9

Soil and Agriculture

Chapter Objectives

This chapter will help students:

Explain the importance of soils to agriculture

Describe the impacts of agriculture on soils

Outline major developments in the history of agriculture

Delineate the fundamentals of soil science, including soil formation and soil properties

Analyze the types and causes of soil erosion and land degradation

Explain the principles of soil conservation and provide solutions to soil erosion and land degradation

Summarize major policy approaches for addressing soil conservation

Lecture Outline

I. **Central Case: Iowa's Farmers Practice No-Till Agriculture**

A. Repeated cycles of plowing and planting since farmers first settled the region have diminished the soil's productivity.

B. Turning the earth by tilling (plowing, disking, harrowing, or chiseling) aerates the soil and works weeds and old crop residue into the soil to nourish it. But, tilling also leaves the surface bare, allowing wind and water to erode away precious topsoil.

C. The conventional practice of tilling the soil after harvests instead turned to no-till farming--rather than plowing after each harvest, crop residues were left atop their fields, keeping the soil covered with plant material at all times.

D. After three years the no-till fields produced as much corn as the conventional fields, while requiring less time and money.

E. By enhancing soil conditions and reducing erosion, no-till techniques are benefiting Iowa's people and environment as well, cutting down on pollution in its air, waterways, and ecosystems.

F. Similar effects are being felt elsewhere in the world where no-till methods are being applied.

II. Soil: The Foundation for Agriculture

A. As population and consumption increase, soils are being degraded.

1. **Agriculture** is the practice of raising crops and livestock for human use and consumption.
2. We obtain most of our food and fiber from **cropland**, land used to raise plants for human use.
3. **Rangeland**, or pasture, is the land used for grazing livestock.
4. **Soil** is a complex system of disintegrated rock, organic matter, water, gases, nutrients, and microorganisms.
5. Throughout the world, especially in drier regions, it has gotten more difficult to raise crops and graze livestock as soils have deteriorated in quality and declined in productivity—a process termed **soil degradation**.

B. Agriculture began 10,000 years ago.

1. Our ancestors began intentionally planting seeds from plants whose produce was most desirable, called *selective breeding*.
2. People followed the same process of selective breeding with animals, creating livestock from wild species.
3. Once our ancestors learned to cultivate crops and raise animals, they began to settle in more permanent camps and villages.
4. **Traditional agriculture** needed human and animal muscle power, hand tools, and simple machines.

C. Industrialize agriculture dominates today.

1. The industrial revolution introduced large-scale fossil fuel combustion and mechanization, enabling farmers to replace horses and oxen with faster and more powerful means of cultivating, harvesting, transporting, and processing crops; this is called **industrial agriculture**.
2. For maximum efficiency, the new agriculture required the uniform planting of a single crop, or **monoculture**.
3. The **green revolution** applied technology to boost crop yields in developing nations.

III. Soil as a System

A. Soil formation is a slow process.

1. **Parent material** is the base geological material in a location. It may be composed of lava or volcanic ash, rock or sediment deposited by glaciers, wind-blown dunes, or sediments deposited by rivers, in lakes, or in the ocean.
2. **Bedrock** is the continuous mass of solid rock that makes up Earth's crust.
3. The **weathering** of parent material is the first step in the formation of soil. This is the physical, chemical, and/or biological process that converts large rock particles into smaller particles.
4. Weathering and the accumulation and transformation of organic matter are the key processes of soil formation, and these are influenced by five factors: climate, organisms, topography, parent material, and time.

B. A soil profile consists of layers known as horizons.

1. Each layer of soil is termed a **horizon**, and the cross-section as a whole, from surface to bedrock, is known as a **soil profile**.
2. Minerals are generally transported downward in the soil as a result of **leaching**, the process whereby solid particles suspended or dissolved in liquid are transported to another location.
3. A crucial horizon for agriculture and ecosystems is the A horizon, or **topsoil**.
4. The O and A horizons are home to most of the countless organisms that give life to soil.
5. Topsoil is vital for agriculture, but agriculture practiced unsustainably over time will deplete organic matter.

