SOIL HEALTH DEFINITIONS

The definition of soil health has evolved over time. The most significant change is the recognition that soil is a living system.

- "*The continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal, and human health*" (Pankhurst et al., 1997).

  Two elements in this definition of soil health distinguish it from the definition of soil quality: (i) the inclusion of a time component (e.g. "the continued capacity of" - reflecting the importance of the soil in being able to continue to function over time); and (ii) recognition of soil "as a vital living system" (emphasizing the importance of the soil biota to soil functioning)).

- *Soil health is defined as the continued capacity of soil to function as a vital living system, by recognizing that it contains biological elements that are key to ecosystem function within land-use boundaries* (Doran and Zeiss, 2000; Karlen et al., 2001).

- "*Soil health is the capacity of soil to function as a living system, with ecosystem and land use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health. Healthy soils maintain a diverse community of soil organisms that help to control plant disease, insect and weed pests, form beneficial symbiotic associations with plant roots; recycle essential plant nutrients; improve soil structure with positive repercussions for soil water and nutrient holding capacity, and ultimately improve crop production*" (FAO, 2008).

- NRCS simply defines soil health as, "*the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans".*

SOIL HEALTH MANAGEMENT

Gabe Brown Video – Building Soil Health
https://youtu.be/9yPjoh9YJMk

Least Amount of Mechanical Disturbance as Possible
Soil disturbance can be the result of physical, chemical or biological activities. Physical soil disturbance, such as tillage, results in bare and/or compacted soil that is destructive and disruptive to soil microbes, and it creates a hostile environment for them to live. Misapplication of farm inputs can disrupt the symbiotic relationships between fungi, other microorganisms, and plant roots. Overgrazing, a form of biological disturbance, reduces root mass, increases runoff, and increases soil temperature. All forms of soil disturbance diminish habitat for soil microbes and result in a diminished soil food web.

Diversify Soil Biota with Plant Diversity
Plants use sunlight to convert carbon dioxide and water into carbohydrates that serve as the building blocks for roots, stems, leaves, and seeds. They also interact with specific soil microbes by releasing carbohydrates (sugars) through their roots into the soil to feed the microbes in exchange for nutrients and water. A diversity of plant carbohydrates is required to support the diversity of soil microorganisms in the soil. In order to achieve a high level of diversity, different plants must be grown. The key to improving soil health is ensuring that food and energy chains and webs consist of several types of plants or animals, not just one or two.

Biodiversity is ultimately the key to the success of any agricultural system. Lack of biodiversity severely limits the potential of any cropping system and increases disease and pest problems. A diverse and fully functioning soil food web provides for nutrient, energy, and water cycling that allows a soil to express its full potential. Increasing the diversity of a crop rotation and cover crops increases soil health and soil function, reduces input costs, and increases profitability.

Keep a Living Root Growing Throughout the Year
Living plants maintain a rhizosphere, an area of concentrated microbial activity close to the root. The rhizosphere is the most active part of the soil ecosystem because it is where the most readily available food is, and where peak nutrient and water cycling occurs. Microbial food is exuded by plant roots to attract and feed microbes that provide nutrients (and other compounds) to the plant at the root-soil interface where the plants can take them up. Since living roots provide the easiest source of food for soil microbes, growing long-season crops or a cover crop following a short-season crop, feeds the foundation species of the soil food web as much as possible during the growing season.

Healthy soil is dependent upon how well the soil food web is fed. Providing plenty of easily accessible food to soil microbes helps them cycle nutrients that plants need to grow. Sugars from living plant roots, recently dead plant roots, crop residues, and soil organic matter all feed the many and varied members of the soil food web.

Keep the Soil Covered as Much as Possible

Soil cover conserves moisture, reduces temperature, intercepts raindrops (to reduce their destructive impact), suppresses weed growth, and provides habitat for members of the soil food web that spend at least some of their time above ground. This is true regardless of land use.

