

Part I

Soil Health Concepts



What is soil?

Representative and State Soils in the Northeast:

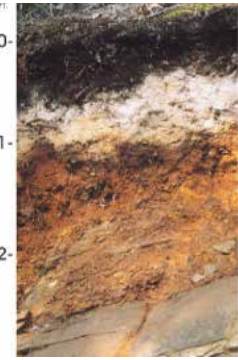
Soil types across the nation and the world are varied. They form with the diverse influences of local climate, organisms, topography, bedrock or underlying sediment type (parent material), and the effects of time. Areas of similar soils are grouped and labeled as a soil series. The series name is usually derived from a town or landmark in the area where the soil was first recognized. Soil series are not bound by political boundaries, therefore a given soil series does not necessarily occur within the confines of only one state. The soil map delineating the soil series informs the land manager of the soil's inherent quality, that cannot be changed through soil management.

According to the Natural Resources Conservation Service (NRCS), a state soil represents a soil series that has special significance to a particular state. Each state has selected a state soil (Figure 1.01). Of those, 20 have been legislatively established as "Official State Soils" and share the same level of distinction as official state flowers and birds.

Soil is at the foundation of everything that we and the other life on earth need to live, including food, fiber, habitat, shelter, recreational space, clean air and water, and more. But first, what is it?



Honeoye (NY)



Tunbridge (VT)



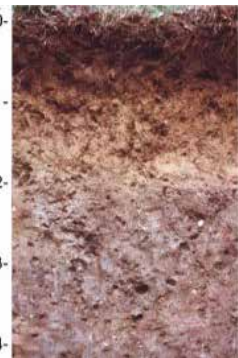
Marlow (NH)



Chesuncook (ME)



Hazleton (PA)



Paxton (MA)



Downer (NJ)



Windsor (CT)



Narragansett (RI)

FIGURE 1.01 Information and soil profile images of the Northeast.
Source: USDA-NRCS.

Soil is a dynamic interface between the lithosphere (rock), atmosphere (air), hydrosphere (water), and biosphere (living things). It is the zone in which rocks and organisms, and the air and water that move in and through and around them, interact. Soil is not just the physical parts that make it up, but also the active interactions between its various physical, biological, and chemical parts. A soil's characteristics determine how that soil functions as a foundation of the ecosystem it is part of, whether natural or managed by humans. When we discuss soil health, we are primarily concerned with the interactive processes involved with this functioning and how human management influences these processes.

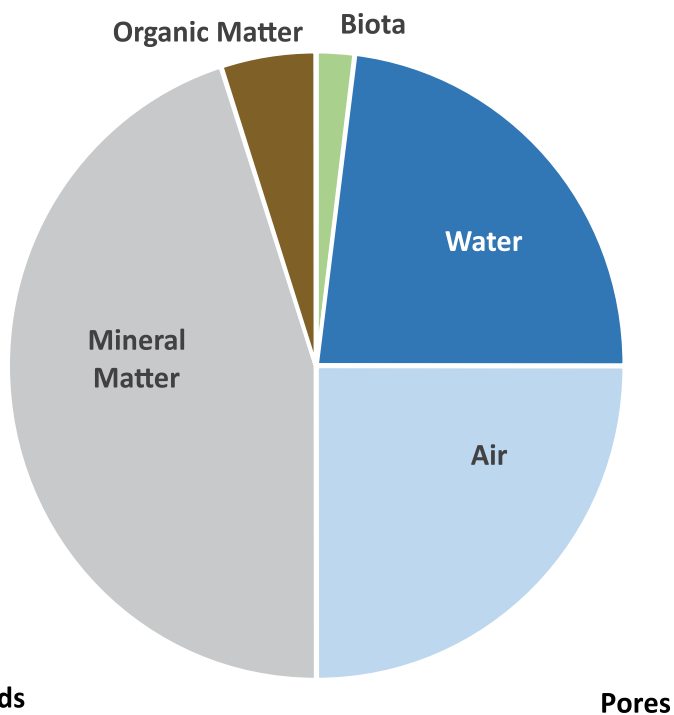


FIGURE 1.02 Distribution of solids and pores in soil. Solids are minerals, organic matter and living organisms, or biota. Pores are filled with water, air, and biota.

Physically, soil is made up of a mixture of materials, including various solids, air, and water in varying proportions (Figure 1.02). The solid components of soil include mineral and organic fractions (both living and non-living). This composition of soil strongly influences how it functions.

Mineral Solids: The large majority of the solids (in most soils) are the mineral parts, consisting of stone fragments, sand, silt, and clay. These particles are defined by their sizes, although they differ in the way they influence soil functioning beyond simply their size-related effects (Figure 1.03). The relative proportions of sand, silt and clay determine a soil's texture and textural class (Figure 1.04, following page).

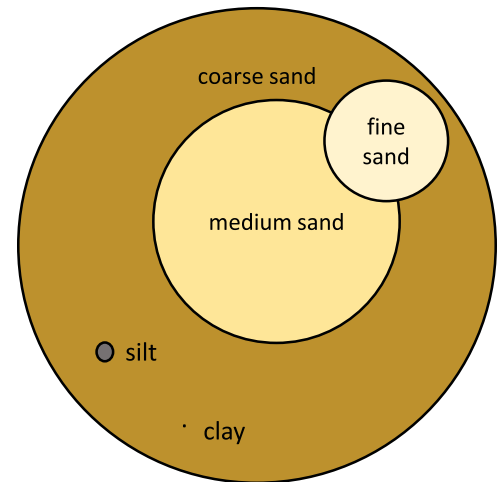


FIGURE 1.03. Relative size of soil particles.

Texture is one of the fundamental characteristics important for quantifying how a soil is functioning. For example, the amount and type of clay, in particular, can greatly influence the ability of soils to hold and exchange nutrients, and to store organic matter. Clays have a lot of surface area because they are very small, layered, platy particles. The surfaces of most clays are negatively charged, so that positively charged nutrient ions can electrostatically 'stick' to them. This ability of soil particles to hold onto positively charged nutrient ions and exchange them with the soil water, or soil solution, is referred to as the soil's cation exchange capacity (CEC), and the surfaces to which the ions can 'stick' are the exchange complex.