C. Soils differ in color, texture, structure, and pH.

1. Soil scientists classify soils—and farmers judge their quality for farming—based largely on properties such as color, texture, structure, and pH.
2. To a scientist or a farmer, the color of soil can indicate its composition and sometimes its fertility.
3. Soil texture is determined by the size of particles.
   a. **Clay** consists of particles less than 0.002 mm in diameter, **silt** of particles 0.002–0.05 mm, and **sand** of particles 0.05–2 mm.
   b. Soil with an even mixture of the three particle sizes is known as **loam**.
4. Soil structure is a measure of the "clumpiness" of soil.
5. Plants can die in soils that are too acidic or alkaline, whereas moderate variation influences the availability of nutrients for plants' roots.

D. Cation exchange is vital for plant growth.

1. Plants gain many nutrients through a process called *cation exchange*.

a. *Cation exchange capacity* expresses a soil's ability to hold cations (preventing them from leaching and thus making them available to plants) and is a useful measure of soil fertility.

E. Regional differences in soil traits can affect agriculture.

IV. Land Degredation and Soil Conservation

1. Land degradation is a general deterioration of land that diminishes its productivity and biodiversity, impairs the functioning of its ecosystems, and reduces the ecosystem services that the land offers.

A. Erosion can degrade ecosystems and agriculture.

1. Erosion is the removal of material from one place and its transport toward another via wind or water.
2. Erosion can occur in several ways, including wind erosion and four principal kinds of water erosion (splash, sheet, rill, and gully).
3. To prevent erosion in vulnerable locations, we can erect a variety of physical barriers that capture soil.

B. Soil erosion is a global problem.

C. Desertification reduces productivity of arid lands.

1. Desertification is a loss of more than 10% productivity due to soil erosion, soil compaction, forest removal, overgrazing, drought, salinization, climate change, depletion of water sources, and so on.

D. The Dust Bowl was a monumental event in the United States.

1. Large-scale cultivation of the southern Great Plains of the United States, combined with a drought in the 1930s, led to dust storms, destroying the land and affecting human health in the Dust Bowl.

E. The Soil Conservation Service pioneered measures to slow soil degradation.

1. Conservation districts within each county promoted soil-conservation practices.
2. In 1994, the SCS was renamed the Natural Resources Conservation Service, and its responsibilities were expanded to include water quality protection and pollution control.

F. Soil conservation efforts are thriving internationally.

G. Farmers can protect soil against degradation in various ways.

1. **Crop rotation** is the practice of alternating the kind of crop grown in a particular field from one season or year to the next.
2. **Contour farming** consists of plowing furrows sideways across a hillside, perpendicular to its slope and following the natural contours of the land, to help prevent formation of rills and gullies.
3. **Terracing** transforms slopes into series of steps like a staircase, enabling farmers to cultivate hilly land without losing huge amounts of soil to water erosion.
4. The planting of different types of crops in alternating bands or other spatially mixed arrangements is called **intercropping.**
5. **Shelterbelts** are rows of trees or other tall plants that are planted along the edges of fields to break the wind.
6. Conservation tillage describes an array of approaches that reduce the amount of tilling relative to conventional farming.

H. Erosion-control practices protect and restore plant cover.

I. Irrigation boosts productivity, but can damage soil.

1. Crops that require a great deal of water can be grown with **irrigation**, artificial provision of water.
2. Soils too saturated with water may experience **waterlogging**, which damages both soil and roots.
3. A more frequent problem is **salinization**, the buildup of salts in surface soil layers.

J. Salinization is easier to prevent than to correct.

K. Fertilizers boost crop yields but can be overapplied.

1. Nutrient depletion creates a need for **fertilizers** containing nutrients.
2. **Inorganic fertilizers** are mined or synthetically manufactured mineral supplements.
3. **Organic fertilizers** consist of the remains or wastes of organisms and include animal manure, crop residues, fresh vegetation (*green manure),* and *compost*, a mixture produced when decomposers break down organic matter, including food and crop waste, in a controlled environment.

L. Grazing practices can contribute to soil degradation.

1. When too many livestock eat too much of the plant cover, impeding plant regrowth and preventing the replacement of biomass, the result is **overgrazing.**

V. Agricultural Policy

A. Some policies worsen land degradation.

B. Wetlands have been drained for farming.

1. Many of our crops grow on the sites of former *wetlands*—swamps, marshes, bogs, and river floodplains—that people drained and filled in.
2. Under the *Wetlands Reserve Program*, the U.S. government offers payments to landowners who protect, restore, or enhance wetland areas on their property.

