E X T E N S I O N

A G R I C U L T U R E

SOIL BIOLOGY

UVM Extension Fact Sheet: Champlain Valley Crop, Soil and Pasture Team

The Living, Breathing Soil: Farming with Soil Biology

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Soil health is the cumulative soil condition based upon chemical, physical and biological properties. While measures of soil often focus on chemical properties, and to a lesser extent physical properties, biological properties may be overlooked. However, your soil is alive! One cup of soil may hold as many individual bacteria as there are people on Earth! *The complex of living organisms in soils plays a critical role in the processes that create and maintain soil health and impact crop yields, quality and vigor.*

∗ Carbon cycling and retention:

Organic matter is the foundation of the soil food web which is constantly being transformed through soil organisms. Many kinds of soil organisms are involved in the process of shredding and decomposing complex plant residues into constituent parts. Different soil organisms are particularly adapted to process different kinds of organic matter.

∗ Nutrient cycling and retention:

When soil organisms decompose plant residues, nutrients such as nitrogen and phosphorus may also become more available to plants. Decomposers transform plant matter and release nitrogen, which is subsequently transformed by other bacteria and chemical processes (see Figure 1). Organisms are like a slow release fertilizer. Soil fauna that consume bacteria often consume and excrete excess nitrogen, thereby transforming it into plant available forms (either ammonium or nitrates). Organisms also hold nutrients in their bodies which are released upon death – this can help hold nutrients in the soil, particularly during periods of slower crop uptake.

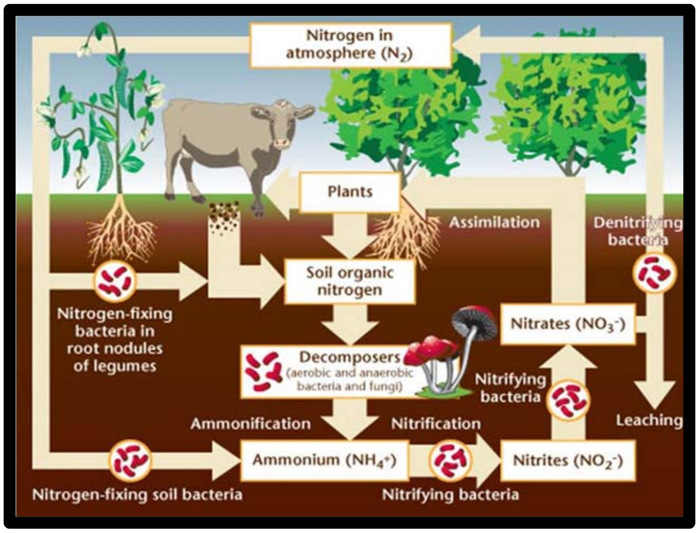


Figure 1. The Role of Soil Organisms in the Nitrogen Cycle.
(Soil fauna are missing from this illustration)

∗ Soil physical properties:

As biota transform and ingest soil organic matter, soil particulates, and other organisms, biota exude sticky binding agents (polysaccharides and glomalin) which hold soil particles together and create spaces in the soil. Soil biota can increase soil aggregation and porosity, and therefore can improve both infiltration and water-holding capacity, providing a more habitable environment for plant roots.

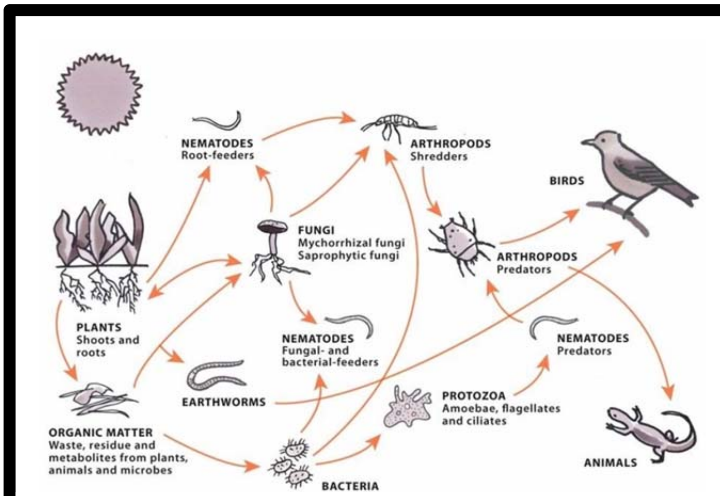
∗ Disease Suppression and Plant Health:

It's easy to get into the trap of thinking of soil biota as "enemies" because we are often focused on agricultural pests. However, most organisms are beneficial to crops. Beneficial soil biota can aid plant health both indirectly and directly. Indirectly, they can create a better growing environment for crops through the processes described above. Directly, soil organisms have been shown to stimulate root growth and development. Soil organisms can also compete with and prey on pest species.

