Chapter 2

ORGANIC MATTER: WHAT IT IS AND WHY IT'S SO IMPORTANT

Follow the appropriateness of the season, consider well the nature and conditions of the soil, then and only then least labor will bring best success. Rely on one's own idea and not on the orders of nature, then every effort will be futile.

—JIA SI XIE, 6TH CENTURY, CHINA

As we will discuss at the end of this chapter, organic matter has an overwhelming effect on almost all soil properties, although it is generally present in relatively small amounts. A typical agricultural soil has 1% to 6% organic matter. It consists of three distinctly different parts—living organisms, fresh residues, and well-decomposed residues. These three parts of soil organic matter have been described as the *living*, the *dead*, and the *very dead*. This three-way classification may seem simple and unscientific, but it is very useful.

The living part of soil organic matter includes a wide variety of microorganisms, such as bacteria, viruses, fungi, protozoa, and algae. It even includes plant roots and the insects, earthworms, and larger animals, such as moles, woodchucks, and rabbits, that spend some of their time in the soil. The living portion represents about 15% of the total soil organic matter. Microorganisms, earthworms, and insects feed on plant residues and manures for energy and nutrition, and in the process they mix organic matter into the mineral soil. In addition, they recycle plant nutrients. Sticky substances on the skin of earthworms and other substances produced by fungi help bind particles together. This helps to stabilize the soil aggregates, clumps of particles that make up good soil structure. Organisms such as earthworms and some fungi also help to stabilize the soil's structure (for example, by producing channels that allow water to infiltrate) and, thereby, improve soil water status and aeration. Plant roots also interact in significant ways with the various microorganisms and animals living in the soil. Another important aspect of soil organisms is that they are in a constant struggle with each other (figure 2.1). Further discussion of the interactions between soil organisms and roots, and among the various soil organisms, is provided in chapter 4.

A multitude of microorganisms, earthworms, and

Photo by Christine Markoe

insects get their energy and nutrients by breaking down organic residues in soils. At the same time, much of the energy stored in residues is used by organisms to make new chemicals as well as new cells. How does energy get stored inside organic residues in the first place? Green plants use the energy of sunlight to link carbon atoms together into larger molecules. This process, known as *photosynthesis,* is used by plants to store energy for respiration and growth.

The fresh residues, or "dead" organic matter, consist of recently deceased microorganisms, insects, earthworms, old plant roots, crop residues, and recently added manures. In some cases, just looking at them is enough to identify the origin of the fresh residues (figure 2.2). This part of soil organic matter is the active, or easily decomposed, fraction. This active fraction of soil organic matter is the main supply of food for various organisms—microorganisms, insects, and earthworms—living in the soil. As organic materials are decomposed by the "living," they release many of the nutrients needed by plants. Organic chemical compounds produced during the decomposition of fresh residues also help to bind soil particles together and give the soil good structure.

Organic molecules directly released from cells of fresh residues, such as proteins, amino acids, sugars, and starches, are also considered part of this fresh organic matter. These molecules generally do not last long in the soil because so many microorganisms use them as food.

The well-decomposed organic material in soil, the "very dead," is called *humus*. Some use the term *humus* to describe all soil organic matter; some use it to describe just the part you can't see without a microscope. We'll use the term to refer only to the well-decomposed part of soil organic matter. Because it is so stable and complex, the average age of humus in soils is usually more than 1,000 years. The already well-decomposed humus is not a food for organisms, but its very small size and chemical properties make it an important part of the soil. Humus holds on to some essential nutrients, storing them for slow release to plants. Humus also can surround certain potentially harmful chemicals and prevent them from causing damage to plants. Good amounts of soil humus can both lessen drainage and compaction problems that occur in clay soils and improve water retention in sandy soils by enhancing aggregation, which reduces soil density, and by holding on to and releasing water.

Another type of organic matter, one that has gained a lot of attention lately, is usually referred to as *black carbon*. Almost all soils contain some small pieces of

Figure 2.1. A nematode feeds on a fungus, part of a living system of checks and balances. Photo by Harold Jensen.

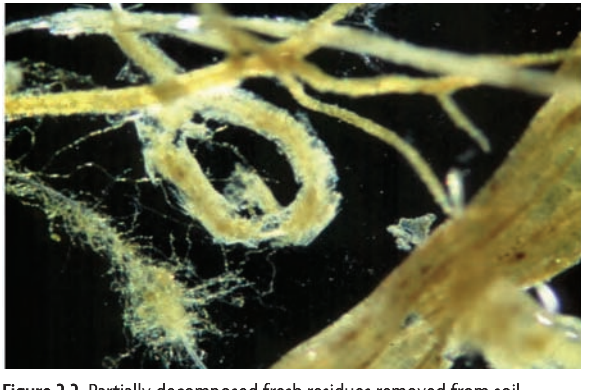

Figure 2.2. Partially decomposed fresh residues removed from soil. Fragments of stems, roots, and fungal hyphae are all readily used by soil organisms.

BIOCHAR AS A SOIL AMENDMENT

It is believed that the unusually productive "dark earth" soils of the Brazilian Amazon region were produced and stabilized by incorporation of vast amounts of charcoal over the years of occupation and use. Black carbon, produced by wildfires as well as human activity and found in many soils around the world, is a result of burning biomass at around 700 to 900°F under low oxygen conditions. This incomplete combustion results in about half or more of the carbon in the original material being retained as char. The char, also containing ash, tends to have high amounts of negative charge (cation exchange capacity), has a liming effect on soil, retains some nutrients from the wood or other residue that was burned, stimulates microorganism populations, and is very stable in soils. Although many times increases in yield have been reported following biochar application—probably a result of increased nutrient availability or increased pH—sometimes yields suffer. Legumes do particularly well with biochar additions, while grasses are frequently nitrogen deficient, indicating that nitrogen may be deficient for a period following application.

