in Soil*. CRC Press, Boca Raton, FL. Pp. 221-234.

Kennedy, A.C., and R.I. Papendick (1995). "Microbial Characteristics of Soil Quality*," Journal of Soil and Water Conservation,* Vol. 50 (Nov.-Dec.), p. 243.

Kimberlin, L.W. (1976). *Conservation Needs and Status of Treatment of Erodible Cropland in Tillage Rotation*. Unpublished paper. U.S. Dept. of Agr., Soil Cons. Serv.

Kinsella, Jim. (1993). "Notes on Weed Control with Herbicides in the Production of Row Crops." Presented to Conservation Technology Information Center Executive Meeting, March 30.

Kladivko, E., L. Brown, and J. Baker (2001). "Pesticide Transport to Subsurface Tile Drains in Humid Regions of North America," *Critical Reviews in Environmental Science and Technology*, Vol. 31, Issue 1, Jan.

Lal, R., J. Kimble, R. Follett, and C. Cole (1998). *The Potential for U.S. Cropland to Sequester Carbon and Mitigate the Greenhouse Effect*. Ann Arbor Press, Chelsea, MI.

Larson, W.E., and F.J. Pierce (1991). "Conservation and enhancement of soil quality," in *Evaluation for Sustainable Land Management in the Developing World*, Vol. 2. J. Dumanski, et al. (eds.), International Board for Soil Research and Management, Bangkok, Thailand. Sept.

Larson, W.E., and F.J. Stewart (1992). "Thresholds for Soil Removal for Maintaining Cropland Productivity." *Proceedings of the Soil Quality Standards Symposium, San Antonio, Texas, Oct. 1990*. Watershed and Air Management Report No. W0-WSA-2. U.S. Dept. Agr., U.S. Forest Service.

Lewis, Jim (2001). Technical Review (personal correspondence). U.S. Dept. of Agr., Natural Resources Conservation Service. Apr.

Lin, W., P. Westcott, R. Skinner, S. Sanford, and D. Ugarte (2000). *Supply Response Under the 1996 Farm Act and Implications for the U.S. Field Crops Sector*. U.S. Dept. Agr., Econ. Res. Serv., TB No. 1888 (July).

Lynne, G.D., J.S. Shonkwiler and LR. Rola (1988). "Attitudes and Farmer Conservation Behavior." *American Journal of Agricultural Economics 70(February)*:12-19.

Martin, Alex R.(1995). "Weed Management," in *Crop Residue Management to Reduce Erosion and Improve Soil Quality: North Central Region,* W.C. Moldenhauer and L.N. Mielke (eds.), U.S. Dept. Agr., Agr. Res. Serv. Conservation Research Report No. 42.

Mausbach, Maurice J., Director of the Soil Quality Institute (1997). Personal correspondence. Jan.

McBride, William D. (1999). "The Economics of Crop Residue Management in U.S. Corn Production." Paper presented at the Southern Agricultural Economics Association meetings, Memphis, TN, January 30-February 3.

McCormack, D.E., and R. Heimlich (1985). *Erodible Soils: Definition and Classification.* A & P Staff Report No. 85-2. U.S. Dept. Agr., Soil Conservation Service.

Meisenbach, T. (1983). *Alternative Farming Task Force Report*. University of Nebraska, Lincoln, NE.

Melvin, Stewart W. (1995). "Effects of Crop Residue Management on Water Quality," in *Crop Residue Management to Reduce Erosion and Improve Soil Quality: North Central Region*, W.C. Moldenhauer and L.N. Mielke (eds.), U.S. Dept. Agr., Agr. Res. Serv., Conservation Research Report No. 42.

Mengel, D. B., J. F. Moncrief, and E. E. Schulte (1992). "Fertilizer Management," in *Conservation Tillage Systems and Management, Crop Residue Management with No-till, Ridge-till, Mulch-till*. Midwest Plan Service, MWPS-45, First Edition, Agricultural and Biosystems Engineering Department, Iowa State University, Ames, IA pp. 83-87.

