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QUICK INTRODUCTION TO SOIL EROSION

Revised 06/18/13 by Chris Lawrence, NRCS State Cropland Agronomist, Richmond, VA
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This document consists of excerpts from the book *Building Soils for Better Crops, 3rd Edition*. These excerpts provide a good plain-language introduction to erosion principles and terminology while emphasizing the key link between erosion and soil health.

After you read these passages, please try to obtain and read the full version of this excellent book, which is available from: *http://www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition*

THIRD EDITION

BUILDING SOILS FOR BETTER CROPS

SUSTAINABLE SOIL MANAGEMENT

BY FRED MAGDOFF AND HAROLD VAN ES

SARE
Sustainable Agriculture Research & Education
HANDBOOK 10

BUILDING SOILS FOR BETTER CROPS

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HANDBOOK SERIES BOOK 10

Published in 2009 by the Sustainable Agriculture Research and Education (SARE) program,
with funding from the National Institute of Food and Agriculture, U.S. Department of Agriculture

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This book was published by the Sustainable Agriculture Research and Education (SARE) program under cooperative agreements with USDA's National Institute of Food and Agriculture, University of Maryland and University of Vermont.

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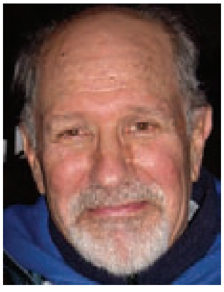
Library of Congress Cataloging-in-Publication Data

Magdoff, Fred, 1942-
Building soils for better crops : sustainable soil management / by Fred Magdoff and Harold van Es. -- 3rd ed.
p. cm. -- (Handbook series ; bk. 10)
Includes bibliographical references and index.
ISBN 978-1-888626-13-1
1. Soil management. 2. Humus. I. Van Es, Harold, 1958- II. Sustainable Agriculture Research & Education (Program) III. Title. IV. Series: Sustainable Agriculture Network handbook series ; bk. 10.
S592.8.M34 2009
631.4--dc22
2009031856

Authors: Fred Magdoff and Harold van Es
Contributing Writer (farmer profiles): Amy Kremen
Production Manager: Dena Leibman
Copy Editing: Jill Mason
Graphic Design: Kirsten Ankers
Cover Illustration: Frank Fretz
Indexing: Jill Mason
Printing: Printed by Linemark Printing using 100% wind power on process-chlorine-free, 100% post-consumer-waste paper.

CONTENTS

ABOUT THE AUTHORS



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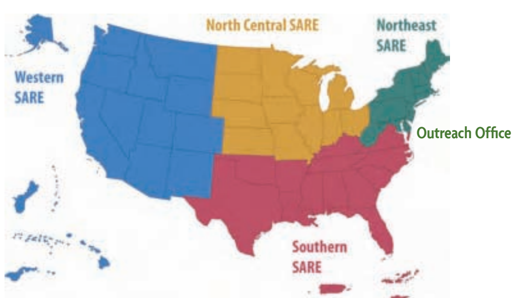

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Chapter 1

HEALTHY SOILS

All over the country [some soils are] worn out, depleted, exhausted, almost dead. But here is comfort: These soils possess possibilities and may be restored to high productive power, provided you do a few simple things.

—C.W. BURKETT, 1907

It should come as no surprise that many cultures have considered soil central to their lives. After all, people were aware that the food they ate grew from the soil. Our ancestors who first practiced agriculture must have been amazed to see life reborn each year when seeds placed in the ground germinated and then grew to maturity. In the Hebrew Bible, the name given to the first man, Adam, is the masculine version of the word "earth" or "soil" (*adama*). The name for the first woman, Eve (or Hava in Hebrew), comes from the word for "living." Soil and human life were considered to be intertwined. A particular reverence for the soil has been an important part of the cultures of many civilizations, including American Indian tribes.

Although we focus on the critical role soils play in growing crops, it's important to keep in mind that soils also serve other important purposes. Soils govern whether rainfall runs off the field or enters the soil and eventually helps recharge underground aquifers. When a soil is denuded of vegetation and starts to degrade, excessive runoff and flooding are more common. Soils also absorb, release, and transform many different chemical compounds. For example, they help to purify wastes flowing from the septic system fields in your back yard. Soils also provide habitats for a diverse group of organisms, many of which are very important—such as those bacteria that produce antibiotics. Soil organic matter stores a huge amount of atmospheric carbon. Carbon, in the form of carbon dioxide, is a greenhouse gas associated with global warming. So by increasing soil organic matter, more carbon can be stored in soils, reducing the global warming potential. We also use soils as a foundation for roads, industry, and our communities.

WHAT KIND OF SOIL DO YOU WANT?

Soil consists of four important parts: mineral solids, water, air, and organic matter. Mineral solids are sand, silt, and clay and mainly consist of silicon, oxygen, aluminum, potassium, calcium, and magnesium. The soil water, also called the soil solution, contains dissolved

Photo by Dan Anderson

nutrients and is the main source of water for plants. Essential nutrients are made available to the roots of plants through the soil solution. The air in the soil, which is in contact with the air above ground, provides roots with oxygen and helps remove excess carbon dioxide from respiring root cells. When mineral and organic particles clump together, aggregates are formed. They create a soil that contains more spaces, or pores, for storing water and allowing gas exchange as oxygen enters for use by plant roots and soil organisms and the carbon dioxide (CO_2) produced by organisms leaves the soil.

Farmers sometimes use the term *soil health* to describe the condition of the soil. Scientists usually use the term *soil quality*, but both refer to the same idea—how good is the soil in its role of supporting the growth of high-yielding, high-quality, and healthy crops? How would you know a high-quality soil from a lower-quality soil? Most farmers and gardeners would say that they know one when they see one. Farmers can certainly tell you which of the soils on their farms are of low, medium, or high quality. They know high-quality soil because it generates higher yields with less effort. Less rainwater runs off, and fewer signs of erosion are seen on the better-quality soils. Less power is needed to operate machinery on a healthy soil than on poor, compacted soils.

The first thing many might think of is that the soil should have a sufficient supply of nutrients throughout the growing season. But don't forget, at the end of the season there shouldn't be too much nitrogen and phosphorus left in highly soluble forms or enriching the soil's surface. Leaching and runoff of nutrients are most likely to occur after crops are harvested and before the following year's crops are well established.

We also want the soil to have good tilth so that plant roots can fully develop with the least amount of effort. A soil with good tilth is more spongy and less compact than one with poor tilth. A soil that has a favorable and stable soil structure also promotes rainfall infiltration and water storage for plants to use later. For good root growth and drainage, we want a soil with sufficient depth before a compact soil layer or bedrock is reached.

We want a soil to be well drained, so it dries enough in the spring and during the following rains to permit timely field operations. Also, it's essential that oxygen is able to reach the root zone to promote optimal root health—and that happens best in a soil without a drainage problem. (Keep in mind that these general characteristics do not hold for all crops. For example, flooded soils are desirable for cranberry and paddy rice production.)

We want the soil to have low populations of plant disease and parasitic organisms so plants grow better. Certainly, there should also be low weed pressure, especially of aggressive and hard-to-control weeds. Most soil organisms are beneficial, and we certainly want high amounts of organisms that help plant growth, such as earthworms and many bacteria and fungi.

THINK LIKE A ROOT!

If you were a root, what would *you* like from an ideal soil? Surely you'd want the soil to provide adequate nutrients and to be porous with good tilth, so that you could easily grow and explore the soil and so that soil could store large quantities of water for you to use when needed. But you'd also like a very biologically active soil, with many beneficial organisms nearby to provide you with nutrients and growth-promoting chemicals, as well as to keep potential disease organism populations as low as possible. You would not want the soil to have any chemicals, such as soluble aluminum or heavy metals, that might harm you; therefore, you'd like the pH to be in a proper range for you to grow. You would also not want any subsurface layers that would restrict your growth deep into the soil.