Organic Matter: Soil organic matter (SOM or OM) is largely made up of carbon, and is any material that originated from living organisms. OM is of profound importance for soil function. It contributes to the soil's ability to hold onto nutrient ions, similarly to clay, but for an even greater range of ionic nutrients. It can also contain nutrients in its molecular structure. As soil biota (living things – see the following page on Life in the Soil) decompose the OM, nutrients can be released and become available to plants. Some of the very small particles of well decomposed organic materials become bound to fine soil mineral particles and can become protected from further biological activity inside very small soil aggregates. There it will remain more stable as part of the soil's structure. This process is known as carbon sequestration, an important process for mitigating climate change (also see page 98).

Stabilized soil organic matter contributes to soil function in numerous ways, including those related to soil structure such as its capacity to store water and thus provide drought resilience.

Pores: The spaces between the solid soil particles, as mentioned previously, are called pores. These are filled with air, water, and biota. Water and air are essential for all life in the soil. Water is the medium that facilitates nutrient transport through the soil and enables plant nutrient uptake. It also allows microbes such as nematodes and bacteria to move through the soil. Air is constantly moving into and out of the soil, providing oxygen required for cell functioning in aerobic organisms including plant roots and most of the biota discussed in the following pages.

The balance of air and water depends on weather conditions, and also on the size of the pores. Pore sizes are determined in part by the sizes of the particles between

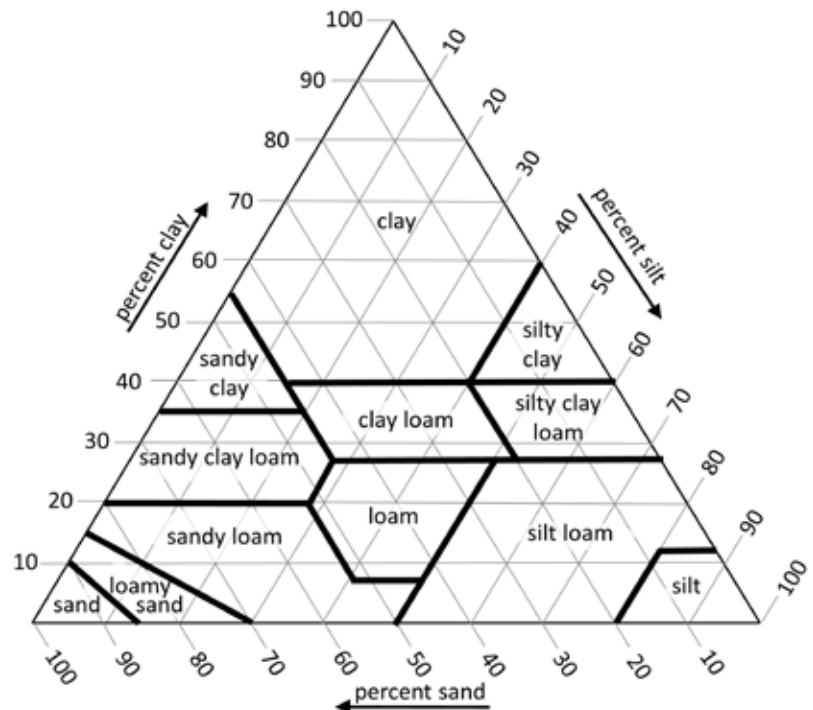


FIGURE I.04. The soil textural triangle. For example, a soil with a texture of 70% silt, 20% sand, and 10% clay can be classified as a silt loam, one of the textural classes. Adapted from USDA-NRCS

which the spaces are formed: for example, clay soils tend to have smaller pores than sandy soils. But just as important as the sizes of the primary particles in this influence, is the aggregation, or ‘clustering’ of these particles into soil crumbs or aggregates, bound together by particle surface chemistry, fungal hyphae, and microbial and plant exudates (see Life in the Soil).

Just as the primary particles are of multiple sizes, soil aggregates can be of varying size, with larger aggregates made up in turn of smaller aggregates. This is referred to as soil structure, or popularly as ‘tilth’. A healthy, well aggregated soil has a range of sizes of both stable crumbs and pores (Figure 1.05).

Pore sizes and their continuity determine how water moves in soil. For example, after a soil becomes wet, gravity will drain larger pores more readily than smaller ones. Due to the same forces responsible for capillary action, smaller pores will store a fraction of the water that infiltrates into the soil. Plants can access water from all but the smallest pores, which hold water too tightly to release it to plants. Thus, a well-structured soil with a range of pore sizes allows plant roots and soil dwelling organisms to have access to a good balance of air from the larger pores that drain readily through gravity, and water from the smaller pores that store water.

Life in the soil

The soil is teeming with life. Some soil scientists say that there are likely more species of organisms in a shovel full of garden soil than exist above ground in the entire Amazon rain forest (NRCS). There are many groups of soil-dwelling organisms, which range in size from those that are easy to see, such as earthworms and arthropods, to those that are microscopic, such as bacteria. Understanding these organisms and their needs, and how they influence soil functioning, can help us improve soil health. The initial source of food that drives the soil food web is organic material (e.g. leaves, roots, sticky substances called ‘exudates’, Figure 1.06). Just like us, biota need energy. Plants gather this energy from the sun as they fix CO₂ from the atmosphere into sugars via photosynthesis. Most other organisms need to consume energy rich materials that are directly or indirectly sourced from plants. Without plentiful plant-derived organic inputs, the soil food web cannot thrive. In essence, managers of healthy soils need to feed, and provide good habitat for, their “livestock” living underground.