Role of Soil Organic Matter

Once a land manager begins working towards enhancing soil organic matter, a series of soil changes and environmental benefits follow. The rate and degree of these changes and the best suite of practices needed to achieve results vary with soil and climate. Initially, managing for greater soil organic matter may require higher pesticide, herbicide, or nutrient applications. In time, productivity and environmental quality will be enhanced.

1. Apply practices that enhance soil organic matter

- Diverse, high biomass crop rotations
- Cover crops
- Reduced tillage
- Rotational or prescribed grazing

2. Organic matter dynamics change

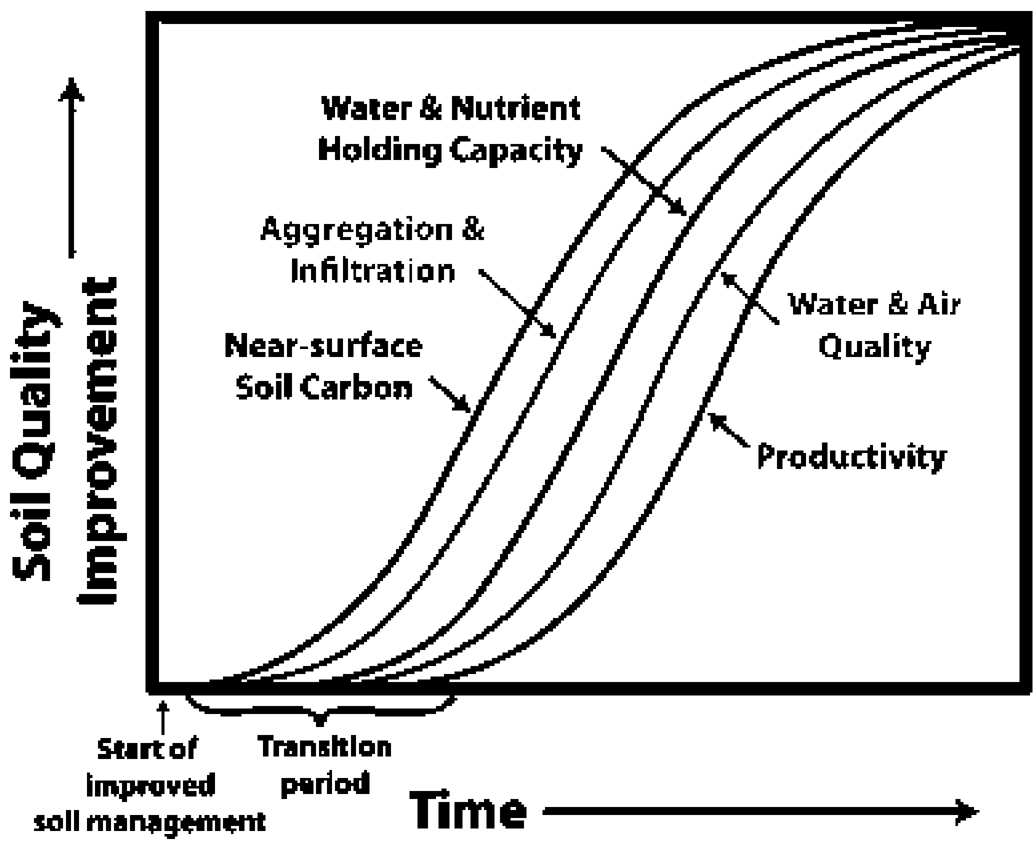
- Increased surface residue forms a physical barrier to wind and water erosion.
- Higher residue rotations and cover crops contribute more organic matter and nutrients to the soil.
- Less soil disturbance means lower organic matter losses.

3. Soil properties change

- Surface structure becomes more stable and less prone to crusting and erosion.
- Water infiltration increases and runoff decreases when soil structure improves.
- Soil organic matter holds 10 to 1,000 times more water and nutrients than the same amount of soil minerals.
- Beneficial soil organisms become more numerous and active with diverse crop rotations and higher organic matter levels.