Note: The effects of biochar on raising soil pH and immediately increasing calcium, potassium, magnesium, etc., are probably a result of the ash rather than the black carbon itself. These effects can also be obtained by using more completely burned material, which contains more ash and little black carbon.

charcoal, the result of past fires, of natural or human origin. Some, such as the black soils of Saskatchewan, Canada, may have relatively high amounts of char. However, the interest in charcoal in soils has come about mainly through the study of the soils called dark earths (*terra preta de indio*) that are on sites of long-occupied villages in the Amazon region of South America that were depopulated during the colonial era. These dark earths contain 10–20% black carbon in the surface foot of soil, giving them a much darker color than the surrounding soils. The soil charcoal was the result of centuries of cooking fires and in-field burning of crop residues and other organic materials. The manner in which the burning occurred—slow burns, perhaps because of the wet conditions common in the Amazon—produces a lot of char material and not as much ash as occurs with more complete burning at higher temperatures. These soils were intensively used in the past but have been abandoned for centuries. Still, they are much more fertile than the surrounding soils—partially due to the high inputs of nutrients in animal and plant residue—and yield better crops than surrounding soils typical of the tropical forest. Part of this higher fertility—the ability to supply plants with nutrients with very low amounts of leaching loss—has been attributed to the large amount of black carbon and the high amount of biological activity in the soils. Charcoal is a very stable form of carbon and apparently helps maintain relatively high cation exchange capacity as well as biological activity. People are beginning to experiment with adding large amounts of charcoal to soils—but we'd suggest waiting for results of the experiments before making large investments in this practice. The quantity needed to make a major difference to a soil is apparently huge—many tons per acre—and may limit the usefulness of this practice to small plots of land.

Normal organic matter decomposition that takes place in soil is a process that is similar to the burning of wood in a stove. When burning wood reaches a certain temperature, the carbon in the wood combines with oxygen from the air and forms carbon dioxide. As this occurs, the energy stored in the carbon-containing chemicals in the wood is released as heat in a process called oxidation. The biological world, including humans, animals, and microorganisms, also makes use of the energy inside carbon-containing molecules. This process of converting sugars, starches, and other compounds into a directly usable form of energy is also a type of oxidation. We usually call it respiration. Oxygen is used, and carbon dioxide and heat are given off in the process.

Soil carbon is sometimes used as a synonym for *organic matter*. Because carbon is the main building block of all organic molecules, the amount in a soil is strongly related to the total amount of all the organic matter—the living organisms plus fresh residues plus well-decomposed residues. When people talk about soil carbon instead of organic matter, they are usually referring to organic carbon. The amount of organic matter in soils is about twice the organic carbon level. However, in many soils in glaciated areas and semiarid regions it is common to have another form of carbon in soils—limestone, either as round concretions or dispersed evenly throughout the soil. Lime is calcium carbonate, which contains calcium, carbon, and oxygen. This is an *inorganic* carbon form. Even in humid climates, when limestone is found very close to the surface, some may be present in the soil.

WHY SOIL ORGANIC MATTER IS SO IMPORTANT

A fertile and healthy soil is the basis for healthy plants, animals, and humans. And soil organic matter is the very foundation for healthy and productive soils. Understanding the role of organic matter in maintaining a healthy soil is essential for developing ecologically sound agricultural practices. But how can organic matter, which only makes up a small percentage of most soils, be so important that we devote the three chapters in this section to discuss it? The reason is that organic matter positively influences, or modifies the effect of, essentially all soil properties. That is the reason it's so important to our understanding of soil health and how to manage soils better. Organic matter is essentially the heart of the story, but certainly not the only part. In addition to functioning in a large number of key roles that promote soil processes and crop growth, soil organic matter is a critical part of a number of global and regional cycles.

It's true that you can grow plants on soils with little organic matter. In fact, you don't have to have any soil at all. (Although gravel and sand hydroponic systems without soil can grow excellent crops, large-scale systems of this type are usually neither economically nor ecologically sound.) It's also true that there are other important issues aside from organic matter when considering the quality of a soil. However, as soil organic matter decreases, it becomes increasingly difficult to grow plants, because problems with fertility, water availability, compaction, erosion, parasites, diseases, and insects become more common. Ever higher levels of inputs—fertilizers, irrigation water, pesticides, and machinery—are required to maintain yields in the face of organic matter depletion. But if attention is paid to proper organic matter management, the soil can support a good crop without the need for expensive fixes.

The organic matter content of agricultural topsoil is usually in the range of 1–6%. A study of soils in Michigan demonstrated potential crop-yield increases of about 12% for every 1% organic matter. In a Maryland experiment, researchers saw an increase of approximately 80 bushels of corn per acre when organic matter increased from 0.8% to 2%. The enormous influence of organic matter on so many of the soil's properties—biological, chemical, and physical—makes it of critical importance to healthy soils (figure 2.3). Part of the explanation for this influence is the small particle size of the well-decomposed portion of organic matter—the humus. Its large surface area–to–volume ratio means that humus is in contact with a considerable portion of the soil. The intimate contact of humus with the rest of the soil allows many reactions, such as the release of available nutrients into the soil water, to occur rapidly. However, the many roles of living organisms make soil life an essential part of the organic matter story.