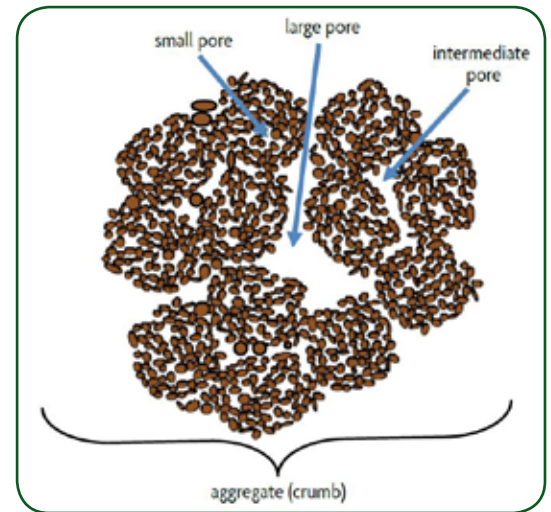


FIGURE 1.05. A healthy soil is well aggregated with a range of pore sizes. Source: *Building Soils for Better Crops*

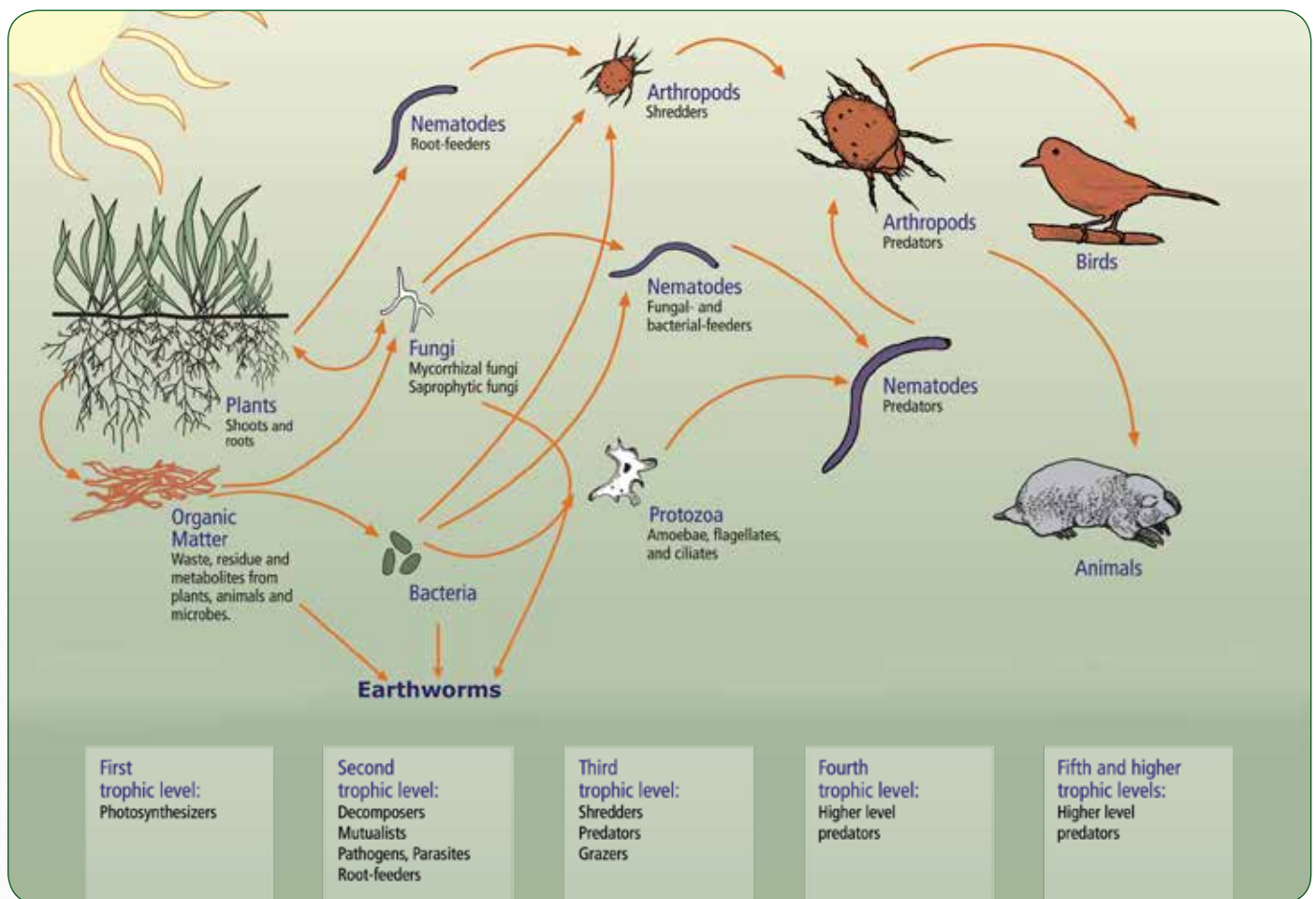


FIGURE 1.06. The soil food web. Relationship between the soil food web, plants, organic matter and animals. Adapted from USDA- NRCS

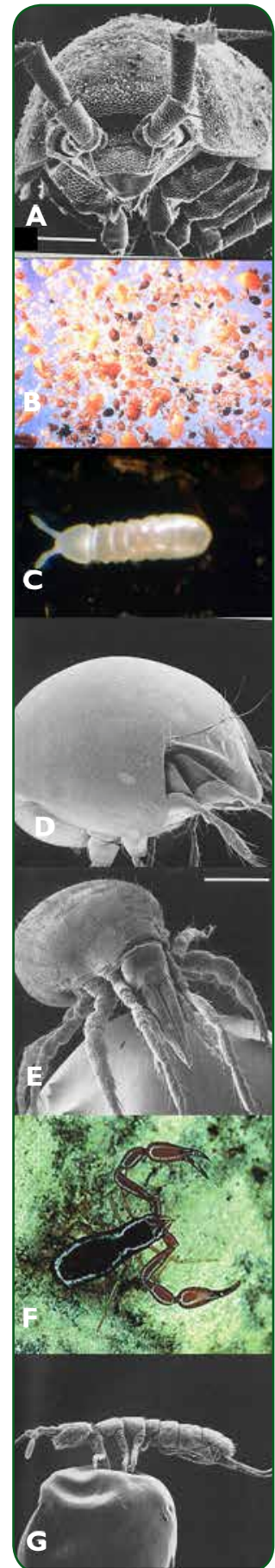


Earthworms aerate soil and provide other benefits as they burrow.