Moldenhauer, W.C., W.D. Kemper, and L.N. Mielke (1995). "Long-Term Effects of Tillage and Crop Residue Management," in *Crop Residue Management to Reduce Erosion and Improve Soil Quality: North Central Region*, W.C. Moldenhauer and L.N. Mielke (eds.), U.S. Dept. Agr., Agr. Res. Serv., Conservation Research Report No. 42.

Monson, Mike and Nyle Wollenhaupt (1995). "Residue Management: Does It Pay? North Central Region," in *Crop Residue Management to Reduce Erosion and Improve Soil Quality: North Central Region*, W.C. Moldenhauer and L.N. Mielke (eds.), U.S. Dept. Agr., Agr. Res. Serv., Conservation Research Report No. 42.

National Research Council (NRC) (1993). *Soil and Water Quality: An Agenda for Agriculture*. National Academy Press, Washington, DC.

National Research Council (1989). *Alternative Agriculture*, National Academy Press, Washington D.C., pp. 135-150.

Nelson, Fredrick J., and Lyle P. Schertz. (eds.), 1996. *Provisions of the Federal Agriculture Improvement and Reform Act of 1996*. AIB No. 729. U.S. Dept. Agr., Econ. Res. Serv. Sept. http://www.ers.usda.gov/publications/aib729/aib729fm.pdf

Norris, P.E. and S.S. Batie (1987). "Virginia Farmers' Soil Conservation Decisions: An Application of Tobit Analysis." *Southern Journal of Agricultural Economics (July): 79-90*.

Olson, K.R. (1992). "Soil Physical Properties as a Measure of Cropland Productivity." *Proceedings of the Soil Quality Standards Symposium, San Antonio, Texas, Oct. 1990*. Watershed and Air Management Report No. W0-WSA-2. U.S. Dept. Agr., U.S. Forest Service.

Onstad, C. A. and W. B. Voorhees (1987). "Hydrologic Soil Parameters Affected by Tillage," in T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash (eds.), *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides.* Lewis Pub., Chelsea, MI, pp. 95-112.

Oskoui, K.E. and W.B. Voorhees (1991). "Economic Consequences of Soil Compaction." *American Society of Agricultural Engineers. Vol. 34(6).*

Padgitt, M., D. Newton, R. Penn, and C. Sandretto (2000). *Production Practices for Major Crops in U.S. Agriculture, 1990-97*. U.S. Dept. Agr., Econ. Res. Serv., SB No. 969, Aug.

Parr, J.F., R.I. Papendick, S.B. Horner, and R.E. Meyer (1992). "Soil Quality: Attributes and Relationship to Alternative and Sustainable Agriculture." *American Journal of Alternative Agriculture, Vol. 7, Numbers 1 and 2*.

Pierce, F.J., and W.E. Larson (1993). "Developing Criteria to Evaluate Sustainable Land Management*," Proceedings of the Eighth International Soil Management Workshop: Utilization of Soil Survey Information for Sustainable Land Use*, J.M. Kimble (ed.). U.S. Dept. Agr., Soil Cons. Serv., Lincoln, NE. May.

Power, J.F (1987). "Legumes: Their Potential Role in Agricultural Production." *American Journal of Alternative Agriculture* 2(2): 69-73.

Pretty, J.N., C. Brett, D. Gee, R.E. Hine, C.F. Mason, J.I.L. Morison, H. Raven, M.D. Rayment, and G. van der Bijl (2000). "An assessment of the total external costs of UK agriculture." *Agricultural Systems* 65 (2000) 113-136. Elsevier Science Ltd.

Rahm, M.R. and W.E. Huffman (1984). "The Adoption of Reduced Tillage: The Role of Human Capital and Other Variables." *American Journal of Agricultural Economics* 66(November 1984):405-413.

