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THE FOOD WEB & SOIL HEALTH

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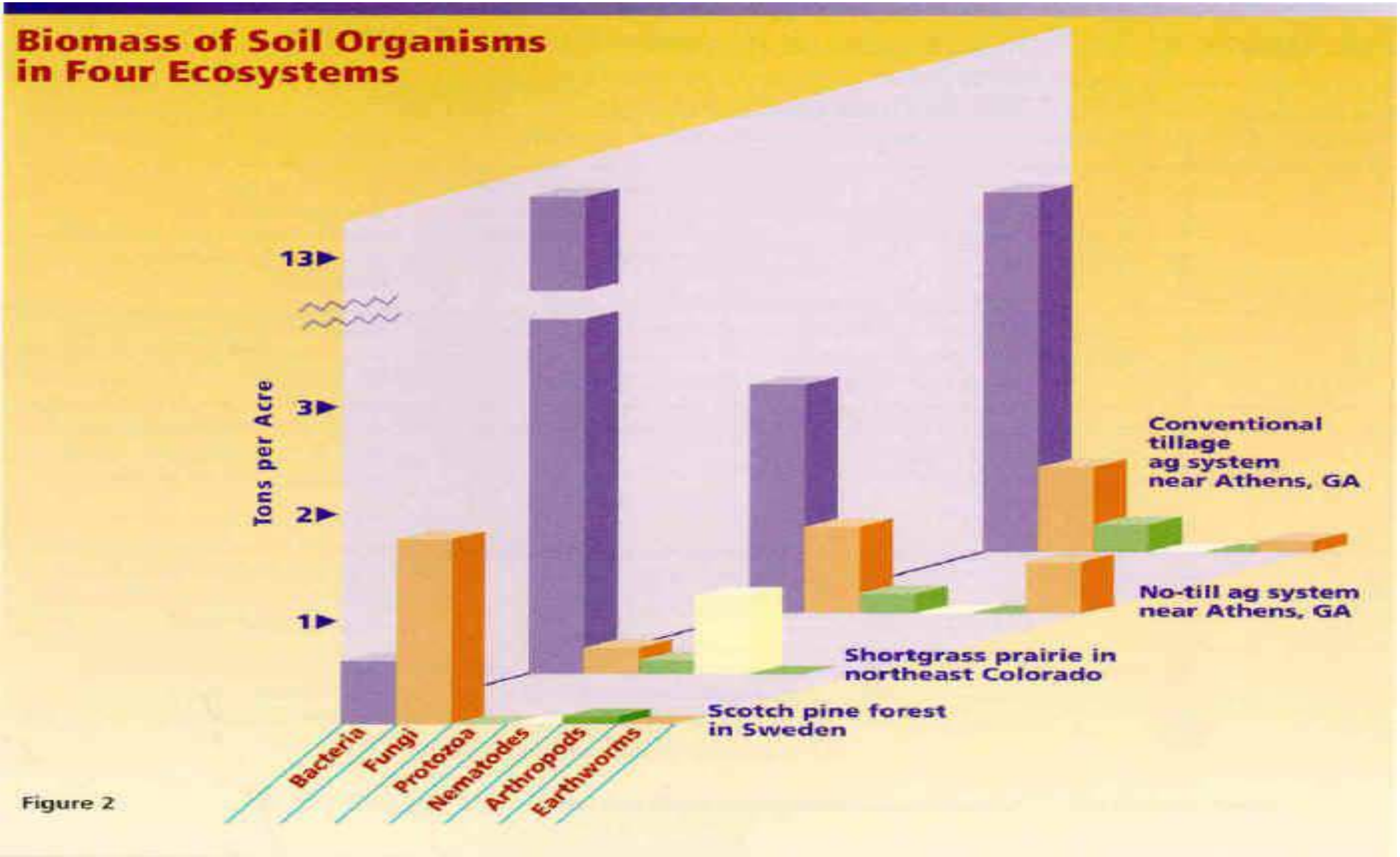
HOW DO FOOD WEBS DIFFER



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

Typical Numbers of Soil Organisms in Healthy Ecosystems

	Unit	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.

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.

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.

Measuring activity levels.