If we ‘follow’ a piece of plant residue into the soil, it will help organize a brief survey of some important soil biota. Picture a leaf falling to the soil surface... earthworms and arthropods are some of first organisms likely to interact with the leaf (Figure 1.07 and 1.08).

Earthworms physically drag organic material into the soil from the surface, exposing it to the activity of other soil biota. There are a number of different types of soil dwelling earthworms (or annelids, that differ from roundworms or nematodes, and will be discussed shortly). While many of these would be considered invasive exotic species in forested systems, their presence and activity are generally considered quite welcome and a sign of a healthy system in agricultural soils. Earthworms burrow through the soil, consuming the solids (including both mineral and organic matter). They digest some of the nutritious material and ‘egest’ the remainder as ‘casts’. These worm castings are coated with microbial cultures from the worm’s gut, which can contribute to both building stable aggregates and suppressing plant disease, depending on the type of worm. They help break down organic matter, mix materials in the soil profile, alleviate compaction, and develop soil pores. Earthworms support the microbial community, and in addition are often considered to be themselves good indicators of the health status of the soil, as they tend to be both easily visible and sensitive to management. Their numbers decline when conditions and management negatively impact a variety of soil processes.

FIGURE I.07. Various Arthropods feed on decaying OM and break larger pieces down into smaller ones: A) Sowbug, B) 200 species of mites, C & G) springtail, D) Oribatid turtle-mite, E) Predatory Pergamasus mite, F) Pseudoscorpion.
Photos credit: Soil and Water Conservation Society



Arthropods, including spiders, mites, and other insects, also interact early with organic matter added to a system. These animals are small from our perspective but immense compared with many of the other soil biota. Among their more important activities with regard to soil functioning, they break larger organic matter pieces down into smaller pieces (shredding), expose the organic matter to microbial cultures (inoculation), and mix the soil materials (bioturbation).

Bacteria and Fungi: Some of the organic material we are following into the soil is directly digested by the annelids and arthropods, although material inoculated with bacteria and fungi is ultimately broken down by them more thoroughly. This is due to both bacteria and fungi producing digestive enzymes that they release into their surroundings. They then absorb the breakdown products and release nutrient ions for plant uptake in the process. This activity is important for carbon and nutrient cycling, and of course for residue management as well. It would be quite inconvenient for management if plant residues and roots continued to accumulate in the soil environment.

Protozoa: As the bacterial colonies grow on and around the degrading organic matter, larger mobile organisms such as ciliates, flagellates, and amoebae (which, informally, may be collectively referred to as protozoans) may consume them. These organisms are single-celled, yet larger than the bacterial cells, and generally live and move about in the thin films of water that can be found on the surfaces of most of the soil solids. These protozoans may also consume algal cells and cyanobacterial cells that grow in habitats with access to sunlight, where they get their energy through photosynthesis, as plants do.

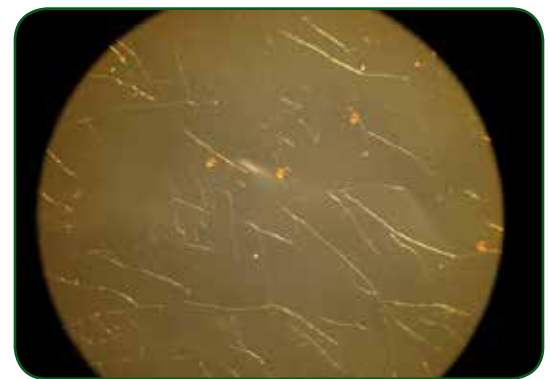


FIGURE I.08. Arbuscular mycorrhizal fungi, growing out of carrot roots (top), and showing network of hyphae and spores (bottom).

Enzymatic breakdown of cellulose:

Cellulose is the main component of plant cell walls, and therefore a large bulk of plant material. It is a large, or high molecular weight compound that has to be broken apart by the enzymes that microbes release, before the smaller breakdown products can be taken up and used as an energy source. Bacteria and fungi produce different and complementary kinds of cellulose degrading enzymes. As the cellulose in the cell wall materials is broken down, other compounds become more exposed and therefore available for uptake by the microbial community. Smaller compounds like amino acids or sugars, or salts can then be taken up directly. Larger compounds, such as proteins, need further breakdown first. Some of these enzymes in fact are the very same enzymes that are being explored for use in cellulosic ethanol production, where cellulose from biomass crops is broken down by enzymes into sugars. Sugars are then fermented by bacterial culture to produce alcohol, which we can use as a liquid fuel.

Nematodes: Larger, yet still microscopic, multicellular animals called nematodes (or roundworms, Figure 1.09) similarly live and move about in the water films, and may consume the bacteria, fungi, and protozoa. There are numerous groups of nematodes, including those that feed on bacteria, fungi, or even other nematodes. Some parasitic nematodes feed on plants or animals – including several agricultural pest. There have been reports of nematodes which contribute to suppression of plant disease by consuming plant pathogens. Some researchers have characterized nematode

diversity as an index to represent soil biological and functional diversity, and therefore soil health.

Nutrient Benefits from Decomposition: As organisms feed on organic matter, or on each other, they respire or ‘burn off’ much of the carbon present in the food (this respiration is representative of general biological activity, and is measured as a soil health indicator). As they do so, they accumulate a small portion of the total carbon, as well as nitrogen and



FIGURE 1.09. Nematode.