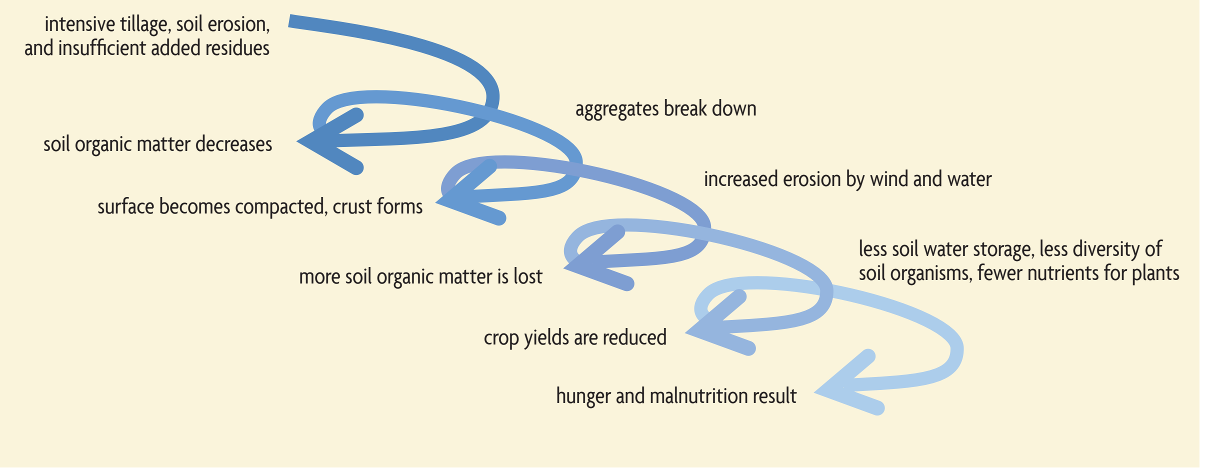

Figure 1.1. The downward spiral of soil degradation. Modified from Topp et al. (1995).

A high-quality soil is free of chemicals that might harm the plant. These can occur naturally, such as soluble aluminum in very acid soils or excess salts and sodium in arid soils. Potentially harmful chemicals also are introduced by human activity, such as fuel oil spills or application of sewage sludge with high concentrations of toxic elements.

A high-quality soil should resist being degraded. It also should be resilient, recovering quickly after unfavorable changes like compaction.

THE NATURE AND NURTURE OF SOILS

Some soils are exceptionally good for growing crops, and others are inherently unsuitable; most are in between. Many soils also have limitations, such as low organic matter content, texture extremes (coarse sand or heavy clay), poor drainage, or layers that restrict root growth. Iowa's loess-derived prairie soils are naturally blessed with a combination of silt loam texture and high organic matter content. By every standard for assessing soil health, these soils—in their virgin state—would rate very high.

The way we care for, or *nurture*, a soil modifies its inherent nature. A good soil can be abused through years of poor management and turn into one with poor health, although it generally takes a lot of mistreatment to reach that point. On the other hand, an innately challenging soil may be very "unforgiving" of poor management and quickly become even worse. For example, a heavy clay loam soil can be easily compacted and turn into a dense mass. Both naturally good and poor soils can be productive if they are managed well. However, they will probably never reach parity, because some limitations simply cannot be completely overcome. The key idea is the same that we wish for our children—we want our soils to reach their fullest potential.

HOW DO SOILS BECOME DEGRADED?

Although we want to emphasize healthy, high-quality soils because of their ability to produce high yields of crops, it is also crucial to recognize that many soils in the U.S. and around the world have become degraded—they have become what many used to call "worn-out" soils. Degradation most commonly occurs when erosion and decreased soil organic matter levels initiate a downward spiral resulting in poor crop production (figure 1.1). Soils become compact, making it hard for water to infiltrate and roots to develop properly. Erosion continues, and nutrients decline to levels too low for good crop growth. The development of saline (too salty) soils under irrigation in arid regions is another cause of reduced soil health. (Salts added in the irrigation water need to be leached beneath the root zone to avoid the problem.)

Historically, soil degradation caused significant harm to many early civilizations, including the drastic loss of productivity resulting from soil erosion in Greece and many locations in the Middle East (such as present-day Israel, Jordan, Iraq, and Lebanon). This led either to colonial ventures to help feed the citizenry or to the decline of the culture.

Tropical rainforest conditions (high temperature and rainfall, with most of the organic matter near the soil surface) may cause significant soil degradation within two or three years of conversion to cropland. This is the reason the "slash and burn" system, with people moving to a new patch of forest every few years, developed in the tropics. After farmers depleted the soils in a field, they would cut down and burn the trees in the new patch, allowing the forest and soil to regenerate in previously cropped areas.

> ...what now remains of the formerly rich land is like the skeleton of a sick man, with all the fat and soft earth having wasted away and only the bare framework remaining. Formerly, many of the mountains were arable. The plains that were full of rich soil are now marshes. Hills that were once covered with forests and produced abundant pasture now produce only food for bees. Once the land was enriched by yearly rains, which were not lost, as they are now, by flowing from the bare land into the sea. The soil was deep, it absorbed and kept the water in the loamy soil, and the water that soaked into the hills fed springs and running streams everywhere. Now the abandoned shrines at spots where formerly there were springs attest that our description of the land is true.
>
> —PLATO, 4TH CENTURY B.C.E.

The westward push of U.S. agriculture was stimulated by rapid soil degradation in the East, originally a zone of temperate forest. Under the conditions of the humid portion of the Great Plains (moderate rainfall and temperature, with organic matter distributed deeper in the soil), it took many decades for the effects of soil degradation to become evident.

The extent of erosion on a worldwide basis is staggering—it is estimated that erosion has progressed far enough to decrease yields on an estimated 16% of all the world's agricultural soils. The value of annual crop loss due to soil degradation by erosion is around $1 billion. And erosion is still a major global problem, robbing people of food and each year continuing to reduce the productivity of the land.

HOW DO YOU BUILD A HEALTHY, HIGH-QUALITY SOIL?

Some characteristics of healthy soils are relatively easy to achieve—for example, an application of limestone will make a soil less acid and increase the availability of many nutrients to plants. But what if the soil is only a few inches deep? In that case, there is little that can be done within economic reason, except on a very small, garden-size plot. If the soil is poorly drained because of a restricting subsoil layer of clay, tile drainage can be installed, but at a significant cost.

We use the term *building soils* to emphasize that the nurturing process of converting a degraded or low-quality soil into a truly high-quality one requires understanding, thought, and significant actions. This is also true for maintaining or improving already healthy soils. Soil organic matter has a positive influence on almost all of the characteristics we've just discussed. As we will discuss in chapters 2 and 8, organic matter is even critical for managing pests—and improved soil management should be the starting point for a pest reduction program on

EVALUATING YOUR SOILS

Score cards and laboratory tests have been developed to help farmers assess their soils, using scales to rate the health of soils. In the field, you can evaluate the presence of earthworms, severity of erosion, ease of tillage, soil structure and color, extent of compaction, water infiltration rate, and drainage status. Then you rate crops growing on the soils by such characteristics as their general appearance, growth rates, root health, degree of resistance to drought, and yield. It's a good idea for all farmers to fill out such a score card for every major field or soil type on their farms every few years, or, alternatively, to send in soil to a lab that offers soil health analyses. But even without doing that, you probably already know what a really high-quality and healthy soil—one that would consistently produce good yields of high-quality crops with minimal negative environmental impact—would be like. You can read more on evaluating soil health in chapter 22.

every farm. Appropriate organic matter management is, therefore, the foundation for high-quality soil and a more sustainable and thriving agriculture. It is for this reason that so much space is devoted to organic matter in this book. However, we cannot forget other critical aspects of management—such as trying to lessen compaction by heavy field equipment and good nutrient management.

Although the details of how best to create high-quality soils differ from farm to farm and even field to field, the general approaches are the same—for example:

- Implement a number of practices that add organic materials to the soil.
- Add diverse sources of organic materials to the soil.
- Minimize losses of native soil organic matter.
- Provide plenty of soil cover—cover crops and/or surface residue—to protect the soil from raindrops and temperature extremes.
- Minimize tillage and other soil disturbances.
- Whenever traveling on the soil with field equipment, use practices that help develop and maintain good soil structure.
- Manage soil fertility status to maintain optimal pH levels for your crops and a sufficient supply of nutrients for plants without resulting in water pollution.
- In arid regions, reduce the amount of sodium or salt in the soil.

