4.2 Managing the Soil—Controlling the Flow of Nutrients and Water

One of Earth's most important resources is, quite literally, under your feet. It is the ground you walk on. You may think of soil as the "dirt" you bring into the house on your shoes or something needed for potted plants. For farmers, fertile soil is essential to their livelihood. Plants depend on the soil for their physical support and to provide water, nutrients, and oxygen to their roots. Farmers must consider these functions to manage soil resources sustainably.

Soil is a complex mixture of minerals, water, dissolved nutrients, air spaces, and decomposing organic matter (Figure 1). It is also home to countless organisms, ranging in size from microscopic bacteria to large burrowing mammals. Soils are among the most complex and poorly understood components of Earth's ecosystems, yet they are critical to our survival.

DID YOU KNOW?

The Speed of Soil Formation

The small mineral particles that make up soil are formed from rock. Wind, water, chemical processes, and living organisms gradually cause rock to break up into small particles. It can take 200 years to form a layer of soil just 1 cm thick!

Figure 1 A few grams of healthy soil contain billions of micro-organisms.

DID YOU KNOW?

The Vital Role of Soil Fungi

Soil fungi can live in a mutualistic relationship with plants. The microscopic filaments of these "mycorrhizal" fungi surround the fine root hairs of their plant partners. The fungi deliver nutrients and water to the plant. In turn, the plant provides energy-rich food molecules to the fungi.

RESEARCH THIS WHAT ARE THE CHEMICAL CONTENTS?

SKILLS: Researching, Communicating

SKILLS HANDBOOK 4.A.

Humans alter the chemical makeup of soils when they add natural or synthetic soil supplements. These may be fertilizers, pesticides, or soil conditioners, such as peat moss. In this activity, you will research the chemical composition of soil supplements.

1. Gather data on 10 commercially available soil supplements. These products are sold at garden and hardware stores. Most of the information you will need is on the ingredient labels. You can also go to online sources.

GO TO NELSON SCIENCE

A. For each product you researched, list the following information: T/I
   (i) Product name
   (ii) Is the product natural or synthetic?
   (iii) What is the product's intended use? (home and garden, agricultural, and so on)
   (iv) What are the main ingredients in the product?
   (v) What is the intended function of the product? Is it a fertilizer, soil conditioner, pesticide, or combination?

B. Present your findings in table form. T/I C

Managing Soil Nutrients

Plants require nutrients to grow. The most important nutrients are nitrogen, phosphorus, and potassium. As you learned in Chapter 2, nutrients are cycled through ecosystems as plants grow and are consumed by animals and micro-organisms as they produce wastes, die, and decompose.

On farmland, or agroecosystems, natural nutrient and water cycles are disrupted. As crops grow, they take up nutrients from the soil and incorporate them into their tissue. However, when farmers harvest crops, the nutrients contained in the crops are removed from the ecosystem (Figure 2). The nutrients enter the human food chain when we eat the crop or the livestock that ate these crops. If human and livestock wastes are not returned to the original farmland, the soil will gradually be depleted of nutrients.