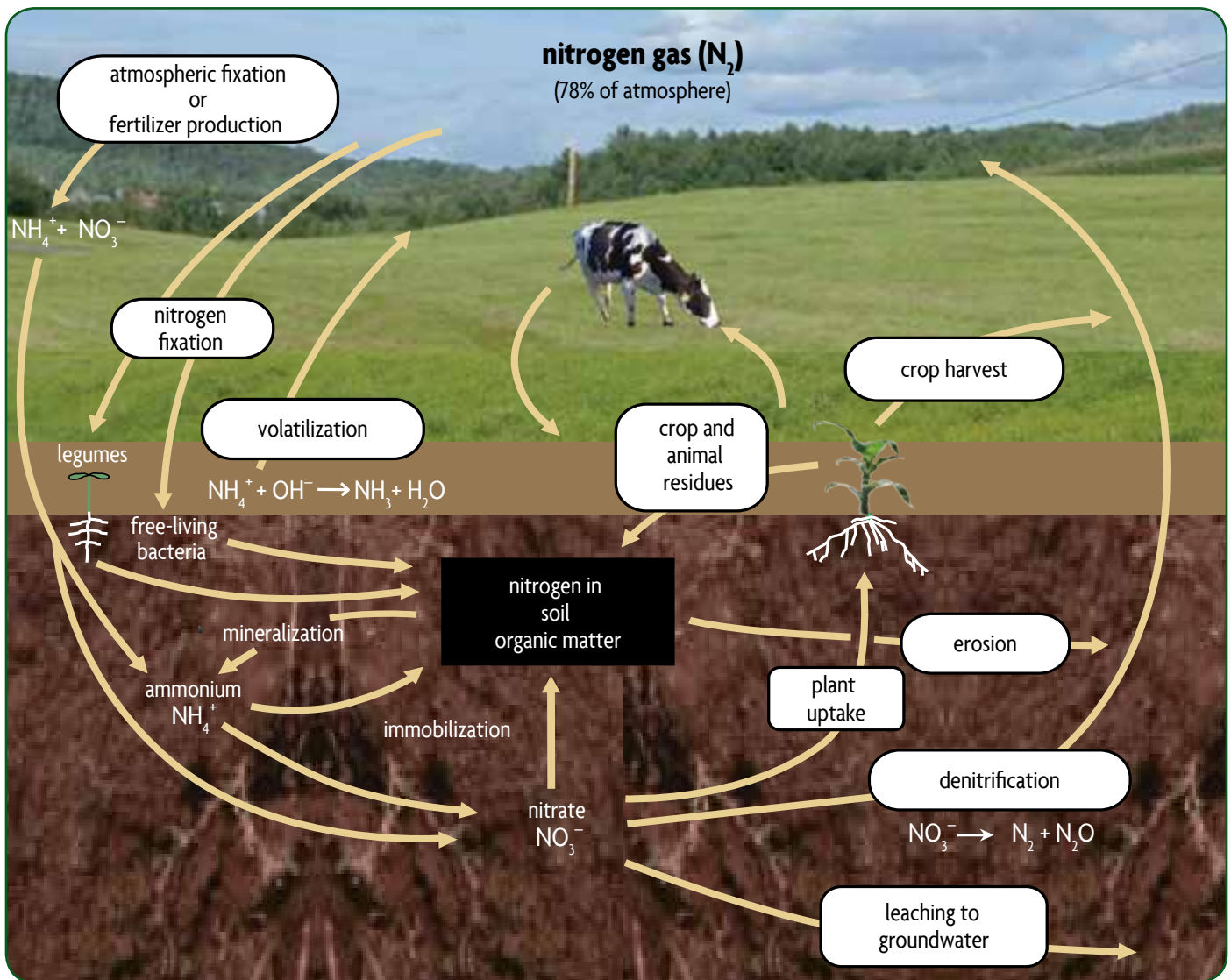


FIGURE 1.10. Nitrogen cycle demonstrating nutrient benefits from decomposition.

other nutrients, in their biomass. Nutrients stored in soil biota are not immediately available to plants (they are ‘immobilized’), but also are protected from environmental loss (such as nitrogen leaching or volatilization), because they are in solid form or within living cells.

An organism’s need for carbon as energy source and for nitrogen or other nutrients usually differs in magnitude and in proportion from what it consumes. To consume enough carbon, biota often consume more nitrogen than necessary, so that they excrete excess N. This is part of the important process called mineralization. In mineralization, nitrogen that has been bound to carbon in relatively large molecules (‘organic nitrogen’) is released in ‘mineral’ form as smaller, more soluble, nitrogen containing ions such as ammonium (NH_4^+) or nitrate (NO_3^-). These can then be taken up by plants. Mineralization is thus a process of great importance in nutrient cycling and availability (Figure 1.10, previous page). The opposite effect, immobilization, may occur as well, when the materials that the soil biota consume contain a very high ratio of carbon to nitrogen. For example, when decomposing plant materials such as straw or wood, bacteria and fungi may take up free nitrogen from their surroundings and make it less available, as little is available to them from the same material that is their carbon-rich energy source.

Much of current fertility management for agriculture relies on supplying nutrients in soluble forms as amendments. However, in some agricultural management systems, an increased emphasis is placed on maintaining soil organic matter, soil microbial diversity and activity. In these systems, as in natural or less managed systems, a significant fraction of plants’ nutrient needs can be stored in and supplied from organic materials.

Soil Structure Benefits: Aggregates are built and stabilized by the soil biota through the growth of fine roots, fungi, and the soil microbial culture, as well as by the periodic wetting and drying of the soil (Figure 1.11). Fine plant roots and the thread-like fungal ‘hyphae’ enmesh primary soil particles, soil organic matter in various states of decomposition, and already formed small aggregates into clumps, or macroaggregates. As these are held together, the roots and hyphae