4. Air quality, water quality, and agricultural productivity improve

- Dust, allergens, and pathogens in the air immediately decline.
- Sediment and nutrient loads decline in surface water as soon as soil aggregation increases and runoff decreases.
- Ground and surface water quality improve because better structure, infiltration, and biological activity make soil a more effective filter.
- Crops are better able to withstand drought when infiltration and water holding capacity increase.
- Organic matter may bind pesticides, making them less active. Soils managed for organic matter may suppress disease organisms, which could reduce pesticide needs.
- Crop health and vigor increase when soil biological activity and diversity increase.
- Wildlife habitat improves when residue management improves.



Manage for Soil Carbon

Managing soil organic matter is the key to healthy soil and air and water quality.

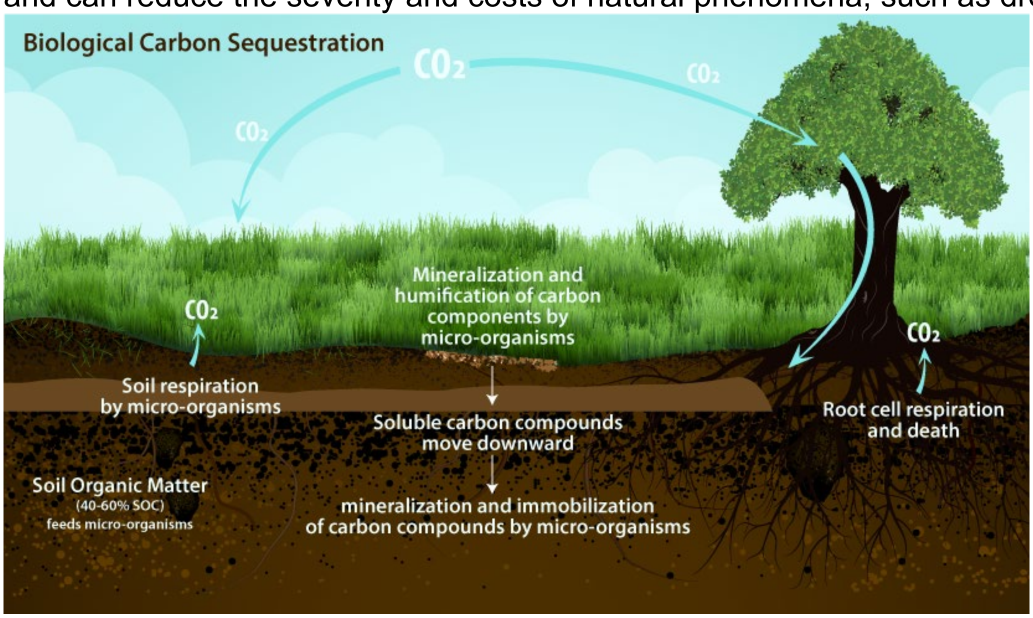
Erosion Control is Not Enough

Soil conservation policy in the United States stems from the devastating erosion events of the 1920s and ’30s. Out of concern for preserving agricultural productivity came the concept of tolerable soil loss and the creation of the "T" factor, which is the maximum annual soil loss that can occur on a particular soil while sustaining long-term agricultural productivity. Conservationists focused on reducing soil loss to T by applying practices, such as terraces, contour strips, grassed waterways, and residue management.

By the end of the twentieth century, concerns about air and water quality became as important as concerns about agricultural productivity. To address these environmental goals and maintain the land’s productive potential, we must now go beyond erosion control and manage for soil health. How soil functions on every inch of a farm, not just in buffers or waterways, affects erosion rates, agricultural productivity, air quality, and water quality. The most practical way to enhance soil health today is to promote better management of soil organic matter or carbon (C). In short, we should go beyond T and manage for C.

Why Focus on Soil Organic Matter?