C. A number of U.S. and international programs promote soil conservation.

1. The Conservation Reserve Program, established in the 1985 farm bill, pays farmers to stop cultivating highly erodible cropland and instead place it in conservation reserves planted with grasses and trees.
2. Internationally, the United Nations promotes soil conservation and sustainable agriculture through a variety of programs led by the Food and Agriculture Organization (FAO).

VI. Conclusion

A. Many policies in the United States and worldwide have been quite successful in reducing erosion.

B. Many challenges remain; better technologies and wider adoption of soil conservation techniques are needed to avoid a food crisis.

Key Terms

agriculture
bedrock
clay
conservation districts
Conservation Reserve Program
conservation tillage
contour farming
crop rotation
cropland
desertification
Dust Bowl
erosion
fertilizer
green revolution
horizon
industrial agriculture
inorganic fertilizers
intercropping
irrigation
land degredation
leaching
loam
monoculture
Natural Resources Conservation Service
no-till
organic fertilizers
overgrazing
parent material
rangeland
salinization
sand

shelterbelts	terracing
silt	topsoil
soil	traditional agriculture
soil degradation	waterlogging
soil profile	weathering

Teaching Tips

1. Bring soil samples to class so students can conduct a soil texture “feel test.” In general, sandy soils feel gritty, silty soils feel like flour, and clay soils are sticky when moistened. Soils feel different because of the size of the most abundant particle type. The USDA categorizes particles as follows:

    Sand: 2.0 mm–0.05 mm in diameter

    Silt: 0.05 mm–0.002 mm in diameter

    Clay: less than 0.002 mm in diameter

    For students to better undrestand the differences in soil particle size, have them visualize a barrel to represent a sand particle, a plate to represent a silt particle, and a dime to represent a clay particle.

    Because most soils are a combination of sand, silt, and clay, soil scientists use a more complicated method to determine the percent composition of each type. These percentage values are used in the USDA textural triangle (available at http://soils.usda.gov/technical/handbook/) to determine the textural class of a soil.

    A good addition to this exercise would be to give each group of students 100 g of soil from a different location. Have them run the soil through a set of soil sieves and then weigh the fractions to determine the percent composition of the different particle types (four or five types, depending on the soil sieves, ranging from gravel to clay). Have students make a pie chart or a bar graph illustrating the composition of their soil. Ask them to compare their results with those of other groups that have soils from other areas.

2. Soil formation is a very slow process, and in some cases it can take 500 years for one inch of soil to develop. To emphasize the importance of soil conservation, use the time line below to show just how much can happen in 500 years, the time required to form an inch of soil:

    2002: West Nile virus infects humans in the United States.

    1996: The first animal, Dolly the sheep, is cloned from an adult cell.

    1989: The Berlin Wall is torn down.

    1970: The first Earth Day is celebrated.

    1962: The Beatles, a British pop group, make their first recordings.

1945: World War II ends.

1934: Dust Bowl occurs in the Great Plains.

1915: Albert Einstein formulates his general theory of relativity.

1872: Congress establishes the first national park, Yellowstone.

1854: Henry David Thoreau publishes *Walden*.

1804: Lewis and Clark begin their expedition to the Northwest.

1788: The U.S. Constitution is ratified.

1681: The dodo, a large flightless bird, becomes extinct.

1608: Native Americans teach colonists how to raise corn.

1513: Juan Ponce de León discovers Florida.

1500: The Incan empire reaches its height.

3. Demonstrate runoff and erosion. First, put a piece of grass sod on a cafeteria tray. Have a student pour water over the sod using a watering can or a spray bottle to simulate rain. Observe the runoff. Repeat this procedure using a pile of loose dirt on a second tray. Compare the runoff. Repeat the procedure with each tray held at a 20- to 30-degree angle to simulate the problems on slopes.

4. Assign students to read the first chapter of *The Grapes of Wrath* by John Steinbeck. This chapter of the classic novel describes the conditions in Oklahoma right after the Dust Bowl that ruined crops, causing massive foreclosures on farmland.