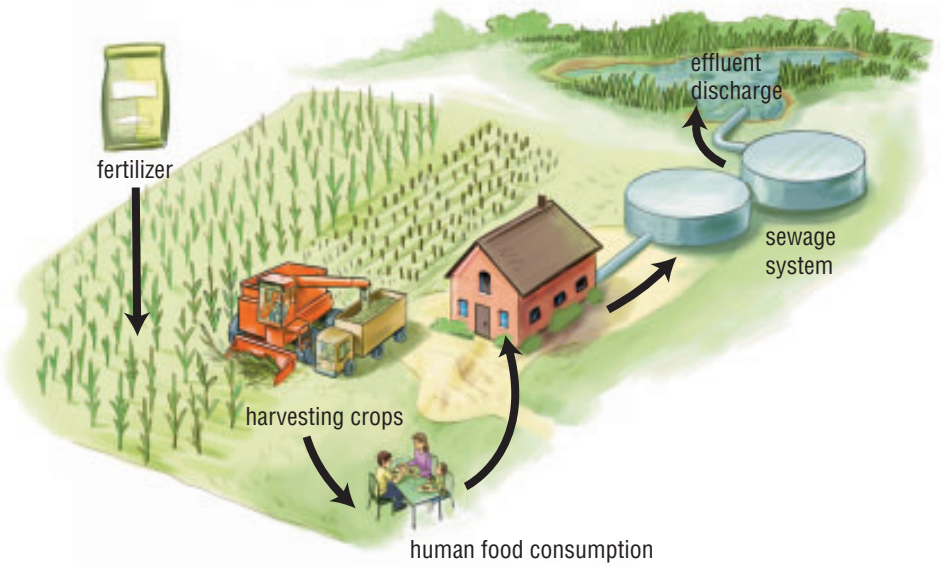

Figure 2 In agroecosystems, many nutrients (shown here as arrows) are added to the soil as fertilizers. Nutrients are taken up by plants and removed from the agroecosystem when we harvest the crop. After we eat the crop, some of the nutrients end up in our waste disposal system.

Natural and Synthetic Fertilizers

How can farmers manage biogeochemical cycles to replace the lost nutrients in an environmentally sustainable way? The most common method of replacing lost nutrients on farmland is to apply fertilizers. All natural ecosystems recycle natural fertilizers in biogeochemical cycles. Most of these ecosystems have remained healthy and sustainable for thousands of years.

natural fertilizer plant nutrients that have been obtained from natural sources and have not been chemically altered by humans

synthetic fertilizer fertilizers that are manufactured using chemical processes

For most of human history, farmers have depended on **natural fertilizers** made from materials such as plant and animal wastes. Currently, the most common practice is to apply **synthetic fertilizers**, manufactured by humans. Synthetic fertilizers were largely responsible for the "Green Revolution." In the 1960s, as farmers began using synthetic fertilizers, crop yields dramatically improved. This increased food production and farm profitability.

Environmental Impacts of Fertilizer Applications

Using fertilizers has drawbacks for both terrestrial and aquatic ecosystems (Figure 3). The nutrients in synthetic fertilizers are highly concentrated. As a result, they may enter the soil rapidly and alter the community of soil organisms. This can lead to soil that has less natural organic matter, as well as stressed soil organisms. Such soils can lose their supply of naturally occurring nutrients. This creates a dependency on synthetic fertilizers. These soils also become susceptible to erosion. Such a situation is not sustainable in the long term.

READING TIP

Read Between the Lines

If you read a word or term that you are unfamiliar with seeing in print, say the word aloud and ask yourself if you have heard the word before or used it when speaking. Also, check the margin and the context of the sentence or paragraph to see if a definition is given.

Figure 3 The use of both (a) natural and (b) synthetic fertilizers increases food production, but has ecological consequences.

Fertilizers, especially concentrated synthetic fertilizers, can have serious impacts on groundwater if they are leached from the soil. **Leaching** occurs when nutrients become dissolved in water and seep out of the soil. Groundwater that has been contaminated with nitrogen compounds is an increasingly serious problem, especially when it is used as drinking water. Drinking water with high levels of nitrogen compounds in it can cause health problems, particularly in infants.

leaching the process by which nutrients are removed from the soil as water passes through it

Aquatic ecosystems are often negatively impacted by agricultural practices. During heavy rain or spring runoff, fertilizers can enter aquatic ecosystems. This effect is more pronounced when synthetic fertilizers are used but also occurs when a large volume of animal manure is applied to a field. Leached nutrients increase the growth of algae, especially in warm, shallow ponds or lakes. The result is an "algal bloom" in which algae grow and then die and decompose (Figure 4). This decomposition is caused by bacteria that use oxygen. These bacteria decrease the level of dissolved oxygen in the water, which kills fish and other aquatic organisms.

Figure 4 Algal blooms decrease the oxygen content of lakes and ponds.

Natural fertilizers tend to be less concentrated than synthetic fertilizers and release nutrients more slowly. Using natural fertilizers is more similar to natural biogeochemical cycles and has less impact on soil quality. However, natural fertilizers can have a negative impact if they are applied inappropriately. Table 1 summarizes some key features of synthetic and natural fertilizers.

Table 1 Advantages and Disadvantages of Using Synthetic and Natural Fertilizers

	Synthetic fertilizers	Natural fertilizers
examples	ammonia, synthetic urea, potash, potassium, commercial chemical fertilizers	animal manure, sludge, plant materials such as seaweed and compost, blood meal, bone meal, wood ashes
advantages	• nutrients are released quickly • amounts of nutrients can be precisely measured • relatively easy to apply	• less danger of overfertilizing • release nutrients slowly • can improve soil structure • benefit soil micro-organisms and nutrient cycling
disadvantages	• production is energy intensive • cause water pollution • nutrients lost from soil through leaching • can cause an imbalance in soil chemistry and upset the balance of soil micro-organisms	• low concentrations of nutrients • release of nutrients may be slower than desired • not easy to measure the quantity of nutrients • may be more difficult to apply

DID YOU KNOW?