Later in the book we will return to these and other practices for developing and maintaining healthy soils.

A LARGER VIEW

In this book we discuss the ecological management of soils. And although the same basic principles discussed here apply to all soils around the world, the problems may differ in specifics and intensity and different mixes of solutions may be needed on any particular farm or in any ecological zone. It is estimated that close to half the people in the world are deficient in nutrients and vitamins and that half the premature deaths that occur globally are associated with malnutrition. Part of the problem is the low amount of nutrient-rich foods such as vegetables and fruits in diets. When grains form too large a part of the diet, even if people obtain sufficient calories and some protein, the lack of other nutrients results in health problems. Although iron, selenium, cobalt, and iodine deficiencies in humans are rare in the U.S., they may occur in developing countries whose soils are depleted and nutrient poor. It frequently is an easier and healthier solution to get these nutrients into people's diets by increasing plant content through adding these essential elements to the soil (or through irrigation water for iodine) rather than to try to provide everyone with supplements. Enhancing soil health—in all its aspects, not just nutrient levels—is probably one of the most essential strategies for providing nutritious food to all the people in the world and ending the scourge of hunger and malnutrition.

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Chapter 3

AMOUNT OF ORGANIC MATTER IN SOILS

The depletion of the soil humus supply is apt to be a fundamental cause of lowered crop yields.

—J.H. HILLS, C.H. JONES, AND C. CUTLER, 1908

The amount of organic matter in any particular soil is the result of a wide variety of environmental, soil, and agronomic influences. Some of these, such as climate and soil texture, are naturally occurring. Agricultural practices also influence soil organic matter levels. Tillage, crop rotation, and manuring practices all can have profound effects on the amount of soil organic matter. Hans Jenny carried out pioneering work on the effect of natural influences on soil organic matter levels in the U.S. more than sixty years ago.

The amount of organic matter in a soil is the result of all the additions and losses of organic matter that have occurred over the years (figure 3.1). In this chapter, we will look at why different soils have different organic matter levels. While we will be looking mainly at the total amount of organic matter, keep in mind that all three "types" of organic matter—the living, dead, and very dead—serve critical roles and the amount of each of these may be affected differently by natural factors and agricultural practices.

Anything that adds large amounts of organic residues to a soil may increase organic matter. On the other hand, anything that causes soil organic matter to decompose more rapidly or be lost through erosion may deplete organic matter.

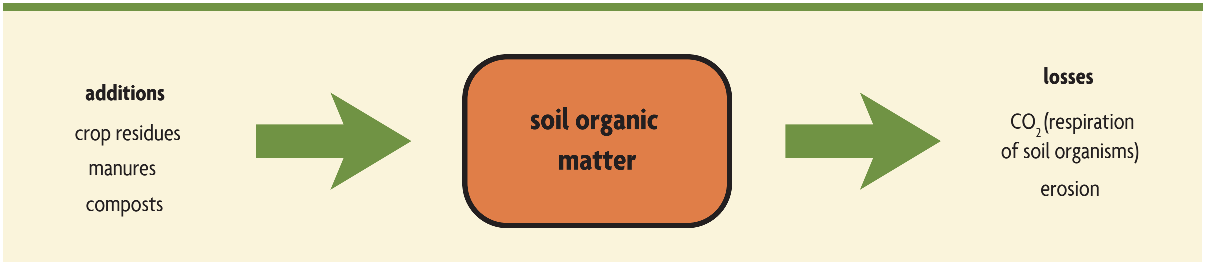


Figure 3.1. Additions and losses of organic matter from soils.

Photo by Jerry DeWitt

STORAGE OF ORGANIC MATTER IN SOIL

Organic matter is protected in soils by:

- Formation of strong chemical organic matter—clay (and fine silt) bonds
- Being inside small aggregates (physically protected)
- Conversion into stable substances such as humic materials that are resistant to biological decomposition
- Restricted drainage, sometimes related to texture, that reduces the activity of the organisms that need oxygen to function
- Char produced by incomplete burning

Large aggregates are made up of many smaller ones that are held together by sticky substances and fungal hyphae. Organic matter in large aggregates—but outside of the small aggregates that make up the larger ones—and freely occurring particulate organic matter (the "dead") are available for soil organisms to use. However, poor aeration resulting from restricted drainage because of a dense subsurface layer, compaction, or being in the bottom of a slope may cause a low rate of use of the organic matter. So the organic matter needs to be in a favorable chemical form and physical location for organisms to use it; *plus*, the environmental conditions in the soil—adequate moisture *and* aeration—need to be sufficient for most soil organisms to use the residues and thrive.

If additions are greater than losses, organic matter increases. When additions are less than losses, there is a depletion of soil organic matter. When the system is in balance and additions equal losses, the quantity of soil organic matter doesn't change over the years.

NATURAL FACTORS

Temperature

In the United States, it is easy to see how temperature affects soil organic matter levels. Traveling from north to south, higher average temperatures lead to less soil organic matter. As the climate gets warmer, two things tend to happen (as long as rainfall is sufficient): More vegetation is produced because the growing season is longer, and the rate of decomposition of organic materials in soils increases because soil organisms work more rapidly and are active for longer periods of the year at higher temperatures. Faster decomposition with warmer temperatures becomes the dominant influence determining soil organic matter levels.

Rainfall

Soils in arid climates usually have low amounts of organic matter. In a very dry climate, such as a desert, there is little growth of vegetation. Decomposition is also low because of low amounts of organic inputs and low micrörganism activity when the soil is dry. When it finally rains, a very rapid burst of decomposition of soil organic matter occurs. Soil organic matter levels generally increase as average annual precipitation increases. With more rainfall, more water is available to plants, and more plant growth results. As rainfall increases, more residues return to the soil from grasses or trees. At the same time, soils in high rainfall areas may have less organic matter decomposition than well-aerated soils—decomposition is slowed by restricted aeration.

Soil Texture

Fine-textured soils, containing high percentages of clay and silt, tend to have naturally higher amounts of soil organic matter than coarse-textured sands or sandy loams. The organic matter content of sands may be less than 1%; loams may have 2% to 3%, and clays from 4% to more than 5%. The strong chemical bonds that develop between organic matter and clay and fine silt protect organic molecules from attack and decomposition by microorganisms and their enzymes. Also, clay and fine silt combine with organic matter to form very small aggregates that in turn protect the organic matter inside from organisms and their enzymes. In addition, fine-textured soils tend to have smaller pores and less oxygen than coarser soils. This also limits decomposition rates, one of the reasons that organic matter levels in fine-textured soils are higher than in sands and loams.

Soil Drainage and Position in the Landscape

Decomposition of organic matter occurs more slowly in poorly aerated soils. In addition, some major plant compounds such as lignin will not decompose at all in anaerobic environments. For this reason, organic matter tends to accumulate in wet soil environments. When conditions are extremely wet or swampy for a very long period of time, organic (peat or muck) soils, with organic matter contents of over 20%, develop. When these soils are artificially drained for agricultural or other uses, the soil organic matter will decompose rapidly. When this happens, the elevation of the soil surface actually decreases. Homeowners on organic soils in Florida normally sink the corner posts of their houses below the organic level to provide stability. Originally level with the ground, some of those homes now perch on posts atop a soil surface that has decreased so dramatically that the owners can park their cars under their homes.

Soils in depressions at the bottom of hills receive runoff, sediments (including organic matter), and seepage from upslope and tend to accumulate more organic matter than drier soils farther upslope. In contrast, soils on a steep slope or knoll will tend to have low amounts of organic matter because the topsoil is continually eroded.

