United States Department of Agriculture
NRCS Natural Resources Conservation Service
Soil Quality

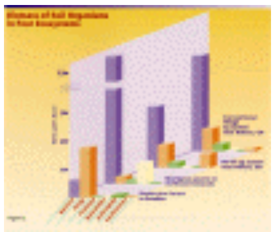
Soil Biology

The Soil Biology Primer

Chapter 2: THE FOOD WEB & SOIL HEALTH

By Elaine R. Ingham

HOW DO FOOD WEBS DIFFER?



Each field, forest, or pasture has a unique soil food web with a particular proportion of bacteria, fungi, and other groups, and a particular level of complexity within each group of organisms. These differences are the result of soil, vegetation, and climate factors, as well as land management practices. (See figure of food webs in different ecosystems.)

TYPICAL FOOD WEB STRUCTURES

The "structure" of a food web is the composition and relative numbers of organisms in each group within the soil system. Each type of ecosystem has a characteristic food web structure (see table of typical numbers of organisms in soil). Some features of food web structures include:

The ratio of fungi to bacteria is characteristic to the type of system. Grasslands and agricultural soils usually have bacterial-dominated food webs – that is, most biomass is in the form of bacteria. Highly productive agricultural soils tend to have ratios of fungal to bacterial biomass near 1:1 or somewhat less. Forests tend to have fungal-dominated food webs. The ratio of fungal to bacterial biomass may be 5:1 to 10:1 in a deciduous forest and 100:1 to 1000:1 in a coniferous forest.

Organisms reflect their food source. For example, protozoa are abundant where bacteria are plentiful. Where bacteria dominate over fungi, nematodes that eat bacteria are more numerous than nematodes that eat fungi.

Management practices change food webs. For example, in reduced tillage agricultural systems, the ratio of fungi to bacteria increases over time, and earthworms and arthropods become more plentiful.

HOW IS THE FOOD WEB MEASURED?

The measurement techniques used to characterize a food web include:

Counting. Organism groups, such as bacteria, protozoa, arthropods, etc.; or subgroups, such as bacterial-feeding, fungal-feeding, and predatory nematodes, are counted and through calculations, can be converted to biomass.

> *Direct counts* – counting individual organisms with the naked eye or with a microscope. All organisms can be counted, or only the active ones that take up a fluorescent stain (Figure 3).
>
> *Plate counts* – counting the number of bacterial or fungal colonies that grow from a soil sample.

Measuring activity levels. Activity is determined by measuring the amount of by-products, such as CO_2, generated in the soil, or the disappearance of substances, such as plant residue or methane used by a large portion of the community or by specific groups of organisms.

These measurements reflect the total "work" the community can do. Total biological activity is the sum of activities of all organisms, though only a portion are active at a particular time.

Respiration – measuring CO_2 production. This method does not distinguish which organisms (plants, pathogens, or other soil organisms) are generating the CO_2.

Nitrification rates – measuring the activity of those species involved in the conversion of ammonium to nitrate.

Decomposition rates – measuring the speed of disappearance of organic residue or standardized cotton strips.

Measuring cellular constituents. The total biomass of all soil organisms or specific characteristics of the community can be inferred by measuring components of soil organisms such as the following.

Biomass carbon, nitrogen, or phosphorus – measure the amount of nutrients in living cells, which can then be used to estimate the total biomass of organisms. Chloroform fumigation is a common method used to estimate the amount of carbon or nitrogen in all soil organisms.

Enzymes – measure enzymes in living cells or attached to soil. Assays can be used to estimate potential activity or to characterize the biological community.

Phospholipids and other lipids – provide a “fingerprint” of the community, and quantify the biomass of groups such as fungi or actinomycetes.

DNA and RNA – provide a “fingerprint” of the community, and can detect the presence of specific species or groups.

WHAT IS COMPLEXITY?

Food web complexity is a factor of both the number of species and the number of different kinds of species in the soil. For example, a soil with ten species of bacterial-feeding nematodes is less complex than a soil with ten nematode species that includes bacterial-feeders, fungal-feeders, and predatory nematodes.

Complexity can be determined, in part, from a food web diagram such as Figure 4 (see diagram), which represents the soil in an old-growth Douglas fir forest. Each box of the food web diagram represents a functional group of organisms that perform similar roles in the soil system. Transfers of energy are represented by the arrows on the diagram and occur when one organism eats another. Complex ecosystems have more functional groups and more energy transfers than simple ecosystems.

The number of functional groups that turn over energy before the energy leaves the soil system is different (and characteristic) for each ecosystem (Figure 5). In the Douglas fir system (Figure 4), energy may undergo more than twenty transfers from organism to organism, or between functional groups. In contrast, a cave or low-residue cultivated system is not likely to include a large variety of higher predators on the right-hand side of a soil food web diagram. Energy and nutrients will be cycled through fewer types of organisms.

Land management practices can alter the number of functional groups – or complexity – in the soil. Intensively managed systems, such as cropland, have varied numbers of functional groups. Crop selections, tillage practices, residue management, pesticide use, and irrigation alter the habitat for soil organisms, and thus alter the structure and complexity of the food web.

BENEFITS OF COMPLEXITY

Biological complexity of a soil system can affect processes such as nutrient cycling, the formation of soil structure, pest cycles, and decomposition rates. Researchers have yet to define how much and what kind of food web complexity in managed ecosystems is optimal for these soil processes.