The Walkerton Tragedy

In 2000, the drinking water for the town of Walkerton was contaminated. Heavy rains washed animal waste containing a deadly strain of *Escherichia coli* bacteria into one of the town's wells. At least seven people died, and 2500 others became ill.

Controlling the Flow of Water in Soil

To raise healthy livestock and grow crops, farmers must have a reliable supply of water. To accomplish this, farmers can add water to fields using irrigation or remove water using drainage technologies (Figure 5).

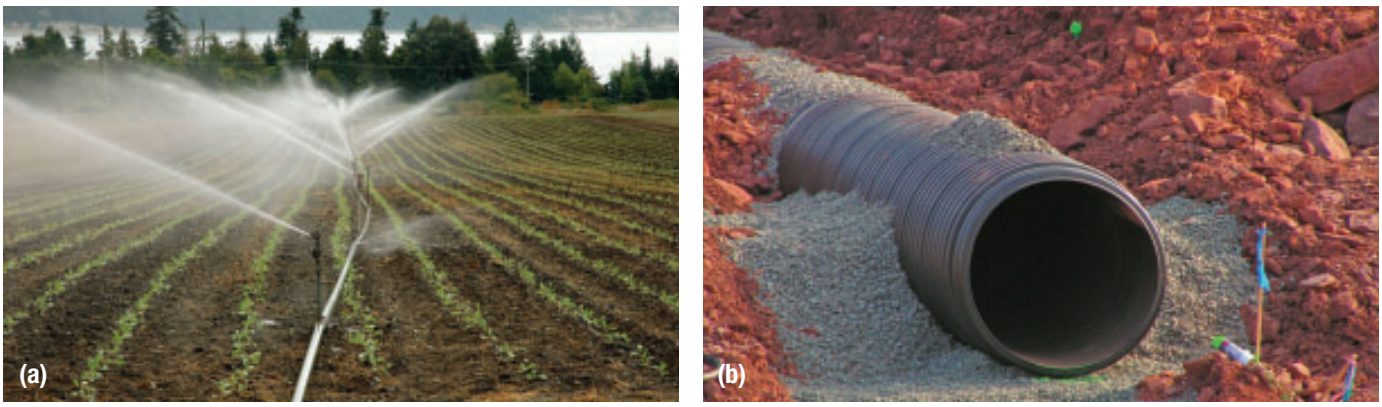

Figure 5 Farmers can (a) add water to agroecosystems using irrigation or (b) remove water using drainage pipes buried below the soil surface.

Farmers obtain water from surface sources such as lakes or rivers or from groundwater. With large-scale irrigation projects, it is possible to even farm a desert. In some cases, irrigation can create ideal growing conditions. In California, for example, by adding water to the otherwise dry environment, farmers have become major producers of rice. This crop requires very wet growing conditions.

To remove water from saturated fields, farmers install drainage tiles. This allows more air to penetrate the soil and gives roots access to oxygen. Drainage is often used to convert natural wetlands into fertile farmland. This has created some of the most productive farmland in Canada. However, this practice has caused a dramatic loss of wetlands and their associated wildlife species.

Irrigation and drainage practices improve our ability to grow food because they allow us to farm land that would otherwise be too dry or too wet. However, altering water levels can have negative consequences. Aquatic ecosystems can be harmed, and water shortages result if too much water is removed from an ecosystem. Water for irrigation may be supplied by reservoirs located behind large dams. Dams and reservoirs alter the aquatic ecosystem that once occupied the natural river. In some places, all of the water that enters a river system is used by humans before reaching the mouth of the river (Figure 6).

Figure 6 At times, none of the water in the Colorado River reaches the ocean. All of it is removed upstream for irrigation, for drinking water supplies, and to meet other human needs.

Soil Air Spaces and Compaction

The air spaces in soil serve two important functions. They allow water and nutrients to pass through the soil to reach roots and they provide oxygen to plant roots and soil organisms. The size of air spaces is influenced by the physical characteristics of soil particles. Soils made up of smaller particles have less air space.