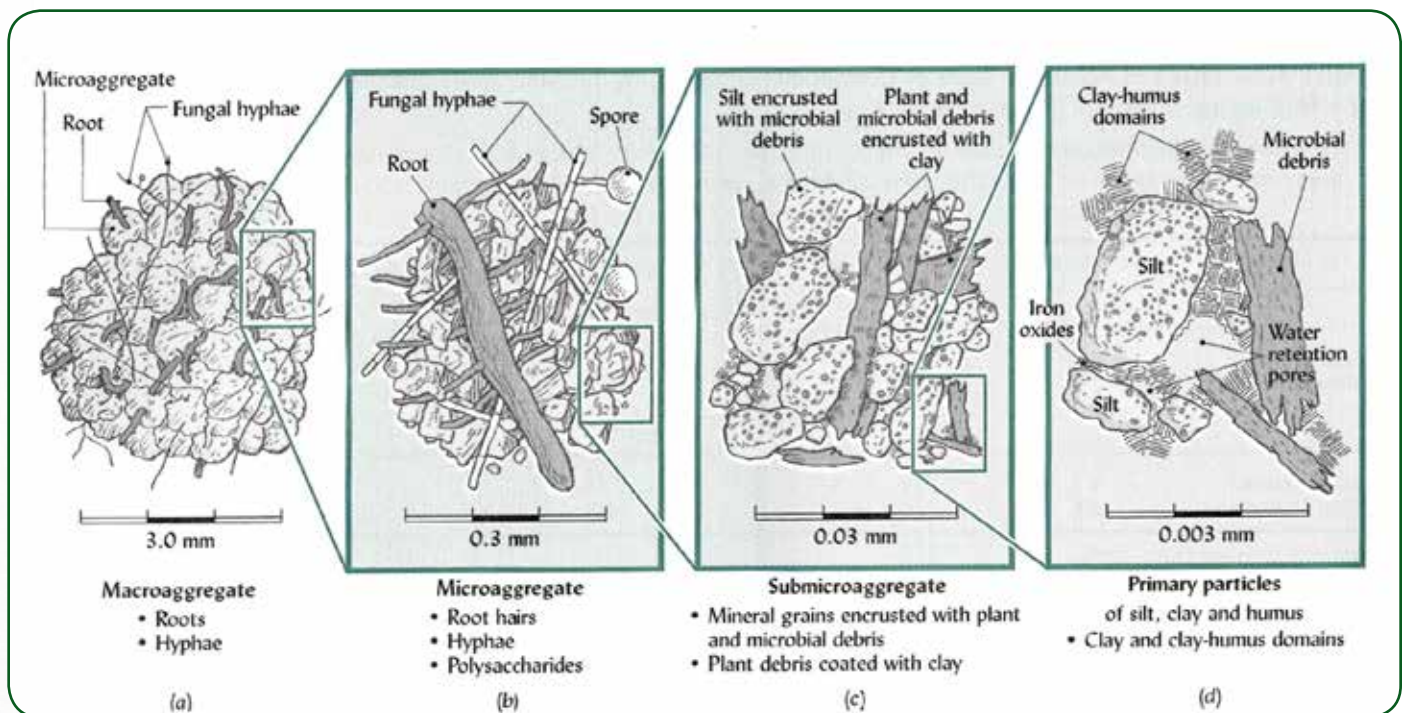


FIGURE 1.11. Aggregate size and composition. An active microbial population will build and stabilize soil through production and interaction with adhesive by products. Each step (a–d) demonstrates the bonding agents and aggregation of soil as size decreases. Adapted from *The Nature and Properties of Soils*, 12th ed., Brady and Weil (1999) Fig. 4.26 from p 150¹.

release exudates that can bind the parts of the aggregates together, and also serve as food for other organisms such as bacteria, colonial unicellular yeasts, and protozoa. Microaggregates form within the macroaggregates as soil microbes release sticky compounds that further bind soil particles together, and form gels that hold water and slowly release it as the soil dries. At the finest scales, microbial cells and debris stick to fine clay particles, and chemical bonds may form between organic matter and mineral particles as they are held close together to make very small microaggregates. For the biota to effectively carry out these processes, it is important for soil disturbance (such as tillage) to be minimized, and of course for there to be a carbon supply for the biota, as well as both air and water availability.

Stable soil aggregates are important for maintaining good (crumbly) soil structure or 'tilth', enabling adequate air exchange and water infiltration, storage, and drainage. Stable soil aggregation minimizes erosion and flooding. These processes are also critical in sequestering, or stabilizing carbon, in the form of well-decomposed organic materials protected within small pores, and tightly bound to soil mineral particles.

Symbiotic Organisms: The organisms discussed so far are free-living in the soil, and decompose and consume plant materials, exudates or secretions that plants release. Two other key groups of soil organisms are not directly involved in decomposition, but are important in soil functioning. These are important symbiotic bacteria and fungi that associate with plant roots. They include nodule-inducing nitrogen fixing bacteria (rhizobia) and mycorrhizal fungi and they live in close association with plant roots, and interact with living plants in a mutually supportive manner.



FIGURE 1.12 Nodules on pea roots.

N fixing bacteria: Gaseous nitrogen (N_2) is a major component of atmospheric air, but plants cannot use it directly. The nodule-inducing nitrogen fixing bacteria (*Rhizobium*, *Bradyrhizobium*, and *Sinorhizobium*, among others) interact with legumes, such as beans, peas, soybeans, clover and vetch. The legume roots develop nodules, which house the bacterial colonies inside (Figure 1.12). Plant tissues provide sugars to the bacteria, while the bacteria convert atmospheric nitrogen into ammonia (NH_3), in a process called nitrogen fixation. Ammonia is quickly converted to ammonium (NH_4^+) in solution and incorporated by the plant into amino acids and other nitrogenous molecules. Sometimes more nitrogen is 'fixed' than is required by the plant,

Soil Microbes Drive Many Soil Processes:

- Decompose organic matter (plant residues)
- Sequester carbon
- Recycle, store (immobilize), and release (mineralize) nutrients for sustained availability to plants
- Increase access to nutrients
- Fix nitrogen
- Stabilize and maintain soil structure
- Biologically suppress plant pests
- Parasitize and damage plants (see "Nematodes" on page 8)
- Promote plant growth
- Detoxify pollutants and clean water



FIGURE 1.13. Mycorrhizal fungi's close association with plant roots form symbiotic relationships.

and so excess is released into the surrounding soil. The fixed nitrogen can also become available for other plants in the system as parts of the legume die and decompose, either through root turnover, or as residues or whole plant biomass is incorporated by biota or human management. Some free-living (not plant associated) and associative (close to roots but not in nodules) nitrogen fixation is known to occur in both natural and managed systems. However, it is the nodule-associated nitrogen fixation that is managed intentionally by inoculating the host plants (legumes) with the appropriate rhizobia, and by maintaining a legume phase in rotations and cover cropping.