Many soil properties impact soil health, but organic matter deserves special attention. It affects several critical soil functions, can be manipulated by land management practices, and is important in most agricultural settings across the country. Because organic matter enhances water and nutrient holding capacity and improves soil structure, managing for soil carbon can enhance productivity and environmental quality, and can reduce the severity and costs of natural phenomena, such as drought, flood, and disease. In addition, increasing soil organic matter levels can reduce atmospheric CO2 levels that contribute to climate change.



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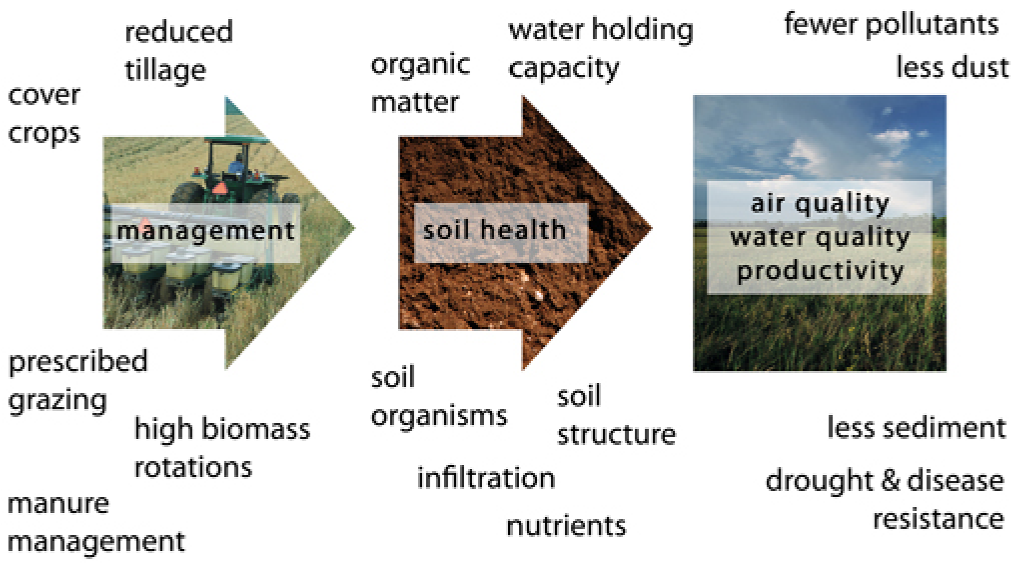
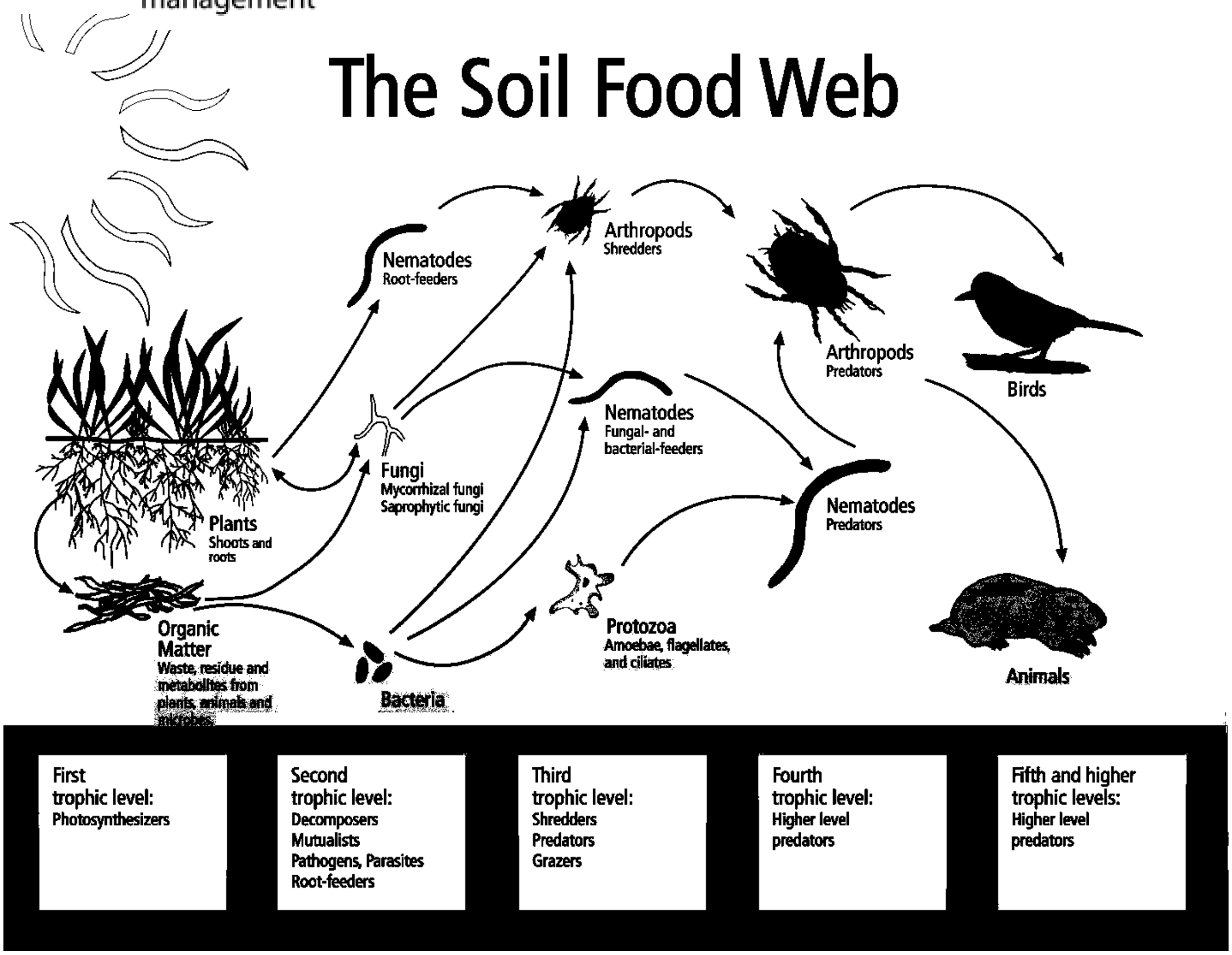