Soil becomes compacted when pressure squeezes soil particles closer together. This reduces air spaces. When compacted, roots may not obtain enough oxygen. Water will have difficulty passing through the soil. Compaction may be caused by heavy equipment or simply by people walking on it. For example, you may have witnessed the impact of compaction along a well-used path.

TRY THIS HUMANS WEIGH IN ON SOIL COMPACTION

SKILLS: Controlling Variables, Performing, Observing, Analyzing, Evaluating

Human actions often cause soil compaction. This reduces the ability of air and water to move through soil. In this activity, you will examine the impact of soil compaction on water movement through soil.

Equipment and Materials: 2 flower pots with drainage holes; tray; stopwatch; measuring cup or graduated cylinder; potting soil; water

1. Obtain two identical flower pots that have drainage holes at the bottom. Fill both pots three-quarters full of loose potting soil.
2. In the first pot, *gently* push down on the soil surface to remove any large air spaces and even out the soil surface.
3. In the second pot, *firmly* push down to compress the soil into the bottom of the pot. Make sure that the entire soil surface has been compressed.
4. Place the pots on a large tray. Using a stopwatch, begin timing as you slowly pour 150 mL of water onto the soil surface in the first pot. Record the time it takes for all the water to have penetrated below the surface of the soil.
5. Repeat step 4 for the pot containing the compressed soil.

A. Describe the effects of soil compaction on the rate at which water can penetrate the soil surface. T/I A

B. Brainstorm human activities on a farm, around your home, in a park, and in other settings that can cause soil compaction. A

C. How might soil compaction influence root growth? Explain your reasoning. T/I

Figure 7 In no-tillage farming, the stubble of the crop is left on the field after the crop is harvested.

Figure 8 Soybeans, corn, and wheat are often grown in rotation in southern Ontario.

Alternative Farming Practices

Farmers use several methods to reduce the impacts of agricultural practices on biogeochemical and water cycles. Three approaches are no-tillage farming, crop rotation, and crop selection.

In no-tillage agriculture, farmers leave the ground undisturbed after the crop is harvested instead of ploughing the remaining vegetation into the soil (Figure 7). This helps retain soil nutrients, reduces soil compaction and water loss, and improves soil quality. The remaining plant stalks (stubble) protect the soil from wind and water erosion. No-tillage agriculture sometimes requires greater pesticide use because weed populations are no longer controlled by ploughing them under.

Most farmers rotate or change the crops they plant on a certain area of land on a regular basis. By rotating crops, farmers can reduce their use of fertilizers and pesticides. For example, in southern Ontario, farmers often plant soybeans, corn, and wheat in a three-year rotation (Figure 8). During a soybean year, the nitrogen concentration of the soil increases through the action of nitrogen-fixing bacteria living in root nodules. This reduces the need to add nitrogen fertilizer the following year for corn. In the third year of the rotation, wheat is planted. Because wheat is not planted in rows, it is competitive against weeds and requires less herbicide.

Farmers can also choose to grow crops that are better suited to the local growing conditions. For example, growing drought-resistant and heat-tolerant plants in an area with hot, dry summers is more sustainable than growing a crop that needs a lot of water. These crops are dependent on extensive irrigation and may deplete groundwater supplies over time.

IN SUMMARY

- Fertilizers disrupt biogeochemical cycles and can pollute the environment.
- Synthetic fertilizers cause more ecological problems than natural fertilizers.
- Farmers alter the water cycle by irrigating fields or using drainage pipes to remove water.
- Soil compaction limits water flow and harms plants by reducing oxygen and nutrient availability.
- Practices such as no-tillage farming, crop rotation, and crop selection reduce the impacts of agriculture on the soil ecosystem.

CHECK YOUR LEARNING

1. How do biogeochemical cycles in agroecosystems differ from those in natural ecosystems? Explain. K/U
2. Define and give examples of synthetic and natural fertilizers. K/U
3. List the advantages and disadvantages of synthetic versus natural fertilizers. K/U
4. Explain how adding fertilizer to an ecosystem can cause damage to it. K/U C
5. Describe how irrigation on farms influences natural sources of water and the ecosystems they support. K/U
6. Identify ways that soil compaction influences nutrient and water cycles. K/U
7. How do humans grow crops on land that would naturally be either too dry or too wet? Explain. K/U
8. Describe three farming methods that can reduce some of the negative impacts of farming on the soil. K/U