* <u>Environmental protection:</u>
Healthy soil provides many functions that are of greater service to both farmers and the larger human communities that agriculture supports. Soils are an important source of biodiversity, which serve many functions in creating stable ecosystems. Soil biota are involved in soil water filtration, as soils retain and break down pollutants before they reach surface or ground waters. Soil biota are also part of the long term process of soil formation.

A Review of Soil Biota: Food webs are a way to envision how nutrients and energy are transmitted and recycled from one group of organisms to another (see Figure 2). Trophic level is how many steps a group is from the primary producer. The base of the soil food web is plant litter, exudates, roots and animal residues. Soil food webs are composed of bacteria and fungi (soil flora, or soil microbes), and many types of soil animals (soil fauna) including protozoa, nematodes, earth worms, and arthropods.

Bacteria: Bacteria are miniscule, single celled organisms with a big function in soil. Many bacteria are decomposers, breaking down organic matter into simpler substances. Some bacteria form a symbiosis with leguminous plants creating nodules in the roots that transform nitrogen from the soil-air into usable forms for plant growth. While some bacteria obtain energy from carbon, other bacteria use and transform substances containing nitrogen, hydrogen, sulfur, or iron. Some bacteria must have oxygen, others are somewhat flexible, and still others can only exist without oxygen. Some bacteria cause disease in plants, while others cause disease in other organisms. The classic example is the bacteria *Bacillus thuringiensis (Bt)* which creates an insecticide utilized by agriculturalists.



Original source: NRCS, http://www.nrcs.usda.gov/Internet/FSE_MEDIA/nrcs142p2_049822.jpg
Adapted from: http://www.agriculturesnetwork.org

Figure 2. An Illustration of the Soil Food Web.

Still other bacteria create compounds that inhibit fungal diseases or stimulate plant growth.

Fungi: When you think of fungi, you might think of the mushroom you had for dinner. However, the mushroom is the fruiting body (reproductive part) of the fungi. Underground, or in the growing medium, these fungi produce many hyphae – thin root-like structures that extend out in search of food. Some of the largest organisms on Earth are actually fungi! In contrast other fungi, such as yeasts, exist as single celled organisms. Fungi provide an important part of decomposition, breaking down more resistant forms of organic matter. Specific fungi can usually survive drought conditions more than bacteria. Fungi generally require oxygen, meaning that saturated soils are usually hostile to them. Mycorrhizae fungi form a special symbiosis with plants, transforming phosphorus into usable forms and bringing macronutrients, micronutrients and potentially water through their hyphae to plants roots (in exchange for photosynthetic carbon from the plant). In effect mycorrhizae extend plant roots. Hyphae also bind soil particles together and enhance soil structure. Most agricultural crops form these associations (some vegetables such as cabbage and beets excluded), and some may for 'hyphae highways' between different crops. While some fungi are detrimental crop diseases others prey on soil pests. A great example is the nematode trapping fungus (see Figure 3).

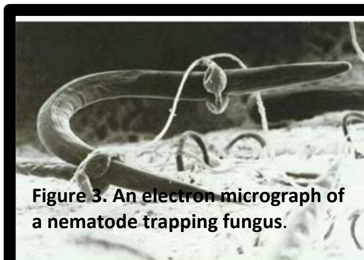


Figure 3. An electron micrograph of a nematode trapping fungus.

Protozoa: Protozoa are single celled animals that graze on microbes in the soil and sometimes other protozoa and organic materials. Protozoa are grouped by cell structure, which is related to mobility: amoeba, which have a unique blob-like movement with "pseudopods" or finger-like projections of their cell; flagellates, with whip or tail-like projections; and ciliates, with many fine hair-like projections. Protozoa are important in particular for nitrogen cycling; in grazing on bacteria they consume more nitrogen than needed for their growth, and therefore excrete excess ammonium-N, creating up to a 10 fold difference in nitrogen mineralization. Because biological activity is often near plant roots, this nitrogen then becomes available for plant uptake as well as for other organisms. By grazing on microbes, protozoa can also help control plant diseases.

Nematodes: While the most well-known nematodes are pests occupying and feeding on plant roots (such as the lesion nematode and the soybean cyst nematode), in fact most nematodes are beneficial organisms. Nematodes are extremely important because they consume a diverse array of food sources, which places them at multiple trophic levels in the soil food web. Nematodes are mostly microscopic, and occupy water pores in soil but also rely on air pores for diffusion. Nematodes are a diverse group of animals, and can be found in almost all soil types and climates including Antarctica. Some nematodes consume bacteria and others fungi. Like protozoa, nematodes have a role in nitrogen mineralization, disease control of microbes, and root growth stimulation. Still other nematodes are opportunistic or omnivorous and feed on a variety of food sources including protozoa. Specific nematodes are used in biological application to consume the larvae of invertebrate pests (e.g. Japanese beetles). Still other nematodes are specifically predators, feeding exclusively on other nematodes. Due to this nature, scientists use nematodes as biological indicators in soil. Nematode community measures are related to the structure of the entire food web and also reflect both chemical and physical disturbances.

