*Chapter 4.2*

# Soil Management and Conservation

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*Soil quality is critical for plant growth, and therefore important to agriculture and rural ecosystems. Management practices that are appropriate for local soil characteristics and climate can enhance soil quality. These beneficial practices include crop rotations, crop residue management (including cover crops and conservation tillage), and various field/landscape structures and buffers. Crop residue management is generally a cost-effective method of erosion control. It usually maintains or increases crop yields, but requires fewer resources than intensive structural measures and can be implemented in a timely manner to meet conservation needs.*

## Introduction

Crop production and its environmental effects depend on the quality of soil. Soil provides the physical, chemical, and biological processes required to sustain most terrestrial plant and animal life. Soil regulates water flow from rainfall, snowmelt, and irrigation between infiltration, root-zone storage, deep percolation, and runoff (National Research Council, 1993). Soil acts as a buffer between production activities and the environment by facilitating the cycling and decomposition of organic wastes and nutrients (carbon, nitrogen, phosphorus, and others), as well as the degradation of nitrates, pesticides, and other toxic substances that are potential pollutants in water or air (Kemper et al., 1997). Soil quality determines how well soil performs its functions.

Soil has both inherent and dynamic qualities. Inherent qualities are those factors, such as texture, that affect a soil's natural ability to function, but do not change easily. Dynamic qualities depend on how a soil is managed. Soils respond differently to management, depending on the inherent properties of the soil and the surrounding landscape. Traditional measures of soil quality include land capability and suitability, productivity, erodibility, and vulnerability to leach pesticides and nitrates (Karlen et al., 1997). A comprehensive soil quality measure would combine these physical attributes with broader societal concerns, such as potential surface-water pollution from field runoff, protecting long-term soil productivity, and the health of agricultural/rural ecosystems.

Soil quality can be maintained or enhanced through the use of appropriate crop production technologies and related resource management systems that involve the composition, structure, and function of entire ecosystems. Beneficial farm-level soil management practices are designed to maintain the quality and long-term productivity of the soil and to mitigate environmental damage from crop production. These practices include crop rotations, crop

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residue management (including cover crops) and conservation tillage, and field/landscape scale engineering structures and buffers like grass waterways, terraces, contour-farming, strip-cropping, underground drainage outlets, and surface diversion/drainage channels. Also beneficial to soil quality are certain nutrient (see Chapter 4.4), pest (see Chapter 4.3), and irrigation practices (see Chapter 4.6).

The appropriateness of soil management technologies depends on topographic and agro-climatic conditions; site-specific technical, economic, and financial feasibility; farmer attitudes, perceptions, and resources; and society's attitudes toward the range of offsite effects associated with agricultural production (USDA, 1997). Soil management practices can enhance soil quality by:

- Increasing ground cover and organic matter,
- Tilling sparingly to reduce organic matter degradation and compaction,
- Managing fertilizer and pesticide use to minimize their impact on nontarget organisms and water/air quality, and
- Increasing the diversity of plants, wildlife, and other organisms to help control pest populations.

## Crop Rotation Systems

Crop rotation (see box, "Cropping Pattern Definitions") can help conserve soil, maintain its fertility, and control pests, diseases, harmful insects, and weeds. Rotating high-residue and/or closely grown crops with row crops can reduce soil losses on erodible soils. Closely grown field grain crops—such as wheat, barley, and oats, as well as hay and forage crops—provide vegetative cover to reduce soil erosion and water runoff while adding organic matter. In addition, these crops help to control broadleaf weeds and may help control weed infestation in subsequent crops. Crop rotation also helps to break disease and insect cycles. Leguminous crops can increase nitrogen levels in the soil, and cover crops planted in the fall help reduce erosion from winter and spring storms, hold nutrients that might otherwise be lost, enhance the soil's biological processes, and lengthen periods of active plant growth (to increase nutrient cycling, disease suppression, soil aggregation, and carbon sequestration).