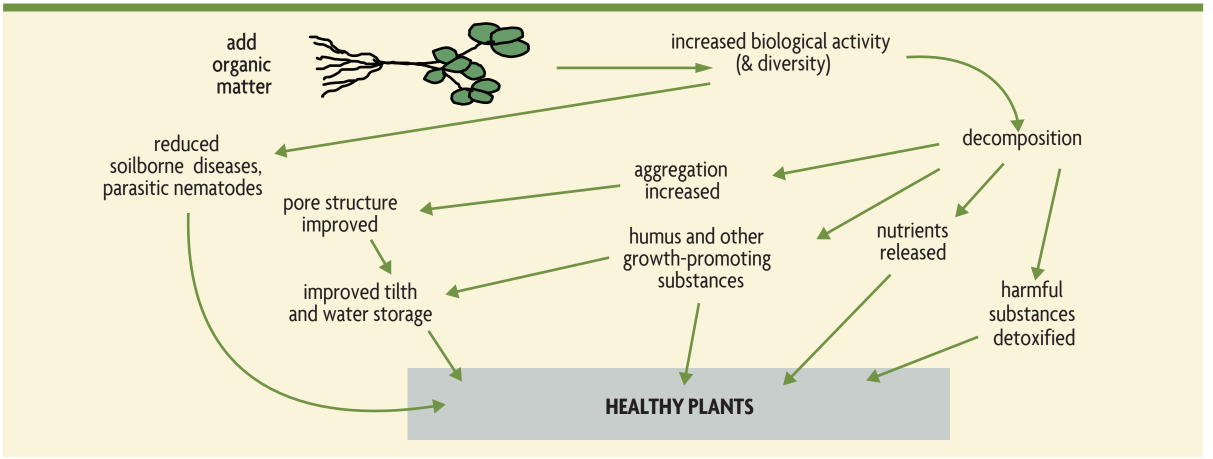

Figure 2.3. Adding organic matter results in many changes. Modified from Oshins and Drinkwater (1999).

Plant Nutrition

Plants need eighteen chemical elements for their growth—carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), boron (B), zinc (Zn), molybdenum (Mo), nickel (Ni), copper (Cu), cobalt (Co), and chlorine (Cl). Plants obtain carbon as carbon dioxide (CO_2) and oxygen partially as oxygen gas (O_2) from the air. The remaining essential elements are obtained mainly from the soil. The availability of these nutrients is influenced either directly or indirectly by the presence of organic matter. The elements needed in large amounts—carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur—are called macronutrients. The other elements, called micronutrients, are essential elements needed in small amounts. (Sodium [Na] helps many plants grow better, but it is not considered essential to plant growth and reproduction.)

Nutrients from decomposing organic matter. Most of the nutrients in soil organic matter can't be used by plants as long as those nutrients exist as part of large organic molecules. As soil organisms decompose organic matter, nutrients are converted into simpler, inorganic, or mineral forms that plants can easily use. This process, called mineralization, provides much of the nitrogen that plants need by converting it from organic forms. For example, proteins are converted to ammonium (NH_4^+) and then to nitrate (NO_3^-). Most plants will take up the majority of their nitrogen from soils in the form of nitrate. The mineralization of organic matter is also an important mechanism for supplying plants with such nutrients as phosphorus and sulfur and most of the

WHAT MAKES TOPSOIL?

Having a good amount of topsoil is important. But what gives topsoil its beneficial characteristics? Is it because it's on TOP? If we bring in a bulldozer and scrape off one foot of soil, will the exposed subsoil now be topsoil because it's on the surface? Of course, everyone knows that there's more to topsoil than its location on the soil surface. Most of the properties we associate with topsoil—good nutrient supply, tilth, drainage, aeration, water storage, etc.—are there because topsoil is rich in organic matter and contains a huge diversity of life.

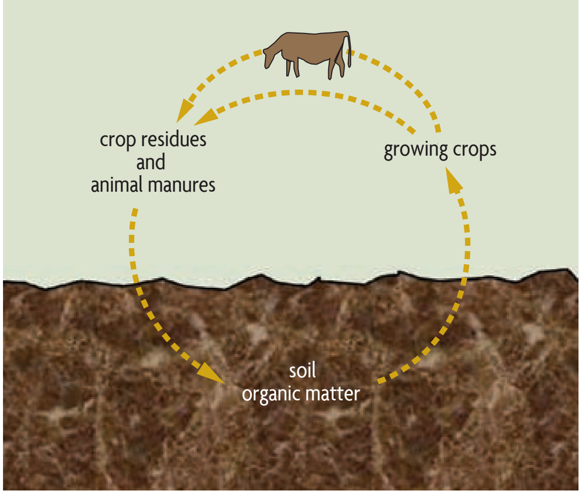

Figure 2.4. The cycle of plant nutrients.

micronutrients. This release of nutrients from organic matter by mineralization is part of a larger agricultural nutrient cycle (see figure 2.4). For a more detailed discussion of nutrient cycles and how they function in various cropping systems, see chapter 7.

Addition of nitrogen. Bacteria living in nodules on legume roots convert nitrogen from atmospheric gas (N_2) to forms that the plant can use directly. A number of free-living bacteria also fix nitrogen.