The Soil Food Web



A Soil Food Web Glossary

Arthropods Invertebrate animals with jointed legs. They include insects, crustaceans, sowbugs, arachnids (spiders), and others.

Bacteria Microscopic, single-celled organisms that are mostly non-photosynthetic. They include the photosynthetic cyanobacteria (formerly called blue-green algae) and actinomycetes (filamentous bacteria that give healthy soil its characteristic smell).

Fungi Multi-celled, non-photosynthetic organisms that are neither plants nor animals. Fungal cells form long chains called hyphae and may form fruiting bodies such as mold or mushrooms to disperse spores. Some fungi, such as yeast, are single-celled.

Saprophytic fungi: Fungi that decompose dead organic matter.

Mycorrhizal fungi: Fungi that form associations with plant roots. These fungi get energy from the plant and help supply nutrients to the plant.

Grazers Organisms, such as protozoa, nematodes, and microarthropods, that feed on bacteria and fungi.

Microbes An imprecise term referring to any microscopic organism. Generally, "microbes" includes bacteria, fungi, and sometimes protozoa.

Mutualists Two organisms living in an association that is beneficial to both, such as the association of roots with mycorrhizal fungi or with nitrogen-fixing bacteria.

Nematodes Tiny, usually microscopic, unsegmented worms. Most live free in the soil. Some are parasites of animals or plants.

Protozoa Tiny, single-celled animals, including amoebas, ciliates, and flagellates.

Trophic levels Levels of the food chain. The first trophic level includes photosynthesizers that get energy from the sun. Organisms that eat photosynthesizers make up the second trophic level. Third trophic level organisms eat those in the second level, and so on. It is a simplified way of thinking about the food web. In reality, some organisms eat members of several trophic levels.