Activity is determined by measuring the amount of by-products, such as CO2, 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.**

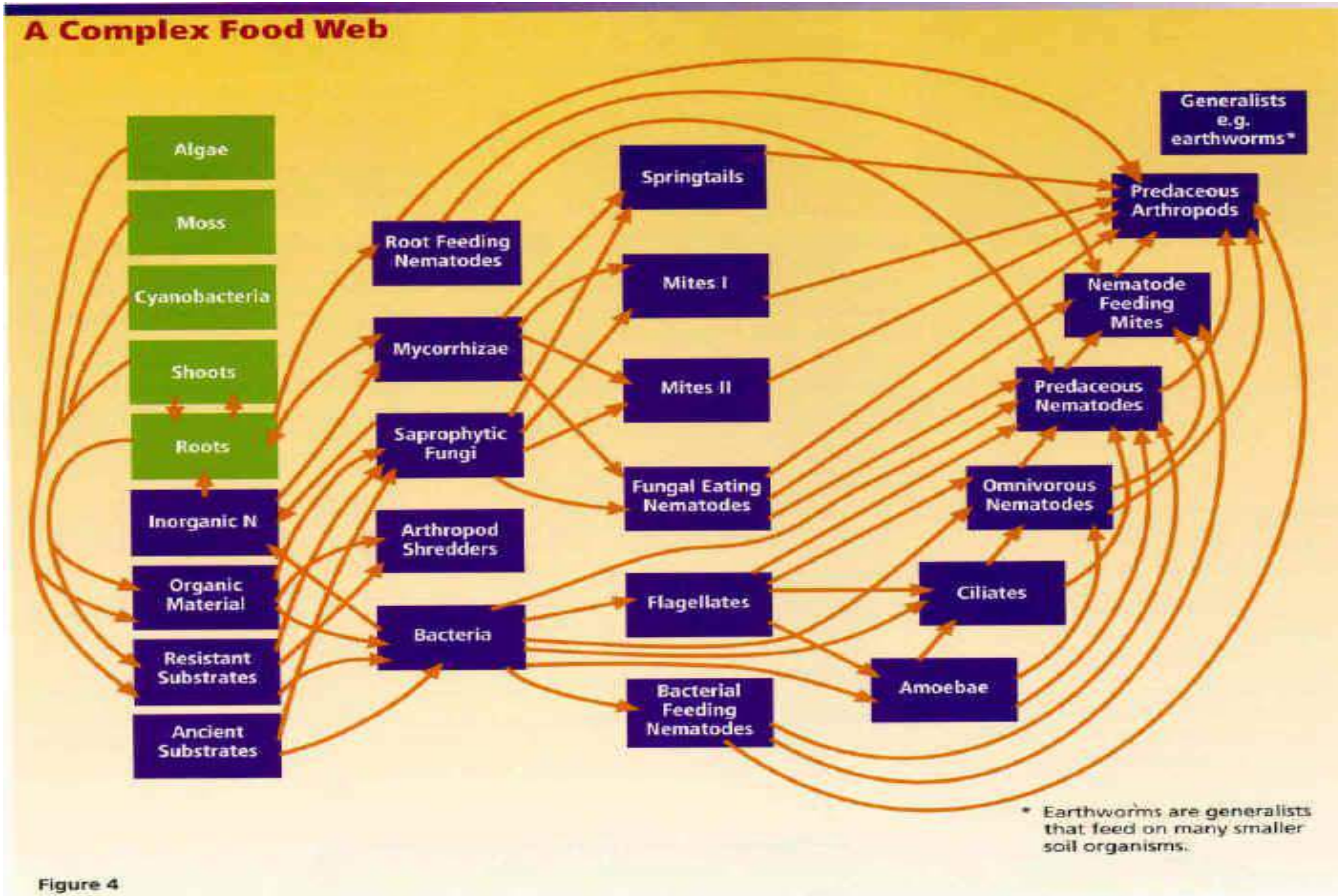
Biomass carbon, nitrogen, or phosphorus – measure the amount of nutrients in living cells, which can then be used to estimate the total biomass of organisms. Chloroform fumigation is a common method used to estimate the amount of carbon or nitrogen in all soil organisms.

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, 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.

The number of functional groups that turn over energy before the energy leaves the soil system is different (and characteristic) for each ecosystem. In the Douglas fir system, energy may undergo more than twenty transfers from organism to organism, or between functional groups.

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 (NH_4^+). Ammonium and other readily utilized nutrients are quickly taken up by other organisms, including plant roots.

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.

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 micro-aggregates from individual soil particles.

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 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.

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?

Is it more useful to count species, or types of organisms?

How should the biology of the soil be managed?

What are the costs and benefits of managing for soil biological functions?