Type of Vegetation

The type of plants that grow on the soil as it forms can be an important source of natural variation in soil organic matter levels. Soils that form under grassland vegetation generally contain more organic matter and a deeper distribution of organic matter than soils that form under forest vegetation. This is probably a result of the deep and extensive root systems of grassland species (figure 3.2). Their roots have high "turnover" rates, for root death and decomposition constantly occur as new roots are formed. Dry natural grasslands also frequently experience slow-burning fires from lightning strikes, which contribute biochar that is very resistant to degradation. The high levels of organic matter in soils that were once in grassland partly explain why these are now some of the most productive agricultural soils in the world. By contrast, in forests, litter accumulates on top of the soil, and surface organic layers commonly contain over 50% organic matter. However, subsurface mineral layers in forest soils typically contain less than 2% organic matter.

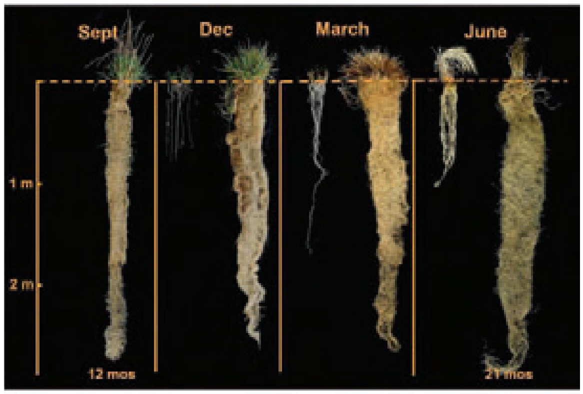


Figure 3.2. Root systems of annual wheat (at left in each panel) and wheatgrass, a perennial, at four times of the year. Approximately 25% to 40% of the wheatgrass root system dies back each year, adding considerable amounts of organic matter, and then grows back again. Compared to annual wheat, it has a longer growing season and has much more growth both above ground and below ground. Wheatgrass was 12 and 21 months old when the first and last photos were taken. Photo by the Land Institute.

Acidic Soil Conditions

In general, soil organic matter decomposition is slower under acidic soil conditions than at a more neutral pH. In addition, acidic conditions, by inhibiting earthworm activity, encourage organic matter to accumulate at the soil surface, rather than distributing throughout the soil layers.

ROOT VS. ABOVEGROUND RESIDUE CONTRIBUTION TO SOIL ORGANIC MATTER

Roots, already being well distributed and in intimate contact with the soil, tend to contribute a higher percentage of their weight to the more persistent organic matter ("dead" and "very dead") than above-ground residues. In addition, compared to aboveground plant parts, many crop roots have higher amounts of materials such as lignin that decompose relatively slowly. One experiment with oats found that only one-third of the surface residue remained after one year, while 42% of the root organic matter remained in the soil and was the main contributor to particulate organic matter. In another experiment, five months after spring incorporation of hairy vetch, 13% of the aboveground carbon remained in the soil, while close to 50% of the root-derived carbon was still present. Both experiments found that the root residue contributed much more to particulate organic matter (active, or "dead") than did aboveground residue.

HUMAN INFLUENCES

Loss of topsoil that is rich in organic matter by erosion has dramatically reduced the total amount of organic matter stored in many soils after they were developed for agriculture. Crop production obviously suffers when part of the most fertile layer of the soil is removed. Erosion is a natural process and occurs on almost all soils. Some soils naturally erode more easily than others, and the problem is greater in some regions than others. However, agricultural practices accelerate erosion. It is estimated that erosion in the United States is responsible for annual losses of about a billion dollars in available nutrients and many times more in total soil nutrients.

Unless erosion is severe, a farmer may not even realize a problem exists. But that doesn't mean that crop yields are unaffected. In fact, yields may decrease by 5% to 10% when only moderate erosion occurs. Yields may suffer a decrease of 10–20% or more with severe erosion. The results of a study of three midwestern soils (referred to as Corwin, Miami, and Morley), shown in table 3.1, indicate that erosion greatly influences both organic matter levels and water-holding ability. Greater amounts of erosion decreased the organic matter content of these loamy and clayey soils. In addition, eroded soils stored less available water than minimally eroded soils.

Organic matter also is lost from soils when organisms decompose more organic materials during the year than are added. This occurs as a result of practices that accelerate decomposition, such as intensive tillage and crop production systems that return low amounts of residues. Much of the rapid loss of organic matter following the conversion of grasslands to agriculture has been attributed to large reductions in residue inputs, accelerated mineralization of organic matter because of plowing, and erosion.

Tillage Practices

Tillage practices influence both the amount of topsoil erosion and the rate of decomposition of organic matter. Conventional plowing and disking of a soil to prepare a smooth seedbed break down natural soil aggregates and

Table 3.1
Effects of Erosion on Soil Organic Matter and Water

Soil	Erosion	Organic Matter (%)	Available Water Capacity (%)
Corwin	slight	3.03	12.9
	moderate	2.51	9.8
	severe	1.86	6.6
Miami	slight	1.89	16.6
	moderate	1.64	11.5
	severe	1.51	4.8
Morley	slight	1.91	7.4
	moderate	1.76	6.2
	severe	1.60	3.6

Source: Schertz et al. (1985).

destroy large, water-conducting channels. The soil is left in a physical condition that is highly susceptible to wind and water erosion.

The more a soil is disturbed by tillage practices, the greater the potential breakdown of organic matter by soil organisms. During the early years of agriculture in the United States, when colonists cleared the forests and planted crops in the East and farmers later moved to the Midwest to plow the grasslands, soil organic matter decreased rapidly. In fact, the soils were literally mined of this valuable resource. In the Northeast and Southeast, it was quickly recognized that fertilizers and soil amendments were needed to maintain soil productivity. In the Midwest, the deep, rich soils of the tall-grass prairies were able to maintain their productivity for a long time despite accelerated loss of soil organic matter and significant amounts of erosion. The reason for this was their unusually high reserves of soil organic matter and nutrients at the time of conversion to cropland.

Rapid decomposition of organic matter by organisms usually occurs when a soil is intensively tilled. Incorporating residues with a moldboard plow, breaking aggregates open, and fluffing up the soil allow microorganisms to work more rapidly. It's something like opening up the air intake on a wood stove, which lets in more oxygen and causes the fire to burn hotter. In Vermont, we found a 20% decrease in organic matter after five years of growing corn on a clay soil that had previously been in sod for decades. In the Midwest, many soils lost 50% of their organic matter within forty years of beginning cropping. Rapid loss of soil organic matter occurs in the early years because of the high initial amount of active ("dead") organic matter available to microorganisms. After much of the active portion is lost, the rate of loss slows and what remains is mainly the already well-decomposed "passive" or "very dead" materials. With the current interest in reduced (conservation) tillage, growing row crops in the future should not have such a detrimental effect on soil organic matter. Conservation tillage practices leave more residues on the surface and cause less soil disturbance than conventional moldboard plow–and–disk tillage. In fact, soil organic matter levels usually increase when no-till planters place seeds in a narrow band of disturbed soil, leaving the soil between planting rows undisturbed. Residues accumulate on the surface because the soil is not inverted by plowing. Earthworm populations increase, taking some of the organic matter deeper into the soil and creating channels that also help water infiltrate into the soil. The beneficial effects of minimizing tillage on soil organic matter levels are often observed quickly at the soil surface; but deeper changes are much slower to develop, and depletion at depth is sometimes observed. In the upper Midwest there is conflicting evidence as to whether a long-term no-till approach results in greater accumulation of soil organic matter (SOM) than a conventional tillage system when the full profile is considered. In contrast, significant increases in profile SOM have been routinely observed under no-till in warmer locations.