Earthworms: Earthworms have many benefits and are also the easiest indicator of biology because they do not require a microscope for observation. Earthworm burrows create increased soil structure and porosity, and habitat for other soil organisms. Earthworms digest substantial quantities of organic matter, turning it into more available nutrients. Different earthworms occupy different places in the soil profile; therefore earthworm diversity is important in maintaining soil health. Interestingly, earthworms are actually not believed to be native to Vermont due to past glaciation, and there has been some recent awareness of potential drawbacks with earthworm communities (however that is particularly in forests, and more inconclusive or debated in agriculture).

Other Soil Organisms: Other soil fauna include arthropods, potworms (also called enchytraeids) and water bears (also called tardigrades). Soil arthropods may spend all or only a part of their life in the soil. While some are pests, many are strictly shredders, breaking down plant litter as they feed on microbes, and like earthworms, enhance soil structure with their fecal pellets and burrows. Some also have a role in nitrogen mineralization (e.g., collebolans). Larger, mobile arthropods actually function to move smaller soil organisms around, dispersing them into new settings where they can then assist in decomposition. Potworms are native, somewhat common, small, light colored worms and serve similar functions to earthworms, but affect smaller pore structure. Like nematodes, water bears live in soil water and through a unique kind of suspended metabolism (crytobiosis) can withstand substantial stresses of moisture loss, temperature extremes, high pressure and even the vacuum of space . They feed on plant residues, algae and small invertebrates, playing a role in nutrient turnover.

How Management Practices Can Impact & Enhance Soil Biota

The great news is that the actions we take to remediate phosphorus pollution or enhance nitrogen uptake can also benefit soil biology. Both physical and chemical disturbances can affect the abundance and diversity of soil organisms, and in particular soil fauna that are higher up on the food web. The complexity and type of a soil food web can vary substantially from one soil and management practice to another. Generally speaking agricultural soils tend to have a greater population of bacteria, and therefore more soil organisms that feed on bacteria, in comparison to forest soils, which tend to have a greater number of fungi and soil organisms that feed on fungi. However, within agricultural soils, management practices can shift the dynamics of the soil food web over time in either direction. Complexity is an important concept in studying soil biology, because it relates to how many kinds and groups of organisms there are. More complex and diverse food webs usually confer more benefits to plants.

Increasing quantity and complexity of soil habitat and food sources, and maintaining water-air balance generally increases biological complexity. For example, providing a diverse array of food sources from organic matter applications, plant rotations and cover crops allows for more diversity in soil biota that feed on the organic matter. Similarly, decreasing compaction and increasing soil structure encourages soil biota. This is both due to increased water infiltration and to diversity in soil pores – allowing for a range of pore sizes that support a range of soil biota. Owing to the fact that soil organisms are so tiny and soil is complex, physical space is a really important piece of maintaining soil biology. Places of high biological activity in soil are mainly near plant roots, in plant litter and earthworm and arthropod burrows. Therefore, increasing soil quality for root growth development can also benefit soil biota. Also, if your soils are permanently saturated only anaerobic organisms- those that do not need oxygen to survive – will be able to live there. This is important for nitrogen cycling because if affects how well nitrogen is mineralized. Many organisms, including nematodes, live in water films; if you have a soil that is in serious drought conditions on a regular basis, many will die, or go into a kind of temporary stasis until more water is available. Soil organisms can also be sensitive to chemical disturbances and low pH to differing degrees by species; however earthworms and other soil animals are usually more sensitive.

While tillage can lead to a bloom of soil activity as organic matter is incorporated into the soil, this activity is generally bacterial in nature and short lived. Every time you till the soil, you are shifting back the soil community either by direct damage or by homogenization of the habitat. Reducing tillage can have positive effects on biology and in particular fungi and larger animals. Reducing tillage leaves more roots intact, and allows more stable, slowly decomposing organic matter and physical structure to develop through time. While a no-till system might not be ideal or practical in all farming situations, reduction and better management of tillage can benefit soil biology. Research has suggested that reducing tillage and increasing plant residues may be a mechanism for suppression of plant disease by supporting a complex food web with organisms that compete with or control the pest of concern.