### *Crop Rotation System Use For Major Crops*

With the exception of cotton, rotational cropping in some form dominates major crop production in the United States. The most common rotation system for both corn and soybeans is a corn-soybean rotation. This combination reduces erosion (compared with continuous-corn or continuous-soybeans); helps control disease, insects, and weeds; and enables soybeans to fix nitrogen for use by the subsequent corn crop. Approximately 75 percent of corn acres and 80 percent of soybean acres in the 10 major producing States used this rotation system in the most recent surveyed year (2001 for corn and 2002 for soybeans) (figs. 4.2.1 and 4.2.2).

## Cropping Pattern Definitions

The following definitions were applied to 3-year crop sequence data reported in the Agricultural Resource Management Survey 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, with the exception of winter wheat in 1996. For this crop, only 2 years were used to determine the rotation due to data limitations.

**Monoculture or continuous same crop:** 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.

**Continuous row crops:** 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.

**Continuous small grain crops:** crop sequence, excluding continuous same crop, where only small grain crops (wheat, barley, oats, rye, etc.) are planted for 3 consecutive years

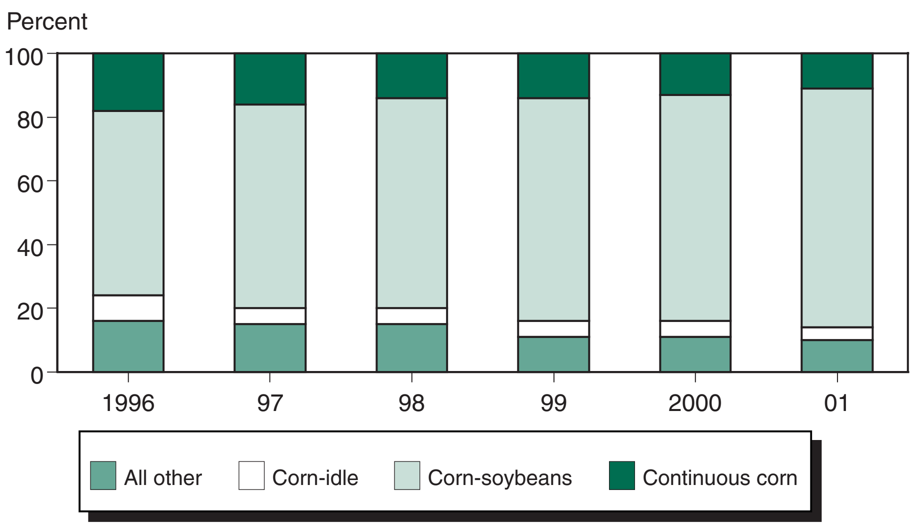
**Row crop/small grain rotation:** crop sequence where some combination of row crops and small grains are planted over the 3-year period.

**Rotation with meadow crops:** 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:** crop sequence that includes idle, diverted, or fallowed land in 1 or more of the previous years.

Figure 4.2.1

**Cropping patterns on corn for 10 major production States, 1996-2001**

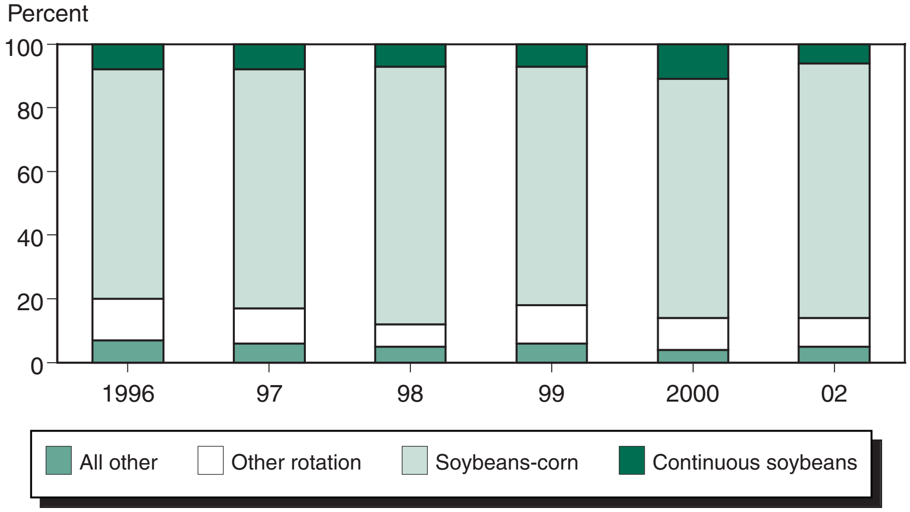



Source: USDA, ERS, Agricultural Resource Management Surveys.