Storage of nutrients on soil organic matter. Decomposing organic matter can feed plants directly, but it also can indirectly benefit the nutrition of the plant. A number of essential nutrients occur in soils as positively charged molecules called cations (pronounced cat-eye-ons). The ability of organic matter to hold on to cations in a way that keeps them available to plants is known as cation exchange capacity (CEC). Humus has many negative charges. Because opposite charges attract, humus is able to hold on to positively charged nutrients, such as calcium (Ca^{++}), potassium (K^+), and magnesium (Mg^{++}) (see figure 2.5a). This keeps them from leaching deep into the subsoil when water moves through the topsoil. Nutrients held in this way can be gradually released into the soil solution and made available to plants throughout the growing season. However, keep in mind that not all plant nutrients occur as cations. For example, the nitrate form of nitrogen is negatively charged (NO_3^-) and is actually repelled by the negatively charged CEC. Therefore, nitrate leaches easily as water moves down through the soil and beyond the root zone.

Clay particles also have negative charges on their surfaces (figure 2.5b), but organic matter may be the major source of negative charges for coarse and medium-textured soils. Some types of clays, such as those found in the southeastern United States and in the tropics, tend to have low amounts of negative charge. When those clays are present, organic matter may be the major source of negative charges that bind nutrients,

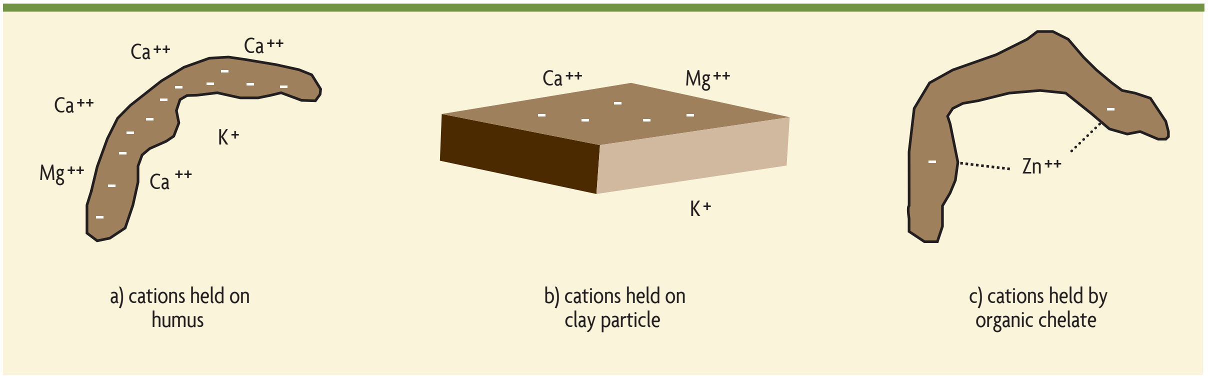

Figure 2.5. Cations held on negatively charged organic matter and clay.

even for fine-textured (high-clay-content) soils.

Protection of nutrients by chelation. Organic molecules in the soil may also hold on to and protect certain nutrients. These particles, called "chelates" (pronounced key-lates) are by-products of the active decomposition of organic materials and are smaller than the particles that make up humus. In general, elements are held more strongly by chelates than by binding of positive and negative charges. Chelates work well because they bind the nutrient at more than one location on the organic molecule (figure 2.5c). In some soils, trace elements, such as iron, zinc, and manganese, would be converted to unavailable forms if they were not bound by chelates. It is not uncommon to find low-organic-matter soils or exposed subsoils deficient in these micronutrients.

Other ways of maintaining available nutrients. There is some evidence that organic matter in the soil can inhibit the conversion of available phosphorus to forms that are unavailable to plants. One explanation is that organic matter coats the surfaces of minerals that can bond tightly to phosphorus. Once these surfaces are covered, available forms of phosphorus are less likely to react with them. In addition, humic substances may chelate aluminum and iron, both of which can react with phosphorus in the soil solution. When they are held as chelates, these metals are unable to form an insoluble mineral with phosphorus.

ORGANIC MATTER INCREASES THE AVAILABILITY OF NUTRIENTS . . .

Directly

- As organic matter is decomposed, nutrients are converted into forms that plants can use directly.
- CEC is produced during the decomposition process, increasing the soil's ability to retain calcium, potassium, magnesium, and ammonium.
- Organic molecules are produced that hold and protect a number of micronutrients, such as zinc and iron.

Indirectly

- Substances produced by microorganisms promote better root growth and healthier roots, and with a larger and healthier root system plants are able to take in nutrients more easily.
- Organic matter contributes to greater amounts of water retention following rains because it improves soil structure and thereby improves water-holding capacity. This results in better plant growth and health and allows more movement of mobile nutrients (such as nitrates) to the root.

Beneficial Effects of Soil Organisms

Soil organisms are essential for keeping plants well supplied with nutrients because they break down organic matter. These organisms make nutrients available by freeing them from organic molecules. Some bacteria fix nitrogen gas from the atmosphere, making it available to plants. Other organisms dissolve minerals and make phosphorus more available. If soil organisms aren't present and active, more fertilizers will be needed to supply plant nutrients.

A varied community of organisms is your best protection against major pest outbreaks and soil fertility problems. A soil rich in organic matter and continually supplied with different types of fresh residues is home to a much more diverse group of organisms than soil depleted of organic matter. This greater diversity of organisms helps insure that fewer potentially harmful organisms will be able to develop sufficient populations to reduce crop yields.