5. Contemporary agriculture occupies a large area of the Midwest that was formerly tallgrass prairie. Innovations in agriculture are reexamining the capacity of this landscape to produce biomass efficiently. Some cattle producers are removing cattle from large feedlots and returning them to permanent pastures comprised of local native prairie grasses and wildflowers. Native prairie vegetation has tremendous potential to store carbon in its root system. When compared to non-native, cool-season European grasses commonly planted for hay and pastures, prairie species are able to absorb and hold much more rainwater and, because of the root system, more carbon.

   To prove this to students, secure seeds of common, cool season lawn grass such as perennial rye and native prairie species like Big Bluestem, Little Bluestem, and Side Oats Grama. Have students plant several seeds in clay or peat pots, place them on a windowsill, and watch the events unfold. When several inches of growth has accumulated, gently pull the plants near the base and observe the root system. Depending on the time of year, the prairie grasses will exhibit robust root growth and might even be pot-bound. Prairies produce two-thirds of their biomass underground, making them excellent carbon sinks.

   Sources for native prairie seed: Ion Exchange. 1878 Old Mission Drive, Harper’s Ferry, Iowa. 800-291-2143. (www.ionxchange.com)

6. Use “signaling” for concept understanding. There are several sets of concepts in this chapter—soil horizons, types of erosion, and erosion reduction methods, for instance. A good way to check for understanding is signaling, originally designed by Dr. Madeline Hunter of UCLA. With the types of erosion, for instance, give students the following keys:

   Wind erosion: Hold out one hand with fingers extended, palm perpendicular to the desk. The fingers look like a flag blowing in the wind.

   Splash erosion: Hold out one hand with palm parallel to and facing the desk, fingers spread wide apart and angling down towards the desk.

   Sheet erosion: Hold out hand with palm parallel to and facing the desk, fingers straight out and close together.

   Rill erosion: Make a small fist.

   Gully erosion: Hold out hand with palm facing up as if cupping a softball or making the shape of a gully.

   Now show students a photo or ask them to decide on the type of erosion that would occur in a particular circumstance. Students, on your mark, will indicate the answer with his or her signal. You can instantly tell which students know the correct answer, which are uncertain (hesitating, glancing around at others), and which have incorrect answers. This is an easy way to know if you need to cover a concept more thoroughly or if students are ready to move on.

Additional Resources

Websites

1. *About the Dust Bowl*, Modern American Poetry (www.english.uiuc.edu/maps/depression/dustbowl.htm)

   This website provides a brief description of the Dust Bowl, plus a map, photos, and timeline.

2. *Best Management Practices for Soil Erosion*, U.S. Environmental Protection Agency (www.epa.gov/seahome/erosion.html)

   A downloadable file at this website provides information about soil erosion worldwide, in the United States, and in the Midwest in particular.

3. *Soil Science Basics*, NASA Goddard Space Flight Center (http://soils.gsfc.nasa.gov/basics.htm)

   This site provides information about soil formation, chemistry, microbiology, and field characterization.

4. *SOILS*, Natural Resources Conservation Service (http://soils.usda.gov)

Part of the National Cooperative Soil Survey, this website is an effort by federal and state agencies to provide scientifically based soil information.

5. *What Is Overgrazing?* Yellowstone National Park, National Park Service (www.nps.gov/yell/nature/northernrange/)

   This website describes overgrazing in Yellowstone National Park.

6. The Leopold Center for Sustainable Agriculture. Iowa State University (http://www.leopold.iastate.edu/)

   The Leopold Center funds innovative research on sustainable agriculture, water quality, fiber production, marketing, and policy initiatives. Their research papers and resources are available online.

Audiovisual Materials

1. *The American Experience: Surviving the Dust Bowl,* 1998, PBS Home Video distributed by WGBH (www.interactive.wgbh.org)

   This program looks at America's "worst ecological disaster," which brought financial and emotional ruin to thousands of people in the Great Plains.

2. *DIRT! The Movie,* 2009, video distributed by Bullfrog Films (www.bullfrogfilms.com)

   The story of Earth's most valuable and underappreciated source of fertility, from its miraculous beginning to its crippling degradation.