Winter wheat in a continuous cropping system (no rotation) reached a high of 47 percent of acreage planted in 2000 (most recent surveyed year) (figure 4.2.3). Winter wheat in rotation with a row crop or small grain (including double cropping) has trended upward in recent years, while rotation with fallow/idle has declined. Cotton is grown primarily in a continuous cropping system, with 73 percent of acreage in the five major States using this system in 2003. The most common cotton rotation was cotton-row crop at around 20 percent (fig. 4.2.4).

Figure 4.2.2

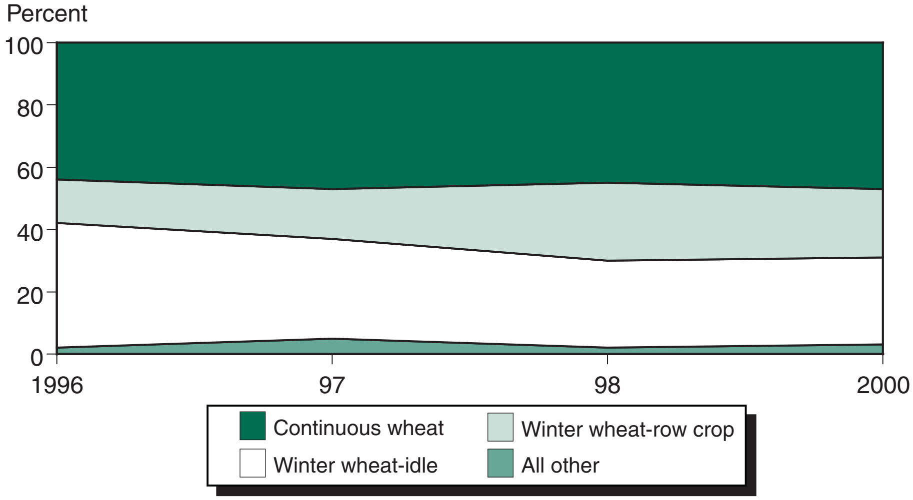
**Cropping patterns on soybeans for 10 major production States, 1996-2002**




Source: USDA, ERS, Agricultural Resource Management Surveys.

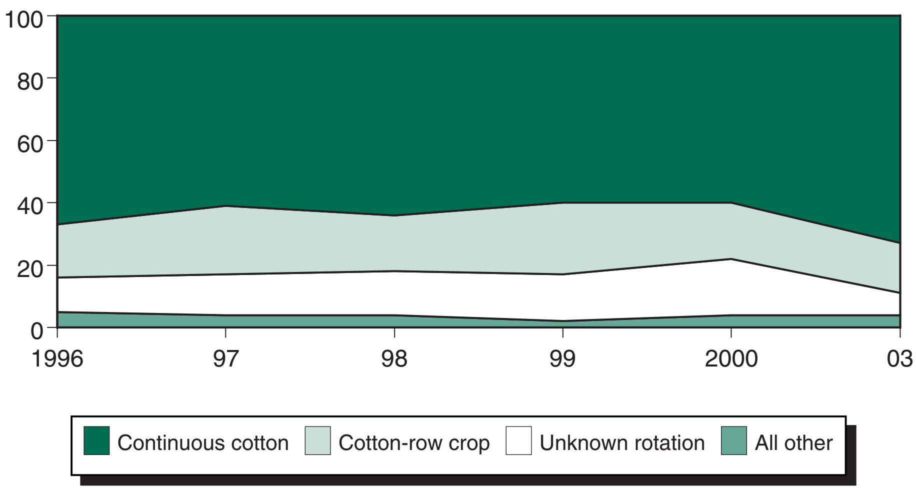
Figure 4.2.3

**Cropping patterns on winter wheat for 10 major production States, 1996-2000**




Source: USDA, ERS, Agricultural Resource Management Surveys.