Mycorrhizal fungi: Most plant roots associate with symbiotic fungi (Figure 1.13). One major group of these are called arbuscular mycorrhizal fungi. Together with plants, these fungi form joint structures called mycorrhizae (from the Greek words for fungus and root). The plant host provides sugars to the fungus, used for growth and metabolism, in exchange for nutrients. Outside of the root, the fungus grows extensively through the soil, and can reach more spaces and absorb more nutrients (especially phosphorus, which is poorly soluble) than the plant roots alone could. In addition to providing a nutrient benefit to the plant host, these fungi contribute to both plant and soil health in multiple ways. They can help the plant resist disease, and tolerate drought and saline (salty) conditions. The arbuscular mycorrhizal fungi also contribute substantially to the accumulation of soil organic matter and to the formation and stabilization of soil aggregates.

Soil organisms are critical to numerous biological, physical, and chemical soil processes. They interact with the plants we generally manage in agricultural systems, and with the physical soil environment that these plants grow in. They are essential parts of the functioning healthy ecosystems that soils supports, and are key contributors to the health of the soil itself.

What is soil health?

The terms ‘soil health’ and ‘soil quality’ are becoming increasingly familiar worldwide. A modern consensus definition of soil health is **“the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals and humans”** (Natural Resources Conservation Service – USDA-NRCS, 2012²; Soil Renaissance, 2014). Doran and Parkin³, in 1994, defined soil quality as **“the capacity of a soil to function, within ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health.”**

In general, soil health and soil quality are considered synonymous and can be used interchangeably, with one key distinction conceptualized by scientists and practitioners over the last decades: soil quality includes both inherent and dynamic quality. Inherent soil quality refers to the aspects of soil quality relating to a soil’s natural composition and properties (soil type, as delineated by the NRCS Soil Survey) influenced by the natural long-term factors and processes of soil formation. These generally cannot be influenced by human management. Dynamic soil quality, which is equivalent to soil health, refers to soil properties that change as a result of soil use and management over the human time scale. (See example, Figure 1.14, on the following page).

Soil health invokes the idea that soil is an ecosystem full of life that needs to be carefully managed to regain and maintain our soil’s ability to function optimally. The term ‘soil health’ has been generally preferred by farmers, while scientists have generally preferred ‘soil quality’.



Harvesting soybeans. Photo credit: Jenn Thomas-Murphy



FIGURE 1.14. Dynamic soil quality- Beneficial vs. unfavorable management.

Left - Management for improved soil health: tillage radish growing in long-term pasture/hay with occasional annual crops;

Right- Intensive management leading to soil degradation: long-term annual tillage and vegetable production without cover crops or other organic inputs.

Note that both photos depict a Buxton silt loam with the same inherent soil quality. However, due to management differences, soil health has diverged significantly.

Important soil functions related to crop production and environmental quality include:

- Retaining and cycling nutrients
- Supporting plant growth
- Sequestering carbon
- Allow infiltration, and facilitate storage and filtration of water
- Suppressing pests, diseases, and weeds
- Detoxifying harmful chemicals
- Supporting the production of food, feed, fiber, and fuel

When the soil is not functioning to its full capacity, sustainable productivity, environmental quality, and net farmer profits are jeopardized over the long term. Impaired function may result from constraints to specific and interacting soil processes (see pages 15-17). Below are some examples of the economic benefits of maintaining and improving soil health:

- Better plant growth, quality, and yield
- Reduced risk of yield loss during periods of environmental stress (e.g., heavy rain, drought, pest or disease outbreak)
- Better field access during wet periods
- Reduced fuel costs by requiring less tillage
- Reduced input costs by decreasing losses, and improving use efficiency of fertilizer, pesticide, herbicide, and irrigation applications.

Characteristics of a healthy soil

Good soil tilth

Soil tilth refers to the overall physical character of the soil in the context of its suitability for crop production. Soil with good tilth is crumbly, well structured, dark with organic matter, and has no large and hard clods (Figure 1.15).

Sufficient depth

Sufficient depth refers to the extent of the soil profile through which roots are able to grow to find water and nutrients. A soil with a shallow depth as a result of a compaction layer or past erosion is more susceptible to damage in extreme weather fluctuations, thus predisposing the crop to flooding, pathogen, or drought stress.

Good water storage and good drainage

During a heavy rain, a healthy soil has large, stable pores to take in water. These large pores conduct water to the medium and small pores where it will be stored for later use. This range of pore sizes in a healthy soil allows for increased water storage for plants during dry spells. During extended rainy periods, the large pores will still empty by gravity and allow fresh air to enter for plants and soil organism to thrive.

Sufficient supply, but not excess of nutrients

An adequate and accessible supply of nutrients is necessary for optimal plant growth and for maintaining balanced cycling of nutrients within the system. An excess of nutrients can lead to leaching and potential ground water pollution, high nutrient runoff and greenhouse gas losses, as well as toxicity to plants and microbial communities.

Characteristics of a healthy soil (continued)

Small population of plant pathogens and insect pests

In agricultural production systems, plant pathogens and pests can cause diseases and damage to the crop. In a healthy soil, the population of these organisms is low or is less active. This could result from direct competition from other soil organisms for nutrients or habitat, hyperparasitism, etc. In addition, healthy plants are better able to defend themselves against a variety of pests (somewhat analogous to the human immune system).

Large population of beneficial organisms

Soil organisms are important to the functioning of the soil. They help with cycling nutrients, decomposing organic matter, maintaining soil structure, biologically suppressing plant pests, etc. A healthy soil will have a large and diverse population of beneficial organisms to carry out these functions and thus help maintain a healthy soil status.

Low weed pressure

Weed pressure is a major constraint in crop production. Weeds compete with crops for water and nutrients that are essential for plant growth. Weeds can block sunlight, interfere with stand establishment and harvest and cultivation operations, and harbor disease causing pathogens and pests.

Free of chemicals and toxins that may harm the crop

Healthy soils are either devoid of excess amounts of harmful chemicals and toxins, or can detoxify or bind such chemicals. These processes make these harmful compounds unavailable for plant uptake, due to the soil's richness in stable organic matter and diverse microbial communities.

Resistant to degradation

A healthy, well aggregated soil full of a diverse community of living organisms is more resistant to adverse events including erosion by wind and rain, excess rainfall, extreme drought, vehicle compaction, disease outbreak, and other potentially degrading influences.