Soil Tilth

When soil has a favorable physical condition for growing plants, it is said to have good *tilth*. Such a soil is porous and allows water to enter easily, instead of running off

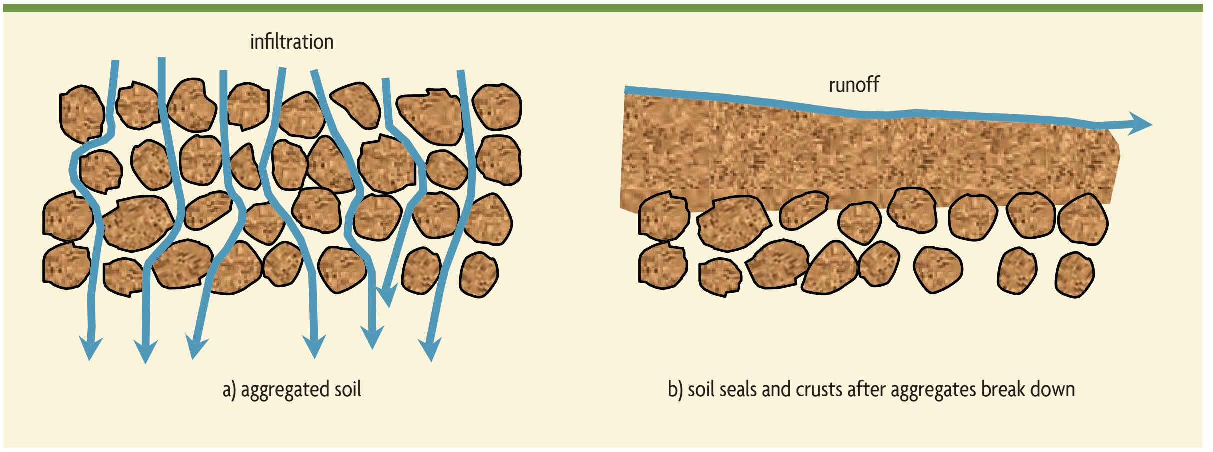

Figure 2.6. Changes in soil surface and water-flow pattern when seals and crusts develop.

the surface. More water is stored in the soil for plants to use between rains, and less erosion occurs. Good tilth also means that the soil is well aerated. Roots can easily obtain oxygen and get rid of carbon dioxide. A porous soil does not restrict root development and exploration. When a soil has poor tilth, the soil's structure deteriorates and soil aggregates break down, causing increased compaction and decreased aeration and water storage. A soil layer can become so compacted that roots can't grow. A soil with excellent physical properties will have numerous channels and pores of many different sizes.

Studies on both undisturbed and agricultural soils show that as organic matter increases, soils tend to be less compact and have more space for air passage and water storage. Sticky substances are produced during the decomposition of plant residues. Along with plant roots and fungal hyphae, they bind mineral particles together into clumps, or aggregates. In addition, the sticky secretions of mycorrhizal fungi—beneficial fungi that enter roots and help plants get more water and nutrients—are important binding material in soils. The arrangement and collection of minerals as aggregates and the degree of soil compaction have huge effects on plant growth (see chapters 5 and 6). The development of aggregates is desirable in all types of soils because it promotes better drainage, aeration, and water storage. The one exception is for wetland crops, such as rice, when you want a dense, puddled soil to keep it flooded.

Organic matter, as residue on the soil surface or as a binding agent for aggregates near the surface, plays an important role in decreasing soil erosion. Surface residues intercept raindrops and decrease their potential to detach soil particles. These surface residues also slow water as it flows across the field, giving it a better chance to infiltrate into the soil. Aggregates and large channels greatly enhance the ability of soil to conduct water from the surface into the subsoil.

Most farmers can tell that one soil is better than another by looking at them, seeing how they work up when tilled, or even by sensing how they feel when walked on or touched. What they are seeing or sensing is really good tilth. For an example, see the photo on the back cover of this book. It shows that soil differences can be created by different management strategies. Farmers and gardeners would certainly rather grow their crops on the more porous soil depicted in the photo on the right.

Since erosion tends to remove the most fertile part of the soil, it can cause a significant reduction in crop yields. In some soils, the loss of just a few inches of topsoil may result in a yield reduction of 50%. The surface of some soils low in organic matter may seal over, or crust, as rainfall breaks down aggregates and pores near the surface fill with solids. When this happens, water that can't infiltrate into the soil runs off the field, carrying valuable topsoil (figure 2.6).

Large soil pores, or channels, are very important because of their ability to allow a lot of water to flow rapidly into the soil. Larger pores are formed in a number of ways. Old root channels may remain open for some time after the root decomposes. Larger soil organisms, such as insects and earthworms, create channels as they move through the soil. The mucus that earthworms secrete to keep their skin from drying out also helps to keep their channels open for a long time.

Protection of the Soil against Rapid Changes in Acidity

Acids and bases are released as minerals dissolve and organisms go about their normal functions of decomposing organic materials or fixing nitrogen. Acids or bases are excreted by the roots of plants, and acids form in the soil from the use of nitrogen fertilizers. It is best for plants if the soil acidity status, referred to as pH, does not swing too wildly during the season. The pH scale is a way of expressing the amount of free hydrogen (H^+) in the soil water. More acidic conditions, with greater amounts of hydrogen, are indicated by lower numbers. A soil at pH 4 is very acid. Its solution is ten times more acid than a soil at pH 5. A soil at pH 7 is neutral—there is just as much base in the water as there is acid. Most crops do best when the soil is slightly acid and the pH is around 6 to 7. Essential nutrients are more available to plants in this pH range than when soils are either more acidic or more basic. Soil organic matter is able to slow down, or buffer, changes in pH by taking free hydrogen out of solution as acids are produced or by giving off hydrogen as bases are produced. (For discussion about management of acidic soils, see chapter 20.)

Figure 2.7. Corn grown in nutrient solution with (right) and without (left) humic acids. Photo by R. Bartlett. In this experiment by Rich Bartlett adding humic acids to a nutrient solution increased the growth of tomatoes and corn as well as the amount and branching of roots.