Functions of Soil Organisms

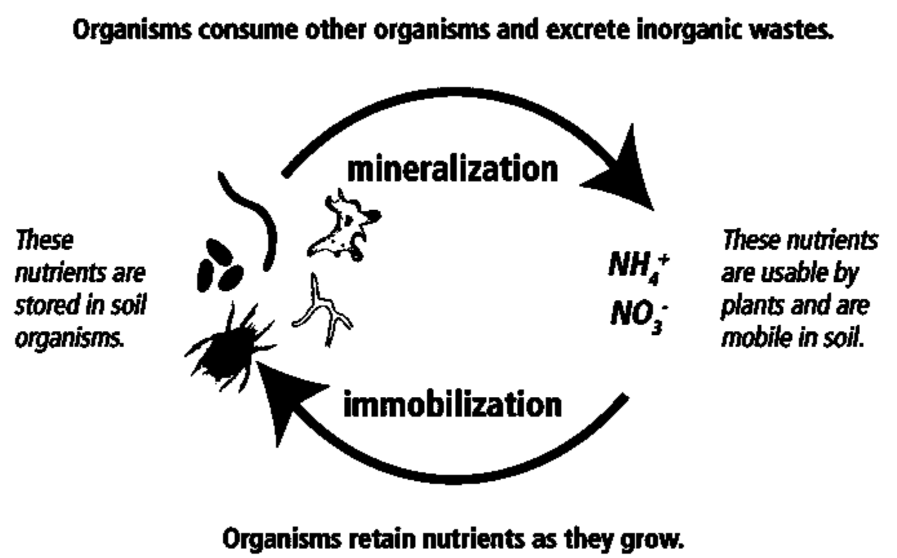
Type of Soil Organism		Major Functions
Photosynthesizers	• Plants • Algae • Bacteria	**Capture energy** • Use solar energy to fix CO_2. • Add organic matter to soil (biomass such as dead cells, plant litter, and secondary metabolites).
Decomposers	• Bacteria • Fungi	**Break down residue** • Immobilize (retain) nutrients in their biomass. • Create new organic compounds (cell constituents, waste products) that are sources of energy and nutrients for other organisms. • Produce compounds that help bind soil into aggregates. • Bind soil aggregates with fungal hyphae. • Nitrifying and denitrifying bacteria convert forms of nitrogen. • Compete with or inhibit disease-causing organisms.
Mutualists	• Bacteria • Fungi	**Enhance plant growth** • Protect plant roots from disease-causing organisms. • Some bacteria fix N_2. • Some fungi form mycorrhizal associations with roots and deliver nutrients (such as P) and water to the plant.
Pathogens **Parasites**	• Bacteria • Fungi • Nematodes • Microarthropods	**Promote disease** • Consume roots and other plant parts, causing disease. • Parasitize nematodes or insects, including disease-causing organisms.
Root-feeders	• Nematodes • Macroarthropods (e.g., cutworm, weevil larvae, & symphylans)	**Consume plant roots** • Potentially cause significant crop yield losses.
Bacterial-feeders	• Protozoa • Nematodes	**Graze** • Release plant available nitrogen (NH_4^+) and other nutrients when feeding on bacteria. • Control many root-feeding or disease-causing pests. • Stimulate and control the activity of bacterial populations.
Fungal-feeders	• Nematodes • Microarthropods	**Graze** • Release plant available nitrogen (NH_4^+) and other nutrients when feeding on fungi. • Control many root-feeding or disease-causing pests. • Stimulate and control the activity of fungal populations.
Shredders	• Earthworms • Macroarthropods	**Break down residue and enhance soil structure** • Shred plant litter as they feed on bacteria and fungi. • Provide habitat for bacteria in their guts and fecal pellets. • Enhance soil structure as they produce fecal pellets and burrow through soil.
Higher-level predators	• Nematode-feeding nematodes • Larger arthropods, mice, voles, shrews, birds, other above-ground animals	**Control populations** • Control the populations of lower trophic-level predators. • Larger organisms improve soil structure by burrowing and by passing soil through their guts. • Larger organisms carry smaller organisms long distances.