Resilience when unfavorable conditions occur

A healthy soil will rebound more quickly after a negative event, such as harvesting under wet soil conditions, or if land constraints restrict or modify planned rotations.

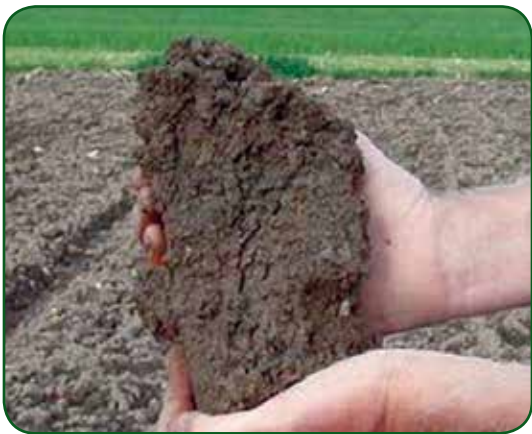


FIGURE I.15. The effect of organic matter (OM) on the same soil type managed using conventional plow tillage (left) or zone tillage for 10 years (right). Soil with good tilth is crumbly, well structured, dark with OM and has no large and hard clods.

Common soil constraints

It is important to recognize soil constraints that limit crop productivity, farm sustainability, and environmental quality. In this way management practices can be adjusted to alleviate these problems. Below is a listing of soil constraints commonly observed in the Northeast region of the U.S., along with some contributing factors and resulting soil conditions.

Soil Compaction

Contributing factors

- Traffic or tillage when soil is wet ('plastic')
- Heavy equipment and loads
- Uncontrolled traffic patterns

Can result in

- Reduced root growth in surface and subsurface soils
- Limited water infiltration, resulting in runoff, erosion, ponding and poor aeration
- Drought sensitivity due to reduced water storage and reduced rooting
- Reduced nutrient access due to poor root growth and restricted water flow
- Increased pathogen pressure due to poor drainage and to plant stress
- Increased cost of tillage and lower yields



Tillage when the soil is too wet (plastic) resulting in clodding and compaction.



Ruts resulting from late fall harvest when soils are wet.

Poor Aggregation

Contributing factors

- Intensive tillage
- Limited use of soil building crops and soil cover
- Low active rooting density
- Limited duration of root presence during the year
- Limited organic additions
- Low biological activity to stabilize aggregates

Can result in

- Crusting and cracking
- Poor seedling emergence and stand establishment
- Poor water infiltration and storage
- Increased occurrence of erosion and runoff
- Reduced root growth
- Less active microbial communities
- Reduced aeration
- Reduced drought resistance due to decreased water intake during rainfall events



Surface crusting in mid-spring.

Weed Pressure

Contributing factors

- Poor crop rotations and omission of cover crops
- Resistance to herbicides
- Poor weed management, poor timing of management practices

Can result in

- Poor stand establishment and crop growth
- Poor crop quality and reduced yield
- Increased disease and pest damage
- Interference with cultural practices and harvest
- Increased cost of weed control



Weedy beet field.

High Pathogen Pressure

Contributing factors

- Poorly planned crop rotations and low rotational diversity
- Ineffective residue management
- Poor sanitary practices (equipment, tools, vehicles not cleaned between operations)
- Low microbial diversity, resulting in reduced suppressiveness
- Poor physical soil functioning, particularly waterlogging, or other plant stress inducing conditions

Can result in

- Damaged and diseased roots
- Uneven and poor growth
- Reduced yields, crop quality, and profits



Symptoms of root rot diseases on pea roots.

Low Water and Nutrient Retention

Contributing factors

- Low organic matter and resulting poor structure, water holding capacity, and exchange capacity
- Poor retention and biological recycling of nutrients in biomass and soil organic matter
- Excessive tillage
- Insufficient use of soil building crops

Can result in

- Ground and surface water pollution
- Nutrient deficiencies and poor plant growth
- Reduced microbial community
- Drought stress



Application of liquid manure to increase water and nutrient retention.

Salinity and Sodicty

Contributing factors

- Frequently found in semi-arid and arid climates, especially under irrigated systems
- Common in the Northeast only in high tunnels and greenhouses, which could be considered to be artificial “irrigated deserts”

Can result in

- Loss of crop yield and quality
- Loss of aggregation and thus infiltration and drainage functions if sodicity is the problem



Saline/sodic soil.

Heavy Metal Contamination⁴

Contributing factors

- Common in urban areas and other sites with past use of contaminant sources such as lead paint, fertilizers, pesticides (e.g., lead arsenate use on orchard land)
- Past activities such as high traffic, industrial or commercial activity, treated lumber, petroleum spills, automobile or machine repair, junk vehicles, furniture refinishing, fires, landfills, or garbage dumps
- Naturally occurring high heavy metal concentrations are generally rare in the Northeast

Can result in

- Higher risks of human exposure when children or adults swallow or breathe in soil particles or eat food raised in or on contaminated soil
- Inhibition of soil biological activity
- Plant toxicity, and reduced yield and/or crop quality



Growth inhibition in soil contaminated with copper and zinc.

Cited References

- ¹ Brady, N.C., and R.R. Weil. 1999. *The Nature and Properties of Soil*. 12th ed. Upper Saddle River, New Jersey: Prentice Hall. Print.
- ² Natrual Resources Conservation Services: Soil Health. 2012. Retrieved June 23, 2016 from <http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/>. The Soil Renaissance accepted this definition in 2014
- ³ Doran, J.W., and T.B. Parkin. 1994. Defining and assessing soil quality. p. 3-21. In: J.W. Doran et al., (ed.) *Defining Soil Quality for a Sustainable Environment*. SSSA Spec. Publ. No. 35, Soil Sci. Soc. Am., Inc. and Am. Soc. Agron., Inc., Madison, WI.
- ⁴ Content adapted from resources developed by the Cornell Waste Management Institute. *Soil Quality and Testing and the Healthy Soils, Healthy Communities Project*. 2007. (<http://cwmi.css.cornell.edu/soilquality.htm> and <http://cwmi.css.cornell.edu/healthysoils.htm>).