Nutrient cycling. When organisms consume food, they create more of their own biomass and they release wastes. The most important waste for crop growth is ammonium (NH4+). Ammonium and other readily utilized nutrients are quickly taken up by other organisms, including plant roots. When a large variety of organisms are present, nutrients may cycle more rapidly and frequently among forms that plants can and cannot use.

Nutrient retention. In addition to mineralizing or releasing nitrogen to plants, the soil food web can immobilize or retain nitrogen when plants are not rapidly growing. Nitrogen in the form of soil organic matter and organism biomass is less mobile and less likely to be lost from the rooting zone than inorganic nitrate (NO_3^-) and ammonium (NH_4^+).

Improved structure, infiltration, and water-holding capacity. Many soil organisms are involved in the formation and stability of soil aggregates. Bacterial activity, organic matter, and the chemical properties of clay particles are responsible for creating microaggregates from individual soil particles. Earthworms and arthropods consume small aggregates of mineral particles and organic matter, and generate larger fecal pellets coated with compounds from the gut. These fecal pellets become part of the soil structure. Fungal hyphae and root hairs bind together and help stabilize larger aggregates. Improved aggregate stability, along with the burrows of earthworms and arthropods, increases porosity, water infiltration, and water-holding capacity.

Disease suppression. A complex soil food web contains numerous organisms that can compete with disease-causing organisms. These competitors may prevent soil pathogens from establishing on plant surfaces, prevent pathogens from getting food, feed on pathogens, or generate metabolites that are toxic to or inhibit pathogens.

Degradation of pollutants. An important role of soil is to purify water. A complex food web includes organisms that consume (degrade) a wide range of pollutants under a wide range of environmental conditions.

Biodiversity. Greater food web complexity means greater biodiversity. Biodiversity is measured by the total number of species, as well as the relative abundance of these species, and the number of functional groups of organisms.

MANAGEMENT AND SOIL HEALTH

A healthy soil effectively supports plant growth, protects air and water quality, and ensures human and animal health. The physical structure, chemical make-up, and biological components of the soil together determine how well a soil performs these services.

In every healthy system or watershed, the soil food web is critical to major soil functions including:

1. sustaining biological activity, diversity, and productivity;
2. regulating the flow of water and dissolved nutrients;
3. storing and cycling nutrients and other elements; and
4. filtering, buffering, degrading, immobilizing and detoxifying organic and inorganic materials that are potential pollutants.

The interactions among organisms enhance many of these functions.

Successful land management requires approaches that protect all resources, including soil, water, air, plants, animals and humans. Many management strategies change soil habitats and the food web, and alter soil quality, or the capacity of soil to perform its functions. Examples of some practices that change the complexity and health of the soil community include:

- Compared to a field with a 2-year crop rotation, a field with a 4 crops grown in rotation may have a greater variety of food sources (i.e., roots and surface residue), and therefore is likely to have more types of bacteria, fungi, and other organisms.

- A cleanly-tilled field with few vegetated edges may have fewer habitats for arthropods than a field broken up by grassed waterways, terraces, or fence rows.

- Although the effect of pesticides on soil organisms varies, high levels of pesticide use will generally reduce food web complexity. An extreme example is the repeated use of methyl bromide which has been observed to eliminate most soil organisms except a few bacteria species.

THE FOOD WEB AND CARBON SEQUESTRATION

Land management practices can be chosen to increase the amount of carbon sequestered as soil organic matter and reduce the amount of CO_2, a greenhouse gas, released to the atmosphere.

As the soil food web decomposes organic material, it releases carbon into the atmosphere as CO_2 or converts it to a variety of forms of soil organic matter. Labile or active fractions of organic matter stay in the soil for a few years. Stable forms reside in the soil for decades or hundreds of years. Physically stabilized organic matter is protected inside soil aggregates that soil organisms help create. Humified organic matter is stable because bacteria and fungi have helped form molecules that are too complex and large for soil organisms to decompose.

LOOKING FORWARD

The functions of the food web are essential to plant growth and environmental quality. Good resource management will integrate food web-enhancing strategies into the regular activities of farms, ranches, forests, or in backyard gardens. Needed research will examine food web functions within whole systems, and will support technology development. Technology to assess and maintain the functions of soil food webs will be developed to assist land managers and researchers as they strive towards soil productivity and stewardship. In the coming years, we can expect progress at answering soil biology questions such as the following.

What is a healthy food web? What measurements or observations can be used to determine whether a particular biological community is desirable for the intended land use? What level of complexity is optimal for highly productive and sustainable crop, range or forest lands?

Is it more useful to count species, or types of organisms? The Soil Biology Primer divides food web organisms into six groups. Achieving an optimal balance of these groups is one approach to managing the food web. Alternatively, identifying the species and complexity present within a group may provide other useful information about the health and productive potential of a soil.

How should the biology of the soil be managed? In the future, land managers may be able to more precisely predict the effect of management decisions such as the timing of tillage, the application of a certain kind of compost, or the use of a particular pesticide. They may choose practices with the intent of making specific changes to the composition of the soil food web.

What are the costs and benefits of managing for soil biological functions? The costs to achieve a highly diverse, or complex, soil community need to be identified. These can be compared to the benefits of biological services provided, such as nutrient cycling, disease suppression, and soil structure enhancement.