Rao, P.S.C., and A.G. Hornsby (1989). "Behavior of Pesticides in Soils and Waters." *Soil Science Fact Sheet SL 40 (revised)*. University of Florida, Gainesville, FL.

Ribaudo, M. (1986). *Reducing Soil Erosion: Offsite Benefits*. AER No. 561. U.S. Dept. Agr., Econ. Res. Serv., Sept.

Ruhl, J.B. 2000. "Farms, Their Environmental Harms, and Environmental Law," *Ecology Law Quarterly* 27:263.

Sander, K. W., W. W. Witt, and M. Barrett (1989). "Movement of Triazine Herbicides in Conventional and Conservation Tillage Systems," in D. L. Weigmann (ed.), *Pesticides in Terrestrial and Aquatic Environments*. Virginia Water Resources Center and Virginia Polytechnic Institute and State University, Blacksburg, VA. pp. 378-382.

Sandretto, Carmen and Len Bull (1996). "Conservation Tillage Gaining Ground," *Agricultural Outlook*, AO No. 232, U.S. Dept. Agr., Econ. Res. Serv., August.

Siemens, John C. and D. Howard Doster (1992). "Costs and Returns," in *Conservation Tillage Systems and Management, Crop Residue Management with No-till, Ridge-till, Mulch-till*. Midwest Plan Service, MWPS-45, First Edition, Agricultural and Biosystems Engineering Department, Iowa State University, Ames, IA pp. 34-41.

Seybold, C.A., M.J. Mausbach, D.L. Karlen, and H.H. Rogers (1997). "Quantification of Soil Quality," in *Advances in Agronomy*, B.A. Stewart and R. Lal (eds.), Lewis Publishers, New York, NY.

Söderbaum, P. (1987). "Environmental Management: A Non-Traditional Approach." *Journal of Economic Issues*. Vol. XXI, No. 1. March.

Soule, M., A. Tegene, and K. Wiebe (2000). "Land Tenure and the Adoption of Conservation Practices." *Amer. J. Agr. Econ*. 82(4) (Nov.): 993-1005.

Torsvik, V., J. Goksoy, and F.L. Daae (1990). "High Diversity in DNA of Soil Bacteria." *Applied Environmental Microbiology 56.*

U.S. Department of Agriculture, Economic Research Service (ERS) (1993). "Water Quality Effects of Crop Residue Management." *Agricultural Resources: Cropland, Water, and Conservation Situation and Outlook Report*, AR No. 30, May.

U.S. Department of Agriculture, Economic Research Service (1997). *Agricultural Resources and Environmental Indicators, 1996-97*, AHB No. 712, Washington, DC, July.

U.S. Department of Agriculture, Natural Resources Conservation Service (2000*). Summary Report, 1997 National Resources Inventory. Revised December 2000.* (Available on http://www.nhq.nrcs.usda.gov/NRI/1997/summary_report/original/contents.html)

U.S. Department of Agriculture, Soil Conservation Service (1973). *Land-Capability Classification (LCC).* AH No. 210. Jan.

U.S. Department of Agriculture, Soil Conservation Service (1983). "Application of Soil Information: Soil Interpretations." Part 603. *National Soil Handbook*.

U.S. Department of Agriculture, Soil Conservation Service (1989a). *The Second RCA Appraisal: Soil, Water and Related Resources on Nonfederal Land in the United States.*

U.S. Department of Agriculture, Soil Conservation Service (1989b). *Summary Report, 1987 National Resources Inventory.* SB No. 790. Dec.

U.S. Department of Agriculture, Soil Conservation Service (SCS) (1993). *Soil Survey Manual*. AH No. 18.

U.S. Department of Agriculture, Soil Conservation Service (1994). *Summary Report, 1992 National Resources Inventory.* July.

Vesterby, M., and K.S. Krupa (1993). "Effects of Urban Land Conversion on Agriculture." in *Urbanization and Development Effects on the Use of Natural Resources*, E. Thunberg and J. Reynold (eds.), Southern Rural Development Center and Farm Foundation. SRDC No. 169.