Crop Rotations and Cover Crops

Levels of soil organic matter may fluctuate during the different stages of a crop rotation. SOM may decrease, then increase, then decrease, and so forth. While annual row crops under conventional moldboard-plow cultivation usually result in decreased soil organic matter, perennial legumes, grasses, and legume-grass forage crops tend to increase soil organic matter. The high amount of root production by hay and pasture crops, plus the lack of soil disturbance, causes organic matter to accumulate in the soil. This effect is seen in the comparison of organic matter increases when growing alfalfa compared to corn silage (figure 3.3). In addition, different types of crops result in different quantities of residues being returned to the soil. When corn grain is harvested, more residues are left in the field than after soybeans, wheat, potatoes, or lettuce harvests. Harvesting the same crop in different ways leaves

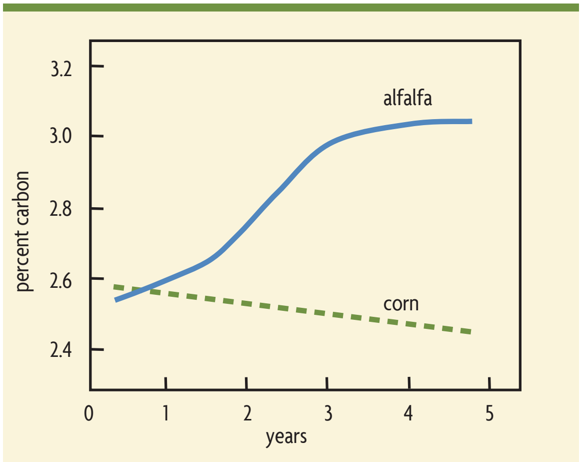


Figure 3.3. Organic carbon changes when growing corn silage or alfalfa. Redrawn from Angers (1992).

different amounts of residues. When corn grain is harvested, more residues remain in the field than when the entire plant is harvested for silage or stover is used for purposes like bioenergy (figure 3.4).

Soil erosion is greatly reduced and topsoil rich in organic matter is conserved when rotation crops, such as grass or legume hay, are grown year-round. The permanent soil cover and extensive root systems of sod crops account for much of the reduction in erosion.

Having sod crops as part of a rotation reduces loss of topsoil, decreases decomposition of residues, and builds up organic matter by the extensive residue addition of plant roots.

Use of Synthetic Nitrogen Fertilizer

Fertilizing very nutrient-deficient soils usually results in greater crop yields. A fringe benefit of this is a greater amount of crop residue—roots, stems, and leaves—resulting from larger and healthier plants. However, nitrogen fertilizer has commonly been applied at much higher rates than needed by plants, frequently by as much as 50%. Evidence is accumulating that having extra mineral nitrogen in soils actually helps organisms better decompose crop residues—resulting in decreased levels of soil organic matter. (See chapter 19 for a detailed discussion of nitrogen management.)

Use of Organic Amendments

An old practice that helps maintain or increase soil organic matter is to apply manures or other organic residues generated off the field. A study in Vermont during the 1960s and 1970s found that between 20 and 30 tons (wet weight, including straw or sawdust bedding)

a) corn silage

b) corn grain

Figure 3.4. Soil surface after harvest of corn silage or corn grain. Photos by Bill Jokela and Doug Karlen.

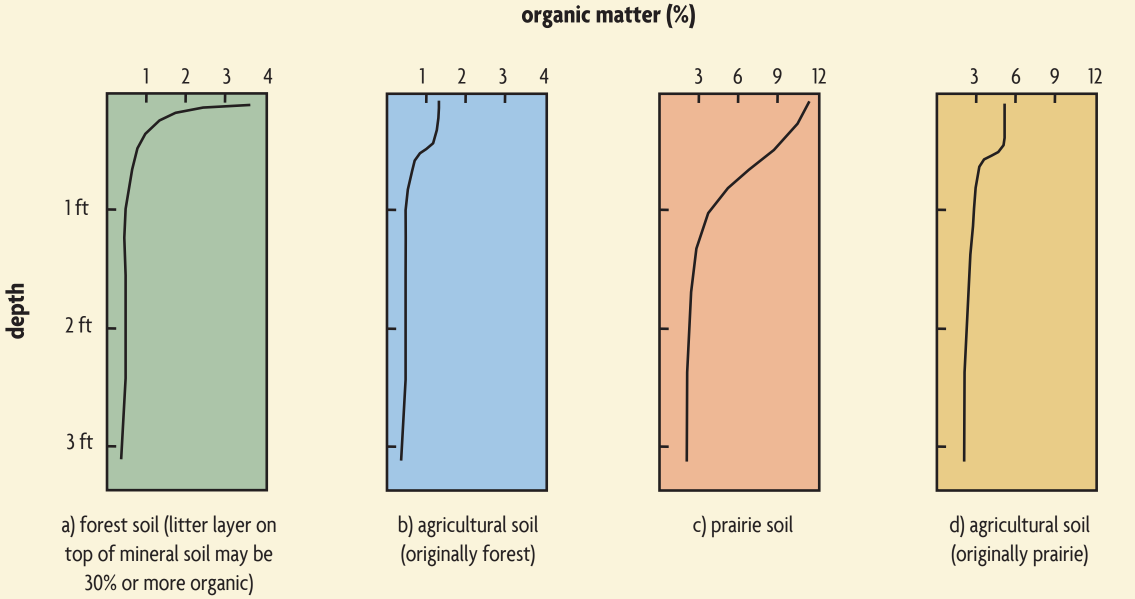


Figure 3.5. Examples of soil organic matter content with depth (note different scales for forest and prairie soils). Modified from Brady and Weil (2008).

of dairy manure per acre were needed to maintain soil organic matter levels when silage corn was grown each year. This is equivalent to one or one and a half times the amount produced by a large Holstein cow over the whole year. Varying types of manure—like bedded, liquid stored, digested, etc.—can produce very different effects on soil organic matter and nutrient availability. Manures differ in their initial composition and also are affected by how they are stored and handled in the field—for example, surface applied or incorporated.

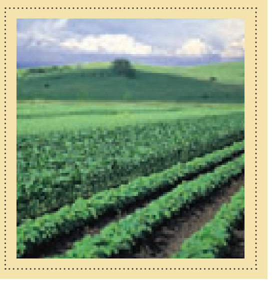
ORGANIC MATTER DISTRIBUTION IN SOIL
With Depth in the Soil

In general, more organic matter is present near the surface than deeper in the soil (see figure 3.5). This is one of the main reasons that topsoils are more productive than subsoils exposed by erosion or mechanical removal of surface soil layers. Some of the plant residues that eventually become part of the soil organic matter are from the aboveground portion of plants. In most cases, plant roots are believed to contribute more to a soil's organic matter than the crop's shoots and leaves. But when the plant dies or sheds leaves or branches, depositing residues on the surface, earthworms and insects help incorporate the residues on the surface deeper into the soil. The highest concentrations of organic matter, however, remain within 1 foot of the surface.

Litter layers that commonly develop on the surface of forest soils may have very high organic matter contents (figure 3.5a). Plowing forest soils after removal of the trees incorporates the litter layers into the mineral soil. The incorporated litter decomposes rapidly, and an agricultural soil derived from a sandy forest soil in the North or a silt loam in the South would likely have a distribution of organic matter similar to that indicated in figure 3.5b. Soils of the tall-grass prairies have a deeper distribution of organic matter (see figure 3.5c). After cultivation of these soils for 50 years, far less organic matter remains (figure 3.5d).

Chapter 6

SOIL DEGRADATION: EROSION, COMPACTION, AND CONTAMINATION



Hard ground makes too great resistance, as air makes too little resistance, to the surfaces of roots.

—JETHRO TULL, 1733

EROSION

Soil loss during agricultural production is mainly caused by water, wind, and tillage. Additionally, landslides (gravitational erosion) may occur on very steep slopes. While water erosion and landslides occur under extremely wet soil conditions, wind erosion is a concern with very dry soil. Tillage erosion occurs on fields that are either steep or have undulating topography and is not affected by soil moisture conditions, because the soil movement downslope is caused by the action of farm implements.

Erosion is the result of the combination of an erosive force (water, wind, or gravity), a susceptible soil, and several other management- or landscape-related factors. A soil's inherent susceptibility to erosion (its erodibility) is primarily a function of its texture (generally, silts more than sands and clays), its aggregation (the strength and size of aggregates, which are related to the amount of organic matter), and soil water conditions. Many management practices can reduce soil erosion, although different types of erosion have different solutions.