Typical Numbers of Soil Organisms in Healthy Ecosystems

		Agricultural Soils	Prairie Soils	Forest Soils
Bacteria	Per teaspoon of soil (one gram dry)	100 million to 1 billion.	100 million to 1 billion.	100 million to 1 billion.
Fungi	Per teaspoon of soil (one gram dry)	Several yards. (Dominated by vesicular-arbuscular mycorrhizal (VAM) fungi).	Tens to hundreds of yards. (Dominated by vesicular-arbuscular mycorrhizal (VAM) fungi).	Several hundred yards in deciduous forests. One to forty miles in coniferous forests (dominated by ectomycorrhizal fungi).
Protozoa	Per teaspoon of soil (one gram dry)	Several thousand flagellates and amoebae, one hundred to several hundred ciliates.	Several thousand flagellates and amoebae, one hundred to several hundred ciliates.	Several hundred thousand amoebae, fewer flagellates.
Nematodes	Per teaspoon of soil (one gram dry)	Ten to twenty bacterial-feeders. A few fungal-feeders. Few predatory nematodes.	Tens to several hundred.	Several hundred bacterial- and fungal-feeders. Many predatory nematodes.
Arthropods	Per square foot	Up to one hundred.	Five hundred to two thousand.	Ten to twenty-five thousand. Many more species than in agricultural soils.
Earthworms	Per square foot	Five to thirty. More in soils with high organic matter.	Ten to fifty. Arid or semi-arid areas may have none.	Ten to fifty in deciduous woodlands. Very few in coniferous forests.

What Are Mineralization and Immobilization?

Soil nutrients generally occur in two forms: inorganic compounds dissolved in water or attached to minerals, and organic compounds part of living organisms and dead organic matter. Bacteria, fungi, nematodes, protozoa, and arthropods are always transforming nutrients between these two forms. When they consume inorganic compounds to construct cells, enzymes, and other organic compounds needed to grow, they are said to be "immobilizing" nutrients. When organisms excrete inorganic waste compounds, they are said to be "mineralizing" nutrients.



BUILDING HEALTHY SOILS

SOIL HEALTH PROPERTIES		
PHYSICAL	**CHEMICAL**	**BIOLOGICAL**
Structure	Nutrients	Microbes

SOIL HEALTH PRINCIPLES				
DISTURBANCE	**ARMORING**	**LIVE ROOTS**	**DIVERSITY**	**LIVESTOCK**
Minimize soil disturbance	Keep soil covered (residue)	Maintain live roots as long as possible	Encourage diverse plant species	Integrate livestock

MANAGEMENT TOOLS
Transition to low or no- till farming
Reduce fallow fields - strive for a live root in the ground at all times
Utilize cover crops to build soil and provide additional grazing
Interseed or reseed diverse species into crop and pasture
Select pasture/crop species that are drought resilient and locally adapted
Integrate livestock into crop systems
Grazing rotations that provide adequate recovery periods for plants
Grazing systems that result in residual plant litter and concentrated waste
Increase stock density and reduce grazing periods
Winter feeding systems that build soil organic matter in strategic locations
Utilize livestock to trample plant litter and provide nutrients through waste
Record management actions and monitor soil conditions over time
Infrastructure: Stockwater systems, cross-fencing,

GOALS AND OUTCOMES
Improved soil structure and water infiltration capacity
Reduced erosion and actively build soils
Increased microbial activity and nutrient cycling
Increased Soil Organinc Matter (SOM) and water holding capacity
Increased resistance to invasive plants, disease, and drought
Reduced inputs (fertilizer, fuel, water)
Increased profit and production