Wagenet, R. J. (1987). "Processes Influencing Pesticide Loss with Water under Conservation Tillage," in T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash (eds.), *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*. Lewis Pub., Chelsea, MI, pp. 190-204.

Warkentin, B.P., and H.F. Fletcher (1977). "Soil quality for intensive agriculture," *Proceedings of International Seminar on Soil Environment and Fertilizer Management*. National Institute of Agricultural Science, Tokyo.

Wauchope, R. D. (1987. "Effects of Conservation Tillage on Pesticide Loss with Water." In T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash [eds.] *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*. Lewis Pub., Chelsea, MI, pp. 205-215.

Wauchope, R. D.,T. M. Buttler, A. G. Hornsby, P. W. M. Augustijn Beckers, and J. P. Burt (1992). "The SCS/ARS/CES Pesticide Properties Database for Environmental Decision-making." Published as Volume 123 of *Reviews of Environmental Contamination and Toxicology* by Springer-Verlag, New York, NY.

Waynne, Thorne D (1978). "Crop Characteristics and Cropping Systems," in *Soil, Water and Crop Production*, AVI publishing Company, Hartford, CT.

Weber, J. B. and R. L. Warren (1993). "Herbicide Behavior in Soils: A Pesticide/Soil Ranking System for Minimizing Ground Water Contamination." *Proceedings of the Northeastern Weed Science Societ*y, 47.

Weersink, A., M. Walker, C. Swanton and F.E. Shaw (1992). "Costs of Conventional and Conservation Tillage Systems." *Journal of Soil and Water Conservatio*n. Vol. 47, No. 4.

World Resources Institute (1992). *World Resources, 1992-1993*. Oxford University Press: Oxford, England.

Young, C. Edwin and James S. Shortle (1984). "Investment in Soil Conservation Structures: The Role of Operator and Operation Characteristics." *Agricultural Economics Research 36*:10-15.

Recent ERS Reports Related to Soil Management and Conservation

"**Conservation Tillage Firmly Planted in U.S. Agriculture**," *Agricultural Outlook*, March 2001 (Carmen Sandretto). Farmers across the Nation used conservation tillage (no-till, ridge-till, and mulch-till) on more than 109 million acres of farmland in 2000, over 36 percent of U.S. planted cropland area and up from 26 percent in 1990. Expansion in no-till accounts for most of the growth in conservation tillage in the last decade.

Adoption of Agricultural Production Practices: Lessons Learned from the U.S. Department of Agriculture Area Studies Project, AER 792, Jan. 2001 (Margriet Caswell et al.). This project looked at the extent of adoption of nutrient, pest, soil, and water management practices and assessed the factors that affected adoption for a wide range of management strategies across different natural resource regions. An operator's education had a significantly positive effect on his or her adoption of information-intensive technologies, such as the use of biological pest control or nitrogen testing. Ownership had less of an impact on adoption of non-structural practices than expected.

Production Practices for Major Crops in U.S. Agriculture, 1990-97, SB 969, Aug. 2000 (M. Padgitt, D. Newton, R. Penn, and C. Sandretto). 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. Three-fourths of the cropland acres were treated with commercial fertilizers, and 90 percent with at least some pesticides. Eighty-two percent of the crop acreage was in a crop rotation. Nearly 80 percent of the surveyed crop acres were scouted for pests, but soil and tissue testing for pests occurred on less than 5 percent.

Soil Erosion and Conservation in the United States: An Overview, AIB 718, Oct. 1995 (R. Magleby, C. Sandretto, W. Crosswhite, and C.T. Osborn). Soil erosion on agricultural land in the United States does not pose an immediate threat to the Nation's ability to produce food and fiber. However, erosion is impairing long-term productivity in some areas and is the largest contributor to nonpoint source pollution of the Nation's waterways. Over half of the erosion comes from slightly more than a quarter of total cropland acreage.

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