Water Erosion

Water erosion occurs on bare, sloping land when intense rainfall rates exceed a soil's infiltration capacity and runoff begins. The water concentrates into tiny streamlets, which detach the saturated soil and transport the particles downhill. Runoff water gains more energy as it moves down the slope, scouring away more soil and also carrying more agricultural chemicals and nutrients, which end up in streams, lakes, and estuaries (figure 6.1). Reduced soil health in many of our agricultural and urban watersheds has resulted in increased runoff during intense rainfall and increased problems with flooding. Also, the lower infiltration capacity of degraded soils reduces the amount of water that is available to plants, as well as the amount that percolates through the soil into underground aquifers. This reduction in underground water recharge results in streams drying up during drought periods. Watersheds with degraded soils thus experience lower stream flow during dry seasons and increased flooding during times of high rainfall.

Soil erosion is of greatest concern when the surface

Photo by Jerry DeWitt

Figure 6.1. Left: Water erosion on clean-tilled soil in Bulgaria. Topsoil has been lost in the background field. Right: A stream in Guarico, Venezuela, contaminated with dispersed sediment.

is unprotected and directly exposed to the destructive energy of raindrops and wind (figure 6.1). While degraded soils tend to promote erosion, the process of erosion in turn leads to a decrease in soil quality. Thus, a vicious cycle is begun in which erosion degrades soils, which then leads to further susceptibility to erosion, and so on. Soil is degraded because the best soil material—the surface layer enriched in organic matter—is removed by erosion. Erosion also selectively removes the more easily transported finer soil particles. Severely eroded soils, therefore, become low in organic matter and have less favorable physical, chemical, and biological characteristics, leading to a reduced ability to sustain crops and increased potential for harmful environmental impacts.

Wind Erosion

The picture of wind erosion from the Dust Bowl era (figure 5.12, p. 55) provides a graphic illustration of land degradation. Wind erosion can occur when soil is dry and loose, the surface is bare and smooth, and the landscape has few physical barriers to wind. The wind tends to roll and sweep larger soil particles along the soil surface, which will dislodge other soil particles

SOIL AND WATER CONSERVATION IN HISTORICAL TIMES

Some ancient farming civilizations recognized soil erosion as a problem and developed effective methods for runoff and erosion control. Ancient terracing practices are apparent in various parts of the world, notably in the Andean region of South America and in Southeast Asia. Other cultures effectively controlled erosion using mulching and intercropping that protected the soil surface. Some ancient desert civilizations, such as the Anasazi in the southwestern U.S. (A.D. 600 to 1200), held back and distributed runoff water with check dams to grow crops in downhill depressions (see the picture of a now forested site). Their methods, however, were specific to very dry conditions. For most agricultural areas of the world today, erosion still causes extensive damage (including the spread of deserts) and remains the greatest threat to agricultural sustainability and water quality.

Figure 6.2. Wind erosion damaged young wheat plants through abrasion. Photo by USDA Wind Erosion Research Unit.

and increase overall soil detachment. The smaller soil particles (very fine sand and silt) are lighter and will go into suspension. They can be transported over great distances, sometimes across continents and oceans. Wind erosion affects soil quality through the loss of topsoil rich in organic matter and can cause crop damage from abrasion (figure 6.2). In addition, wind erosion affects air quality, which is a serious concern for nearby communities.

The ability of wind to erode a soil depends on how that soil has been managed, because strong aggregation makes it less susceptible to dispersion and transportation. In addition, many soil-building practices like mulching and the use of cover crops protect the soil surface from both wind and water erosion.

Landslides

Landslides occur on steep slopes when the soils have become supersaturated from prolonged rains. They are especially of concern in places where high population pressure has resulted in farming of steep hillsides (figure 6.3). The sustained rains saturate the soil (especially in landscape positions that receive water from upslope areas). This has two effects: It increases the weight of

Figure 6.3. Sustained rains from Hurricane Mitch in 1998 caused supersaturated soils and landslides in Central America. Photo by Benjamin Zaitchik.

the soil mass (all pores are filled with water), and it decreases the cohesion of the soil (see the compaction of wet soil in figure 6.10, right, p. 64) and thereby its ability to resist the force of gravity. Agricultural areas are more susceptible than forests because they lack large, deep tree roots that can hold soil material together. Pastures on steep lands, common in many mountainous areas, typically have shallow-rooted grasses and may also experience slumping. With certain soil types, landslides may becomes liquefied and turn into mudslides.

Tillage Erosion

Tillage degrades land even beyond promoting water and wind erosion by breaking down aggregates and exposing soil to the elements. It can also cause erosion by directly moving soil down the slope to lower areas of the field. In complex topographies—such as seen in figure 6.4—tillage erosion ultimately removes surface soil from knolls and deposits it in depressions (swales) at the bottom of slopes. What causes tillage erosion? Gravity causes more soil to be moved by the plow or harrow downslope than upslope. Soil is thrown farther downslope when tilling in the downslope direction than is thrown uphill when tilling in the upslope direction (figure 6.5a).

Figure 6.4. Effects of tillage erosion on soils. Photo by USDA-NRCS.

Downslope tillage typically occurs at greater speed than when traveling uphill, making the situation even worse. Tillage along the contour also results in downslope soil movement. Soil lifted by a tillage tool comes to rest at a slightly lower position on the slope (figure 6.5b). A more serious situation occurs when using a moldboard plow along the contour. Moldboard plowing is typically performed by throwing the soil down the slope, as better inversion is thus obtained than by trying to turn the furrow up the slope (figure 6.5c). One unique feature of tillage erosion compared to wind, water, and gravitational

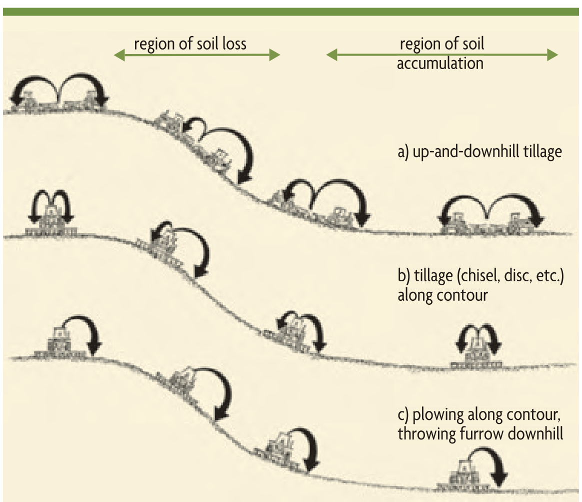


Figure 6.5. Three causes of erosion resulting from tilling soils on slopes.

erosion is that it is unrelated to extreme weather events and occurs gradually with every tillage operation.

Soil loss from slopes due to tillage erosion enhances the potential for further soil losses from water or wind erosion. On the other hand, tillage erosion does not generally result in off-site damage, because the soil is merely moved from higher to lower positions within a field. However, it is another reason to reduce tillage on sloping fields.

SOIL TILTH AND COMPACTION

A soil becomes more compact, or dense, when aggregates or individual particles of soil are forced closer together. Soil compaction has various causes and different visible effects. Compaction can occur either at or near the surface (surface compaction, which includes surface crusting as well as plow layer compaction) or lower down in the soil (subsoil compaction). See figure 6.6.

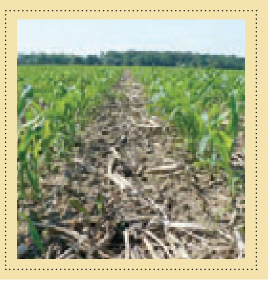
Surface Compaction

Plow layer compaction—compaction of the surface layer—has probably occurred to some extent in all intensively worked agricultural soils. It is the result of a loss of soil aggregation that typically has three primary causes—erosion, reduced organic matter levels, and force exerted by the weight of field equipment. The first two result in reduced supplies of sticky binding materials and a subsequent loss of aggregation.

Surface crusting has the same causes as plow layer compaction but specifically occurs when the soil surface is unprotected by crop residue or a plant canopy and the energy of raindrops disperses wet aggregates, pounding them apart so that particles settle into a thin, dense surface layer. The sealing of the soil reduces water infiltration, and the surface forms a hard crust when dried. If the crusting occurs soon after planting, it may delay or prevent seedling emergence. Even when the crust is not severe enough to limit germination, it can reduce water infiltration. Soils with surface crusts are prone to

Chapter 14

REDUCING EROSION AND RUNOFF



So long! It's been good to know you.

This dusty old dust is a gettin' my home.