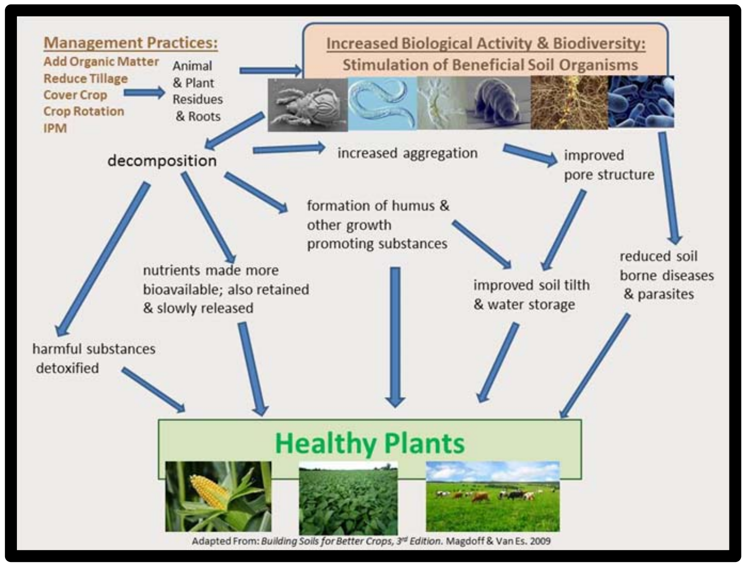


Figure 4. Management techniques that lead to healthy plants are mediated by soil biota.

In summary: Practices that increase quantity and quality of organic matter and physical habitat have beneficial impacts on soil biota. *A diverse array of foods and habitats generally leads to a more complex and stable food web.*

Supply diverse organic matter – which provides both food and habitat for soil biota. Practices that increase diversity of food sources, encourage beneficial biota, and interrupt pest cycles include:

- applying compost & manure
- planting cover crops and legumes (consider inoculation)
- crop rotation
- planting a diversity of crops or forages
- maximizing plant residues
- reducing tillage

Protect the soil habitat. Soil organisms need space to live, and they need a balance of air & water. Soil organisms also need intact root structures. Practices that can preserve and improve soil habitat include:

- minimizing compaction
- reducing tillage
- improving drainage (in wet soils) or supplying moisture or cover (in dry soils)
- minimizing/managing pesticides & inorganic fertilizer use (IPM & NMP)
- optimizing pH (as with agronomic crops)
- managing grazing to increase plant root biomass

Developing healthy soil biota in your soil is a feedback process on your farm. When conditions are more favorable for soil biota they will begin to sustain and enhance their own habitat and provide conditions more conducive to other organisms. The long term biological goals on agricultural soils would be to establish a set of management practices that maintain a semi-stable condition for soil biota, so that the community is less affected by more extreme conditions that farmers cannot control – like a drought or flood. Management would focus first on the farm or field specific soil properties that are most limiting for soil biota. A healthy soil community – just like a healthy agricultural community – will be more capable of bouncing back from a disturbance than one that is already highly stressed before the disturbance occurs.

Measuring Soil Biology:
Estimations of soil activity can be made through indirect means that measure activity (e.g., enzymes or respiration), the community as whole (e.g., DNA or RNA), or direct extraction and identification of individuals (usually requires a microscope). Unlike soil chemistry, there is no 'standard' test for soil biology, and testing usually costs more money. Research and development is still underway to make soil health and soil biology tests more accessible to farmers. The University of Maine does offer a soil biological test based upon microbial biomass. One of the best commercially-available measures in our area is the Cornell Soil Health analysis, which indirectly accounts for biology through analysis of carbon and nitrogen partitioning and an assessment of potential plant root health by growing beans in the soil sampled. Also included is an analysis of physical properties including aggregation and compaction. On-farm observations of this nature can also be done by a farmer or agronomist, which assist in understanding the habitat availability for soil organisms. Cornell also has a protocol that a farmer can use in determining pest nematode populations by growing plants in the soil and counting root lesions. Being attentive to soil organic matter content from a regular soil test and being observant to how much and what kind of plant residue is left on the field can be very informative. Visual field observations of organic matter and manure decomposition rates can also give you a qualitative understanding of soil biology activity. Visual inspection of soil for earthworms and their burrows and casts is another simple way to get a qualitative understanding of soil biology.

More Reading:

NRCS Soil Biology Website: http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/biology/

Building Soils for Better Crops (Chapter 4: The Living Soil), (2010) online at:
http://www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition

Cornell Soil Health Website: http://soilhealth.cals.cornell.edu/

University of Minnesota, Extension Service Website: http://www.extension.umn.edu/agriculture/tillage/soil-management/soil-management-series/soil-biology-and-soil-management/

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