Stimulation of Root Development

Microorganisms in soils produce numerous substances that stimulate plant growth. Humus itself has a directly beneficial effect on plants (figure 2.7). The reason for this stimulation has been found mainly to be due to making micronutrients more available to plants—causing roots to grow longer and have more branches, resulting in larger and healthier plants. In addition, many soil microorganisms produce a variety of root-stimulating substances that behave as plant hormones.

Darkening of the Soil

Organic matter tends to darken soils. You can easily see this in coarse-textured sandy soils containing light-colored minerals. Under well-drained conditions, a darker soil surface allows a soil to warm up a little faster in the spring. This provides a slight advantage for seed germination and the early stages of seedling development, which is often beneficial in cold regions.

Protection against Harmful Chemicals

Some naturally occurring chemicals in soils can harm plants. For example, aluminum is an important part of many soil minerals and, as such, poses no threat to

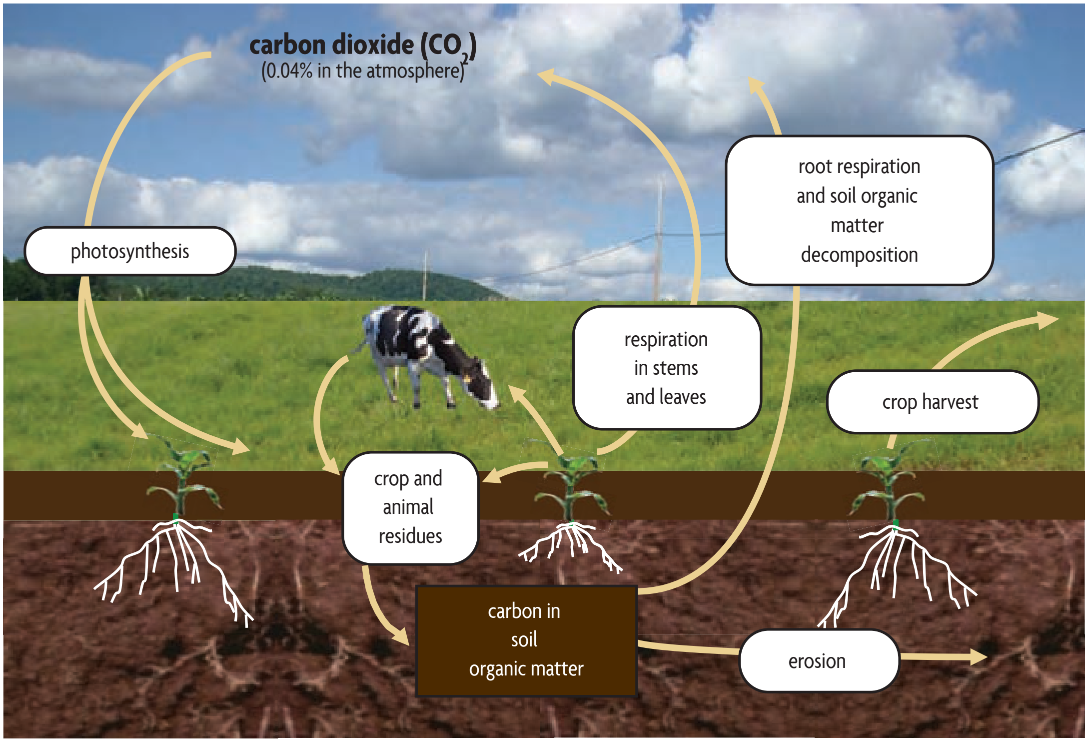

Figure 2.8. The role of soil organic matter in the carbon cycle.

plants. As soils become more acidic, especially at pH levels below 5.5, aluminum becomes soluble. Some soluble forms of aluminum, if present in the soil solution, are toxic to plant roots. However, in the presence of significant quantities of soil organic matter, the aluminum is bound tightly and will not do as much damage.

Organic matter is the single most important soil property that reduces pesticide leaching. It holds tightly on to a number of pesticides. This prevents or reduces leaching of these chemicals into groundwater and allows time for detoxification by microbes. Microorganisms can change the chemical structure of some pesticides, industrial oils, many petroleum products (gas and oils), and other potentially toxic chemicals, rendering them harmless.

ORGANIC MATTER AND NATURAL CYCLES

The Carbon Cycle

Soil organic matter plays a significant part in a number of global cycles. People have become more interested in the carbon cycle because the buildup of carbon dioxide in the atmosphere is thought to cause global warming. Carbon dioxide is also released to the atmosphere when fuels, such as gas, oil, and wood, are burned. A simple version of the natural carbon cycle, showing the role of soil organic matter, is given in figure 2.8. Carbon dioxide is removed from the atmosphere by plants and used to make all the organic molecules necessary for life. Sunlight provides plants with the energy they need to carry out this process. Plants, as well as the animals feeding on plants, release carbon dioxide back into the

COLOR AND ORGANIC MATTER

In Illinois, a hand-held chart has been developed to allow people to estimate percent of soil organic matter. Their darkest soils—almost black—indicate from 3.5 to 7% organic matter. A dark brown soil indicates 2 to 3%, and a yellowish brown soil indicates 1.5 to 2.5% organic matter. (Color may not be as clearly related to organic matter in all regions, because the amount of clay and the types of minerals also influence soil color.)

atmosphere as they use organic molecules for energy.