Figure 4.2.4
**Cropping patterns on cotton for 5 major production States, 1996-2003**




Source: USDA, ERS, Agricultural Resource Management Surveys.

## *Economic Factors Affecting Farmers' Choices*

A farmer chooses a cropping pattern based mostly on the relative rate of return resulting from differences in yields, costs and returns, and government policy. Crop rotations usually result in yields higher than those achieved with continuous cropping under similar conditions. Rotations that add organic matter can improve soil tilth and water-holding capacity, and thus increase crop yields. Grain yields following legumes are often 10 to 20 percent higher than continuous grain, regardless of the amount of fertilizer applied (Heichel, 1987; Power, 1987). Corn following wheat produces a greater yield than continuous-corn with the same amount of fertilizer, even though wheat is not a legume and cannot fix atmospheric nitrogen (Power, 1987). Rotations with legumes can increase available soil nitrogen and reduce the need for commercial nitrogen fertilizers. Legumes in a rotation are most effective in humid and sub-humid climates where they do not decrease subsoil moisture for subsequent crops.

Crop rotations—by alternating a susceptible crop with a nonhost crop—can help to control a variety of pests by disrupting their life cycles. Soil microbiology and beneficial insects thrive under crop rotations, and this helps control disease and other pests, particularly those that attack plant roots. For example, rotating corn with soybeans can reduce the need for insecticide treatment when the field is in corn by reducing the number of corn rootworm larvae in the soil (although the effectiveness of this practice may be decreasing in some areas).

The diversification inherent in rotations can be an economic buffer against fluctuating prices of crops or production inputs and against the vagaries of weather, disease, and pest infestations.

### *Policies and Programs Affecting Cropping Patterns*

Federal policies influence farmers' choices of crops and management practices. Past commodity programs that restricted base acreage to program crops encouraged monoculture or continuous planting of the same crop. Starting with the 1990 Food, Agriculture, Conservation and Trade Act, farmers were given the option to diversify (without incurring a penalty) their program crop base acres. Farmers began to grow other crops and/or use rotations in response to changes in prices and loan deficiency payments.

Under the 1985 Food Security Act and subsequent farm legislation, 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 5.3, Compliance Provisions for Soil and Wetland Conservation). Rotating row crops with less erosive crops such as small grains and hay/pasture is a key part of some conservation plans for HEL, usually in combination with cover crops, crop residue management, and conservation tillage.

## 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 returns by reducing fuel, machinery, and labor costs while maintaining or increasing crop yields, but requires fewer resources than intensive structural measures and can be implemented in a timely manner to meet conservation needs (USDA, 1997). 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 System Definitions").

### *Why Manage Residue?*

Historically, crop residues were removed from farm fields for livestock bedding, feed, or sale. Residues that remained on the field were burned off to control pests, plowed under, or tilled into the soil. Culturally, some farmers would 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 government encouragement—because of new knowledge about residue's benefits and improved planters, crop protection technologies, and the like (USDA, 1997).

CRM can benefit society through enhanced environmental quality and farmers through higher overall economic returns. However, adoption of CRM may not lead to clear environmental benefits in all regions and may not be 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

## Crop Residue Management and Tillage System Definitions

| Unmanaged | Crop Residue Management (CRM) | | | |
|---|---|---|---|---|
| Intensive- or conventional-till | Reduced-till | 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 | Full-width tillage, but further decrease in tillage intensity | Only the tops of ridges are tilled | No tillage performed since harvest of previous crop |
| <15% residue cover remaining | 15-30% residue cover remaining | 30% or greater residue cover remaining on soil surface after planting | | |

**Crop Residue Management (CRM)—**A year-round 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 is an umbrella term encompassing several tillage systems including conservation tillage (no-till, ridge-till, and mulch-till), and reduced-till. (Note: reduced-till is not considered a part of conservation 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. 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. No-till, ridge-till and mulch-till are thee common types of conservation tillage systems.

**No-till—**Residue from the previous crop is undisturbed from harvest to planting except for nutrient injection or narrow strips. Weed control is primarily accomplished with crop protection products.