And I've got to be drifting along.

—WOODY GUTHRIE, 1940

The dust storms that hit the Great Plains of the U.S. during the 1930s were responsible for one of the great migrations in our history. As Woody Guthrie pointed out in his songs, soil erosion was so bad that people saw little alternative to abandoning their farms. They moved to other parts of the country in search of work. Although changed climatic conditions and agricultural practices improved the situation for a time, there was another period of accelerated wind and water erosion during the 1970s and 1980s. Also, in many other countries land degradation has forced families off the farm to urban areas or caused them to seek out new lands by developing natural areas like rainforests.

Erosion by wind and water has occurred since the beginning of time. Although we should expect some soil loss to occur on almost all soils, agriculture can greatly aggravate the problem. Erosion is the major hazard or limitation to the use of about half of all cropland in the United States. On much of that land, erosion is occurring fast enough to reduce future productivity. As we discussed earlier, erosion is also an organic-matter issue because it removes the richest soil layer, the topsoil. The soil removed from fields also has huge negative effects off the farm, as sediment accumulates in streams, rivers, reservoirs, and estuaries, or blowing dust reaches towns and cities. In fact, sediment remains the number one contaminant for most waters around the world, and it often also carries other contaminants like nutrients, pesticides, and other chemicals.

Climate and soil type are important factors affecting erosion. Intense or prolonged rainstorms are major causes of water erosion and landslides, while drought and strong winds are critical factors in wind erosion. Soil type is important because it influences the susceptibility to erosion as well as the amount that can occur without loss of productivity. In chapter 6 we discussed how some soils (especially silts) with poor aggregation are more susceptible than other soils, especially those

Photo courtesy Harold van Es

Figure 14.1. A waterway scoured into a gulley on a midwestern cornfield after erosive spring rains. Photo by Andrew Phillips.

Figure 14.2. Erosion on steep lands in Central America. Removal of the fine topsoil left mostly boulders behind. Sorghum plants show drought stress due to lack of rain and low water storage capacity in soil.

with good aggregation. This is reflected in the soil *erodibility* ratings, which soil conservationists use to plan control practices.

A small amount of erosion is acceptable, as long as new topsoil can be created as rapidly as soil is lost. The maximum amount of soil that can be lost to erosion each year, while maintaining reasonable productivity, is called the *soil loss tolerance,* or T value. For a deep soil with a rooting depth of greater than 5 feet, the T value is 5 tons per acre each year. Although this sounds like a large amount of soil loss, keep in mind that the weight of an acre of soil to 6 inches of depth is about 2 million pounds, or 1,000 tons. So 5 tons is equivalent to about .03 inch (less than 1 mm). If soil loss continued at that rate, at the end of 33 years about 1 inch would be lost. On deep soils with good management of organic matter, the rate of topsoil creation can balance this loss. The soil loss tolerance amount is reduced for soils with less rooting depth. When it is less than 10 inches, the tolerable rate of soil loss is the same as losing 0.006 inch per year and is equivalent to 1 inch of loss in 167 years. Of course, on agricultural fields the soil loss is not evenly distributed over the field, and areas of water confluence experience greater losses (figure 14.1). Also, many conservationists would argue that any amount of erosion is unacceptable, as the off-site damage to water and air quality may still be considerable.

When soil loss is greater than the tolerance value, productivity suffers in the long run. Yearly losses of 10 or 15 tons or more per acre occur in many fields. In extreme cases, as with croplands on steep slopes in tropical climates, losses of five or ten times that much

EROSION: A SHORT-TERM MEMORY PROBLEM?

It's difficult to fully appreciate erosion's damage potential, because the most severe erosion occurs during rare weather events and climate anomalies. Wind erosion during the Dust Bowl days of the 1930s, which resulted from a decade of extremely dry years, was especially damaging. And about one-third of the water erosion damage that occurs in a particular field during a thirty-year period commonly results from a single extreme rainfall event. Like stock market crashes and earthquakes, catastrophic erosion events are rare, but the impacts are great. We must do our best to understand the risks, prevent complacency, and adequately protect our soils from extreme weather events.

may occur. For example, originally fertile soils on steep slopes in southern Honduras are now severely eroded (figure 14.2) after years of slash-and-burn agriculture.

Management practices are available to help reduce runoff and soil losses. For example, an Ohio experiment in which runoff from conventionally tilled and no-till continuous-corn fields was monitored showed that over a four-year period, runoff averaged about 7 inches of water each year for conventional tillage and less than 0.1 inch for the no-till planting system. Researchers in the state of Washington found that erosion on winter wheat fields was about 4 tons each year when a sod crop was included in the rotation, compared to about 15 tons when sod was not included.

ADDRESSING RUNOFF AND EROSION

Effective runoff and erosion control is possible without compromising crop productivity. However, it may require considerable investment or new management. The numerous methods of controlling soil and water can be grouped into two general approaches: structural measures and agronomic practices. Creating structures for reducing erosion generally involves engineering practices, in which an initial investment is made to build terraces, diversion ditches, drop structures, etc. Agronomic practices that reduce erosion focus on changes in soil and crop management, such as reduced tillage and cover cropping, and planting vegetation in critical areas. Appropriate conservation methods may vary among fields and farms, but recently there has been a clear trend away from structural measures in favor of agronomic practices. The primary reasons for this change are as follows:

- Management measures help control erosion, while also improving soil health and crop productivity.
- Significant advances have been made in farm machinery and methodologies for alternative soil and crop management.
- Structures generally focus on containing runoff and sediment once erosion has been initiated, whereas agronomic measures try to prevent erosion from occurring in the first place by decreasing runoff potential.
- Structures are often expensive to build and maintain.
- Most structures do not reduce tillage erosion.

The use of soil-building conservation management practices is preferred for long-term sustainability of crop production, and they are also the first choice for controlling runoff and erosion. Structural measures still have a place, but that is primarily to complement agronomic measures. Erosion reduction works by either decreasing the shear forces of water and wind or keeping soil in a condition in which it can't easily erode. Many conservation practices actually reduce erosion by using both approaches. In general, the following are good principles:

- Keep the soil covered; water and wind erosion occur almost exclusively when the soil is exposed.
- Use management practices that increase aggregation and infiltration.
- Do not loosen the soil unless it is well covered. Loose soil is more erodible than stable soil, like in no-till systems. Loosening may initially reduce runoff potential but this effect is generally short-lived, as the soil will settle. If loosening is required to reduce compaction, do it with tools that limit disturbance (e.g., zone builders or strip tillers). Soil disturbance is also the single cause of tillage erosion.
- Take a landscape-scale approach for additional control. Focus on areas with high risk, those where runoff water concentrates, and maximize the use of inexpensive biological approaches like grass seeding in waterways and filter strips.
- Focus on critical periods. For example, in temperate areas the soil is most susceptible after the winter fallow, and in semiarid regions it is most fragile after the dry period when heavy rains begin and there is little surface cover. In some regions, heavy rainfall is associated with hurricane or monsoon seasons.

Figure 14.3. Soybeans grown under no-till with corn residue.

Reduced Tillage

Transition to tillage systems that increase surface cover and reduce disturbance is probably the single most effective and economical approach to reducing erosion. Restricted and no-till regimes succeed in many cropping systems by providing better economic returns than conventional tillage, while also providing excellent runoff and erosion control. Maintaining residues on the soil surface (figure 14.3) and eliminating the problem of soil loosening by tillage greatly reduce dispersion of surface aggregates by raindrops and runoff waters. The effects of wind on surface soil are also greatly reduced by leaving crop stubble on untilled soil and anchoring the soil with roots. These measures facilitate infiltration of precipitation where it falls, thereby reducing runoff and increasing plant water availability.

In cases where tillage is necessary, reducing its intensity and leaving some residue on the surface minimizes the loss of soil organic matter and aggregation. Leaving a rougher soil surface by eliminating secondary tillage passes and packers that crush natural soil aggregates may significantly reduce runoff and erosion losses by preventing surface sealing after intense rain (see figure 6.9, p. 63). Reducing or eliminating tillage also diminishes tillage erosion and keeps soil from being moved downhill. The gradual losses of soil from upslope areas expose subsoil and may in many cases further aggravate runoff and erosion. We discuss tillage practices further in chapter 16.