The largest amount of carbon present on the land is not in the living plants, but in soil organic matter. That is rarely mentioned in discussions of the carbon cycle. More carbon is stored in soils than in all plants, all animals, and the atmosphere combined. Soil organic matter contains an estimated four times as much carbon as living plants. In fact, carbon stored in all the world's soils is over three times the amount in the atmosphere. As soil organic matter is depleted, it becomes a source of carbon dioxide for the atmosphere. Also, when forests are cleared and burned, a large amount of carbon dioxide is released. A secondary, often larger, flush of carbon dioxide is emitted from soil from the rapid depletion of soil organic matter following conversion of forests to agricultural practices. There is as much carbon in six inches of soil with 1% organic matter as there is in the atmosphere above a field. If organic matter decreases from 3% to 2%, the amount of carbon dioxide in the atmosphere could double. (Of course, wind and diffusion move the carbon dioxide to other parts of the globe.)

The Nitrogen Cycle

Another important global process in which organic matter plays a major role is the nitrogen cycle. It is of direct importance in agriculture, because there is frequently not enough available nitrogen in soils for plants to grow their best. Figure 2.9 shows the nitrogen cycle and how soil organic matter enters into the cycle. Some bacteria living in soils are able to "fix" nitrogen, converting nitrogen gas to forms that other organisms, including crop plants, can use. Inorganic forms of nitrogen, like ammonium and nitrate, exist in the atmosphere naturally, although air pollution causes higher amounts than normal. Rainfall and snow deposit inorganic nitrogen forms on the soil. Inorganic nitrogen also may be added in the form of commercial nitrogen fertilizers. These fertilizers are derived from nitrogen gas in the atmosphere through an industrial fixation process.

Almost all of the nitrogen in soils exists as part of the organic matter, in forms that plants are not able to use as their main nitrogen source. Bacteria and fungi convert the organic forms of nitrogen into ammonium, and different bacteria convert ammonium into nitrate. Both nitrate and ammonium can be used by plants.

Nitrogen can be lost from a soil in a number of ways. When crops are removed from fields, nitrogen and other nutrients also are removed. The nitrate (NO_3^-) form of nitrogen leaches readily from soils and may end up in groundwater at higher concentrations than may be safe for drinking. Organic forms of nitrate as well as nitrate and ammonium (NH_4^+) may be lost by runoff water and erosion. Once freed from soil organic matter, nitrogen may be converted to forms that end up back in the atmosphere. Bacteria convert nitrate to nitrogen (N_2) and nitrous oxide (N_2O) gases in a process called denitrification, which occurs in saturated soils. Nitrous oxide (also a "greenhouse gas") contributes strongly to global warming. In addition, when it reaches the upper atmosphere, it decreases ozone levels that protect the earth's surface from the harmful effects of ultraviolet (UV) radiation. So if you needed another reason not to