3. *My Father's Garden,* 1995, Miranda Productions, video distributed by Bullfrog Films (www.bullfrogfilms.com)

   This documentary examines the use and misuse of technology on American farms. Compares industrial and organic farms.

4. *New Deal for the Dust Bowl,* 1991, distributed by Films for the Humanities and Sciences (www.films.com)

   Investigates the causes and effects of the Dust Bowl, as well as the government's intervention to prevent another one from occurring.

Weighing the Issues: Facts to Consider

Earth's Soil Resources

Facts to consider: At the rate of 500 to 1,000 years to produce one inch of topsoil, soil cannot be considered a renewable resourceaccording to human timescales. Though some soil is forming, soil is presently being lost much more quickly than it is being gained. The best way to have the soil resources we need is to preserve the soil that exists today. Examples of agricultural practices that enhance and preserve existing soils include: preserving and allowing natural flooding, no-till farming, using compost, increasing soil biodiversity, and following practices that encourage the growth of plant cover.

How Would You Farm?

Facts to consider: There are two related concerns: water conservation and soil conservation. Water conservation is important because a poorly designed field on this hill will have high runoff, removing soil through erosion. Irrigation techniques will need to prevent excessive runoff. Soil conservation has a second component—the quality of the soil. This includes nutrients, soil fauna diversity, and the abiotic structure of the soil (the percentage of sand, clay, and the like). Crop rotation is one strategy. The quantity of the soil must also be maintained through contour farming, terracing, or methods to prevent wind from removing soil. An additional factor is cost. For example, if no- or reduced-tillage farming is used, the farmer may have extra herbicide or labor costs because unwanted seeds can become buried alongside planted seeds. Other costs might be the work of contouring or terracing and the careful construction of irrigation.

Soils, Subsidies, and Sustainability

Facts to consider: Lands under the Conservation Reserve Program now cover an area nearly the size of Iowa, and the United States Department of Agriculture (USDA) estimates that each dollar invested in this program saves nearly one ton of topsoil. Congress reauthorized and expanded the Conservation Reserve Program in the farm bills of 1996, 2002, and 2008. The 2008 bill limited total conservation reserve lands to 32 million acres, but also funded 14 other similar programs (including the Wetlands Reserve Program) for the conservation of grasslands, wetlands, wildlife habitat, and other resources.

Have students reflect on the economics chapter, as well as the definition of sustainability. Have them revisit the concept of assessing monetary value to the benefit received by preserving and conserving land. Have students map the pros and the cons of what the Conservation Reserve Program has accomplished with taxpayer money. Then, address how this would change, for both the good and the bad, without government regulation.

The Science behind the Stories: Thinking Like a Scientist

Measuring Erosion with Pins, and . . . Nuclear Fallout?

Observation: In Maryland, U.S. government researchers noted that rows of stiff grass seemed to help stop soil erosion on some slopes.

Hypothesis: The grass hedges could greatly reduce erosion problems at the Maryland site—and perhaps elsewhere around the world.

Experiment: The researchers used both low-tech and high-tech erosion tracking around the hedges planted near gullies. Erosion pins were used to determine erosion rate. Catchpits were used to measure the volume of soil eroded. Analysis of cesium-137 concentrations in soil were used to find out where and how much soil was moved to verify results from erosion pins and catchpits.

Results: Researchers found that the hedges slowed erosion but didn't eliminate it entirely.

Restoring the Malpai Borderlands

Observation: In the Malpai borderlands between Arizona and New Mexico, decades of cattle ranching and fire suppression had damaged the land, causing native grasses to be crowded out by trees and shrubs.

Hypothesis: Returning natural fire cycles, along with more careful control of cattle, would reduce shrubs and trees and allow grasses to grow back.

Experiment: Scientists set up separate research plots and allowed different combinations of fire and grazing on each. Long-term monitoring tracked which plants thrived as well as the distribution and abundance of animals and plants.

Results: When exposed to fire and grazing, woody plant species were reduced, and desert grasses and grassland fauna showed positive or neutral reactions. Fire and grazing can be used to enhance desert grasslands.