Significance of Plant Residues and Competing Uses

Reduced-tillage and no-tillage practices result in less soil disturbance and leave significant quantities of crop residue on the surface. Surface residues are important because they intercept raindrops and can slow down water running over the surface. The amount of residue on the surface may be less than 5% for the moldboard plow, while continuous no-till planting may leave 90% or more of the surface covered by crop residues. Other reduced-tillage systems, such as chiseling and disking (as a primary tillage operation), typically leave more than 30% of the surface covered by crop residues. Research has shown that 100% soil cover virtually eliminates runoff and erosion on most agricultural lands. Even 30% soil cover reduces erosion by 70%.

As discussed in chapter 9, there are many competing uses for crop residues as fuel sources, as well as building materials. Unfortunately, permanent removal of large quantities of crop residues will have a detrimental effect on soil health and the soil's ability to withstand water and wind erosion.

Cover Crops

Cover crops result in decreased erosion and increased water infiltration in a number of ways. They add organic residues to the soil and help maintain soil aggregation and levels of organic matter. Cover crops frequently can be grown during seasons when the soil is especially susceptible to erosion, such as the winter and early spring in temperate climates, or early dry seasons in semiarid climates. Their roots help to bind soil and hold it in place. Because raindrops lose most of their energy when they hit leaves and drip to the ground, less soil crusting occurs. Cover crops are especially effective in reducing erosion if they are cut and mulched, rather than incorporated. Ideally, this is done when the cover crop has nearly matured (typically, milk stage)—that is, when it is somewhat lignified but seeds are not yet viable and C:N ratios are not so high as to cause nutrient immobilization. In recent years, new methods of cover cropping, mulching, and no-tillage crop production, often jointly referred to as conservation agriculture, have been worked out by innovative farmers in several regions of the world (figure 14.4; see also the farmer case study at the end of this chapter). In parts of temperate South America this practice has revolutionized farming with rapid and widespread adoption in recent years. It has been shown to virtually eliminate runoff and erosion and also appears to have great benefits for moisture conservation, nitrogen cycling, weed control, reduced fuel consumption, and time savings, which altogether can result in significant increases in farm profitability. See chapter 10 for more information on cover crops.

Perennial Rotation Crops

Grass and legume forage crops can help lessen erosion because they maintain a cover on most of the soil surface for the whole year. Their extensive root systems hold soil in place. When they are rotated with annual row crops, the increased soil quality will reduce erosion and runoff potential during that part of the crop cycle. Benefits are greatest when such rotations are combined with reduced- and no-tillage practices for the annual crops. Perennial crops like alfalfa and grass are often rotated with row crops, and that rotation can be readily combined with the practice of strip cropping (figure 14.5). In such a system, strips of perennial sod crops and row crops are laid out across the slope, and erosion from the row crop is filtered out when the water reaches the sod strip. This conservation system is quite effective in fields with moderate erosion potential and on operations that use both row and sod crops (for example, dairy farms). Each crop may be grown for two to five years on a strip, which is then rotated into the other crop.

Permanent sod, often as pasture, is a good choice for steep soils or other soils that erode easily, although slumping and landslides may be a concern under extreme conditions.

Adding Organic Materials

Maintaining good soil organic matter levels helps keep topsoil in place. A soil with more organic matter usually has better soil aggregation and less surface crusting. These conditions ensure that more water is able to infiltrate the soil instead of running off the field, taking soil with it. When you build up organic matter, you help control erosion by making it easier for rainfall to

Figure 14.4. Field and close-up views of soybean grown in black oat cover crop mulch in South America. Photos by Rolf Derpsch.

Figure 14.5. Corn and alfalfa grown in rotation through alternating strips.

Figure 14.6. Equipment for manure injection with minimal soil disturbance.

enter the soil. Reduced tillage and the use of cover crops already help build organic matter levels, but regularly providing additional organic materials like compost and manure results in larger and more stable soil aggregates and stimulates earthworm activity.

The adoption rate for no-till practices is lower for livestock-based farms than for grain and fiber farms. Manures may need to be incorporated into the soil for best use of nitrogen, protection from runoff, and odor control. Also, the severe compaction resulting from the use of heavy manure spreaders on very moist soils may need to be relieved by tillage. Direct injection of liquid organic materials in a zone-till or no-till system is a recent approach that allows for reduced soil disturbance and minimal concerns about manure runoff and odor problems (figure 14.6).

Other Practices and Structures for Soil Conservation

Soil-building management practices are the first approach to runoff and erosion control, but structural measures may still be appropriate. For example, *diversion ditches* are channels or swales that are constructed

Figure 14.7. Hillside ditch in Central America channeling runoff water to a waterway on the side of the slope (not visible). A narrow filter strip is located on the upslope edge to remove sediment.

Figure 14.8. Grassed waterway in a midwestern cornfield safely channels and filters runoff water. Photo courtesy of USDA-NRCS.

Figure 14.9. Edge-of-field filter strips control sediment losses to streams. Photo courtesy of USDA-NRCS.

across slopes to divert water across the slope to a waterway or pond (figure 14.7). Their primary purpose is to channel water from upslope areas away and prevent the downslope accumulation of runoff water that would then generate increased scouring and gullies.

Grassed waterways are field water channels that reduce scouring in areas where runoff water accumulates; they also help prevent surface water pollution by filtering sediments out of runoff (figure 14.8). They require only small areas to be taken out of production and are used extensively in the midwestern U.S. grain belt region, where long gentle slopes are common.

Terracing soil in hilly regions is an expensive and labor-intensive practice, but it is also one that results in a more gradual slope and reduced erosion. Well-constructed and maintained structures can last a long time. Most terraces have been built with significant cost-sharing from government soil conservation programs prior to the widespread adoption of no-tillage and cover cropping systems.

Tilling and planting along the contour is a simple practice that helps control erosion. When you work along the contour, instead of up- and downslope, wheel tracks and depressions caused by the plow, harrow, or planter will retain runoff water in small puddles and allow it to slowly infiltrate. This approach is not very effective when dealing with steep erodible lands, however, and also does not reduce tillage erosion.

There are a number of other practices that do little to reduce runoff and erosion or build soil health but can decrease channel erosion and sediment losses. *Filter strips* remove sediment and nutrients before runoff water enters ditches and streams (figure 14.9). *Sediment control basins* have been constructed in many agricultural regions to allow sediment to settle before stream water is further discharged; they are often used in areas where conventional soil management systems still generate a lot of erosion (figure 14.10).

Wind erosion is reduced by most of the same practices that control water erosion by keeping the soil covered and increasing aggregation: reduced tillage or

Figure 14.10. Top: A sediment control basin in a Central European landscape where conventional tillage is widely used. Bottom: Sediment regularly fills the basin and needs to be dredged.

Figure 14.11. Field shelterbelt reduces wind erosion and evaporative demand and increases landscape biodiversity.

Figure 14.12. An experiment with wide-spaced poplar trees planted in a New Zealand pasture to reduce landslide risk.

no-till, cover cropping, and perennial rotation crops. In addition, practices that increase roughness of the soil surface diminish the effects of wind erosion. The rougher surface increases turbulent air movement near the land surface and reduces the wind's shear and ability to sweep soil material into the air. Therefore, if fields are tilled and cover crops are not used, it makes sense to leave soil subject to wind erosion in a rough-tilled state when crops aren't growing. Also, *tree shelterbelts* planted at regular distances perpendicular to the main wind direction act as windbreaks and help reduce evaporative demand from dry winds (figure 14.11). They have recently received new attention as ecological corridors in agricultural landscapes that help increase landscape biodiversity.

Finally, a few words about landslides. They are difficult to control, and unstable steep slopes are best left in forest cover. A compromise solution is the use of wide-spaced trees that allow for some soil stabilization by roots but leave enough sunlight for a pasture or crops (figure 14.12). In some cases, horizontal drains are installed in critical zones to allow dewatering and prevent supersaturation during prolonged rains, but these are generally expensive to install.

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