**Ridge-till—**Residue from the previous crop is undisturbed from harvest to planting except for nutrient injection. Planting is completed in a seedbed prepared on 4- to 6-inch high ridges that are formed and rebuilt during row cultivation for weed control. Residue is left on the surface between ridges.

**Mulch-till—**A full-width tillage system usually involving one to three tillage passes over the field performed prior to and/or during planting, that leaves, after planting, at least 30 percent of the soil surface covered with residue.

**Reduced-till (15-30% residue)—**Full-width tillage usually involving one or more tillage passes over the field performed prior to and/or during planting, that leaves 15-30 percent residue cover after planting.

**Conventional-till or intensive-till (less than 15% residue)—**Full-width tillage that is performed prior to and/or during planting, that generally involves plowing with a moldboard plow and/or other intensive tillage equipment. Less than 15 percent residue cover remains on the soil surface after planting.

seeding new crops through heavier surface residue into untilled soil and even directly into killed sod (USDA, 1997).

### *Trends In Crop Residue Management Use*

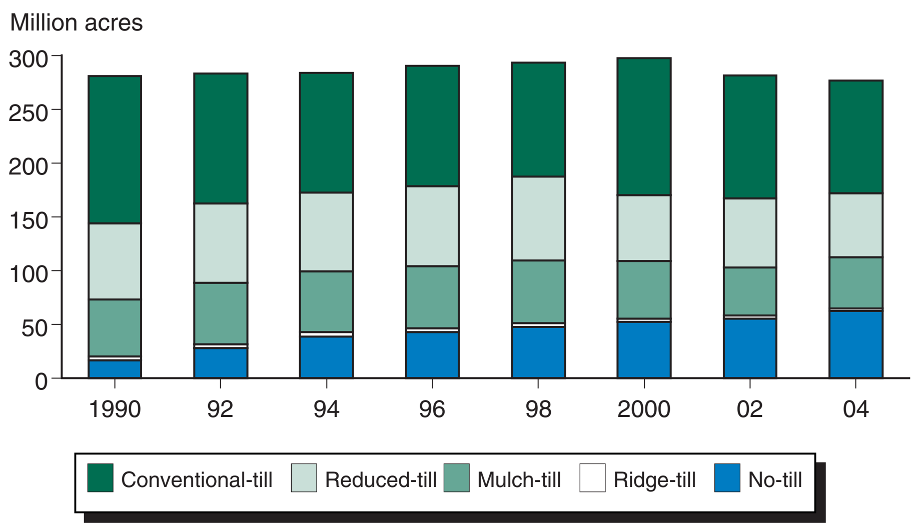
According to the Conservation Technology Information Center's National Crop Residue Management Survey, U.S. farmers practiced CRM on about 172 million acres in 2004, or 62 percent of planted acreage, up from 144 million acres in 1990. Conservation tillage accounted for 41 percent of U.S. planted crop acreage in 2004, compared with 26 percent in 1990. Most of the growth in conservation tillage since 1990 has come from expanded adoption of no-till (fig. 4.2.5), which can leave 70 percent or more of the soil surface covered with crop residue. U.S. crop area planted with no-till more than tripled from 17 million acres (6 percent) to 62 million acres (22 percent) between 1990 and 2004 (CTIC, 2005).

### *Economic Incentives For CRM Adoption*

Yield response with soil-conserving tillage systems varies with location, soil characteristics, climate, cropping patterns, and level of management skills (Sandretto, 2001). 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 (CTIC, 1996). Benefits from improved moisture retention in the root zone usually increase crop yields, especially under dry conditions. In some areas, these benefits permit a change in the cropping pattern to reduce the frequency of moisture-conserving fallow periods (USDA, 1997). Other benefits derive from more timely preparation for double cropping, with better yields as one result.