Answers to End-of-Chapter Questions

Testing Your Comprehension

1. It is hypothesized that hunter-gatherers noticed and propagated plants that produced better fruits, eventually learning to save their seeds to plant the next year. This constitutes artificial selection, or the evolution of new crop varieties by selective breeding. Agriculture then encouraged a more sedentary lifestyle, a growing population, and economic specialization.
2. Traditional agriculture is biologically powered; the work is performed by animal and human effort along with simple tools and machines. This can be done at a subsistence level, in which the farm family raises just enough food for itself, or intensively, in which an excess of food is produced for sale in the market. Industrial agriculture, by comparison, uses fossil fuel combustion to power much of the work on the farm: tilling, sowing, harvesting, irrigation, and fertilizer application. Efficiencies of scale encourage raising crop monocultures.
3. Soil is formed by the weathering of rocks and minerals, and by the input of organic material. Physical or mechanical weathering breaks down rocks without

changing them chemically. For example, ice wedges can form in small cracks in a rock, breaking it in two. Chemical weathering results from water or other substances chemically interacting with the parent material. Biological weathering occurs when living things are responsible for breaking down the parent material by either physical or chemical means. For example, root growth can wedge cracks open, and organic acids can dissolve some minerals. The five factors influencing soil formation are climate, organisms, relief, parent material, and time. Warmer and wetter climates have accelerated rates of physical weathering. Differences in local vegetation alter the input of organic material. Steeper slopes lead to higher rates of erosion. Soil formed from the weathering of limestone will be different from that formed from granite. Recently formed soils will not be as well developed as older soils.

4. Soil horizons, or distinct layers, are created by the processes of weathering, erosion, deposition, and organic matter generation and decay. Generally, the degree of weathering and the concentration of organic material decreases as one moves downward in the soil profile.
5. Erosion is considered a destructive process because local rates of erosion can greatly exceed local rates of soil formation. Erosion is increased by the over-cultivation of fields, over-grazing of rangelands, and deforestation. Erosion by water may occur as splash erosion, sheet erosion, rill erosion, or gully erosion. The intensity of water erosion is greater in places that receive more precipitation, and where the slope of the land surface is steeper.
6. Hugh Hammond Bennett advocated soil conservation techniques such as contour farming, strip cropping, crop rotation, terracing, grazing management, reforestation, and wildlife management. Additional techniques include establishing shelterbelts, and using conservation tillage, or “no-till” farming.
7. No-till farming drills seeds and fertilizer into the stubble of the previous year’s crop without first plowing or cultivating the field. The old crop’s roots and aboveground stubble are left in place between the harvest and the next planting to hold the soil and protect it from splash and wind erosion.
8. Fertilizers boost crop growth if they supply required nutrients that were otherwise not sufficiently available to the crop plants. If more fertilizer is added to a field than the crop can take up, the excess nutrients may be leached from the soil into streams or groundwater. Some nutrients may also be converted to a gaseous form, mostly by bacteria. These gases may then be released to the atmosphere.
9. Overgrazing exposes the soil surface to erosion by wind and water and may cause soil compaction that limits water infiltration, soil aeration, and plant growth. Public land policies can be linked to the practice of overgrazing, as Garrett Hardin did in *The Tragedy of the Commons*. Grazing practices are sustainable if they do not decrease the amount and diversity of vegetation on the grazed lands over time.

10. The U.S. government's Conservation Reserve Program pays farmers to take highly erodible land out of cultivation. These measures save farmers money while nurturing soil as an investment for sustainable yields in the future.

Calculating Ecological Footprints

	Plant products consumed (lb)	**Soil loss at 5:1 ratio (lb)**	**Soil loss at 3.25:1 ratio (lb)**	**Reduced soil loss at 3.25:1 relative to 5:1 ratio (lb)**
You	365	1,825	1,186	639
Your class	*Answers will vary*	*Answers will vary*	*Answers will vary*	*Answers will vary*
Your state	*Answers will vary*	*Answers will vary*	*Answers will vary*	*Answers will vary*
United States	1.095×10^{11}	5.48×10^{11}	3.56×10^{11}	1.54×10^{11}

1. Answers in table.
2. Answers in table.
3. A sustainable rate of soil loss is one that does not exceed the local rate of soil formation. Measuring the amount of topsoil at a farm over time will reveal whether farm practices are sustainable.