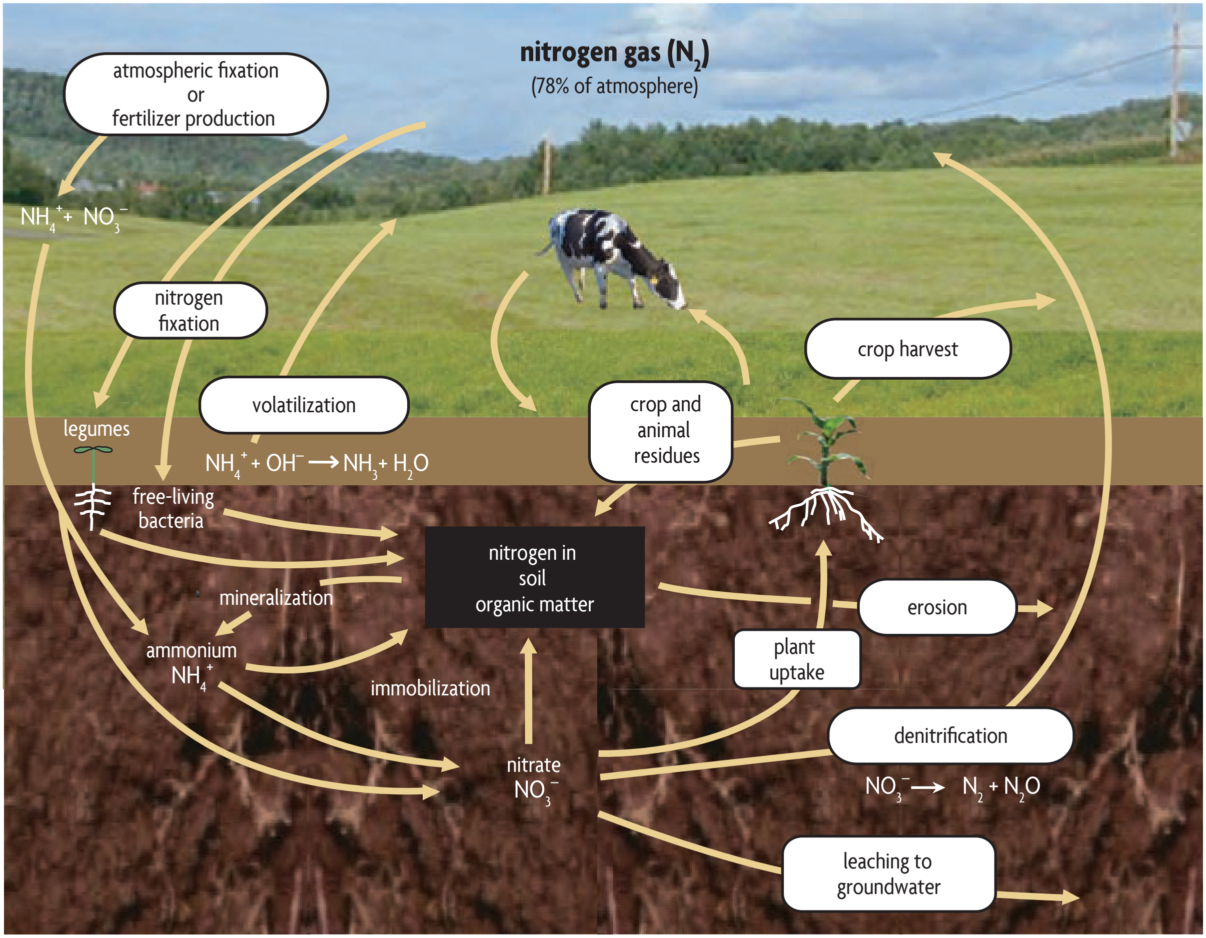

Figure 2.9. The role of organic matter in the nitrogen cycle.

apply excessive rates of nitrogen fertilizers or manures—in addition to the economic costs and the pollution of ground and surface waters—the possible formation of nitrous oxide should make you cautious.

The Water Cycle

Organic matter plays an important part in the local, regional, and global water cycles due to its role in promoting water infiltration into soils and storage within the soil. The water cycle is also referred to as the *hydrologic* cycle. Water evaporates from the soil surface and from living plant leaves as well as from the ocean and lakes. Water then returns to the earth, usually far from where it evaporated, as rain and snow. Soils high in organic matter, with excellent tilth, enhance the rapid infiltration of rainwater into the soil. This water may be available for plants to use or it may percolate deep into the subsoil and help to recharge the groundwater supply. Since groundwater is commonly used as a drinking water source for homes and for irrigation, recharging groundwater is important. When the soil's organic matter level is depleted, it is less able to accept water, and high levels of runoff and erosion result. This means less water for plants and decreased groundwater recharge.

VALUE OF SOIL ORGANIC MATTER

It is very difficult, if not impossible, to come up with a meaningful monetary value for the worth of organic matter in our soils. It positively affects so many different properties that taking them all into account and figuring out their dollar value is an enormous task. One study published in 2004 estimated the value of nitrogen contributions and the added water availability from increased organic matter. In 2008 dollars, their estimates for just those two aspects would amount to about $20 per acre per year for every extra percent of organic matter.

SUMMARY

Soil organic matter is the key to building and maintaining healthy soils because it has such great positive influences on essentially all soil properties—helping to grow healthier plants. It also plays a critical role in the water, nitrogen, and carbon cycles. Organic matter consists mainly of the living organisms in the soil ("the living"), the fresh residue ("the dead"), and the very well decomposed (or burned) material ("the very dead"). Each of these types of organic matter plays an important role in maintaining healthy soils.

SOURCES

Allison, F.E. 1973. *Soil Organic Matter and Its Role in Crop Production*. Amsterdam: Scientific Publishing Co.

Brady, N.C., and R.R. Weil. 2008. *The Nature and Properties of Soils*, 14th ed. Upper Saddle River, NJ: Prentice Hall.

Follett, R.F., J.W.B. Stewart, and C.V. Cole, eds. 1987. *Soil Fertility and Organic Matter as Critical Components of Production Systems*. Special Publication No. 19. Madison, WI: Soil Science Society of America.

Lehmann, J., D.C. Kern, B. Glaser, and W.I. Woods, eds. 2003. *Amazonian Dark Earths: Origin, Properties, Management*. Dordrecht, Netherlands: Kluwer Academic Publishing.

Lehmann, J., and M. Rondon. 2006. Bio-char soil management on highly weathered soils in the humid tropics. In *Biological Approaches to Sustainable Soil Systems,* ed. N. Uphoff et al., pp. 517–530. Boca Raton, FL: CRC Press.

Lucas, R.E., J.B. Holtman, and J.L. Connor. 1977. Soil carbon dynamics and cropping practices. In *Agriculture and Energy,* ed. W. Lockeretz, pp. 333–451. New York: Academic Press. See this source for the Michigan study on the relationship between soil organic matter levels and crop-yield potential.

Manlay, R.J., C. Feller, and M.J. Swift. 2007. Historical evolution of soil organic matter concepts and their relationships with the fertility and sustainability of cropping systems. *Agriculture, Ecosystems and Environment* 119: 217–233.

Oshins, C., and L. Drinkwater. 1999. *An Introduction to Soil Health*. A slide set available at the Northeast Region SARE website: www.uvm.edu/~nesare/slide.html.

Powers, R.F., and K. Van Cleve. 1991. Long-term ecological research in temperate and boreal forest ecosystems. *Agronomy Journal* 83: 11–24. This reference compares the relative amounts of carbon in soils with that in plants.

Stevenson, F.J. 1986. *Cycles of Soil: Carbon, Nitrogen, Phosphorus, Sulfur, Micronutrients*. New York: John Wiley & Sons. This reference compares the amount of carbon in soils with that in plants.

Strickling, E. 1975. Crop sequences and tillage in efficient crop production. *Abstracts of the 1975 Northeast Branch American Society Agronomy Meetings,* pp. 20–29. See this source for the Maryland experiment relating soil organic matter to corn yield.

Tate, R.L., III. 1987. *Soil Organic Matter: Biological and Ecological Effects*. New York: John Wiley & Sons.

Weil, R., and F. Magdoff. 2004. Significance of soil organic matter to soil quality and health. In *Soil Organic Matter in Sustainable Agriculture,* ed. F. Magdoff and R. Weil, pp. 1–43. Boca Raton, FL: CRC Press.