Figure 4.2.5

**Tillage types, 1990-2004**




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

Crop yields can be significantly reduced by pest populations, which frequently change under different tillage systems and are also affected by cropping pattern. Maintaining or increasing yields when changing tillage systems requires skillful use of the various means of pest control, including crop variety selection, proper application of crop protection products, row cultivation, cover crops, crop rotation, scouting, and other integrated pest management practices (see Chapter 4.3, "Pest Management Practices"). Use of crop protection products on major crops differs among tillage systems, but the effects related to tillage systems are difficult to distinguish from differences in pest populations due to other factors, including use of other pest control practices (USDA, 1997).

Choice of tillage system affects machinery, chemical, fuel, and labor costs. Decreasing the intensity of tillage and/or reducing the number of tillage operations (fewer trips over the field) reduces labor requirements per acre, extends equipment life, increases the area covered, and reduces fuel and maintenance costs. These cost savings may be offset by increased crop protection costs and the fertilizers required to attain optimal yields (Sandretto, 2001). Conservation tillage may increase net returns on the entire farming operation even if returns for a particular crop do not increase. For example, a tillage system that requires substantially less labor per acre and reduces returns per acre only slightly may free up labor to serve more acres or generate more income elsewhere (Sandretto and Bull, 1996).

### *Potential Environmental Benefits of Crop Residue Management*

Soil quality can benefit from minimum tillage and maximum residue, and this combination contributes to improved ecosystem health in several ways.

Tillage systems that leave substantial amounts of crop residue evenly distributed over the soil surface **reduce soil erosion**, from reduced wind erosion and reduced kinetic impact of rainfall, surface sediment transport and water runoff; with increased water infiltration and moisture retention (Edwards, 1995). Several field studies conducted on small watersheds under natural rainfall on highly erodible land have shown that erosion rates with the moldboard plow can be reduced by 70 percent or more with conservation tillage (USDA, 1997).

Surface residues help intercept nutrients and chemicals and hold them in place until they are used by the crop or degrade into harmless components, which provide **cleaner surface runoff** (USDA, 1997). Increased organic matter in the top layer of soil results in cleaner runoff, and thus benefits water quality by reducing the flow of contaminants such as sediment and adsorbed/dissolved chemicals into lakes and streams (USDA, 1997; 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). Average herbicide runoff losses from treated fields under 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).

Crop residues on the soil surface, by creating tiny dams, enhance infiltration, reduce surface-crust formation, and slow water runoff, which **increases water infiltration and soil moisture** (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 and provide water quality benefits. 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).

Less intensive tillage reduces breakdown of crop residue and loss of soil organic matter **improving long-term soil quality**. Carbon sequestration may increase to build soil organic matter, enhance biological (including earthworm) activity, and maintain long-term productivity. Conservation tillage, particularly continuous 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 equipment weight and horsepower requirements (CTIC, 1996).

These potential environmental benefits suggest a **public role** in encouraging adoption of crop residue management practices. Conservation compliance provisions of the 1985 Food Security Act and subsequent farm legislation have given farmers additional incentives to adopt CRM to control erosion (and thereby improve water quality), particularly on highly erodible cropland (HEL) (see Chapter 5.3, "Compliance Provisions for Soil and Wetland Conservation"). Expanded use of CRM practices on non-HEL indicates that producers are motivated by the potential to reduce costs, improve efficiency, and/or increase soil productivity.

## Conservation Buffers and Structures

Soil and water conservation structures and buffer zones can significantly reduce erosion and sediment transport caused by rainfall and water runoff. These structures allow for surface water to be captured onsite or slowed and diverted from the field via erosion-resistant waterways, channels, or outlets. While management practices, such as crop rotation, crop residue management (including cover crops), and conservation tillage practices help to control erosion, they may not sufficiently control runoff water after heavy rainfall events. Soil- and water-conserving structures, therefore, are important in farm soil management systems. Engineering structures and buffer zones for soil and water conservation vary significantly across crop production regions to reflect the wide variation in soil, climate, and cropping patterns.

A variety of USDA programs since the 1930s have provided cost-sharing and technical assistance for conservation buffers, structures, and practices (see Chapter 5.4, "Working-Land Payment Programs"). While recent program efforts have been directed toward management practices, including vegetative cover establishment and crop residue management, some cropland continues to be served by installation of terraces and other structural measures to better control sediment and water runoff.

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