MODULE ONE

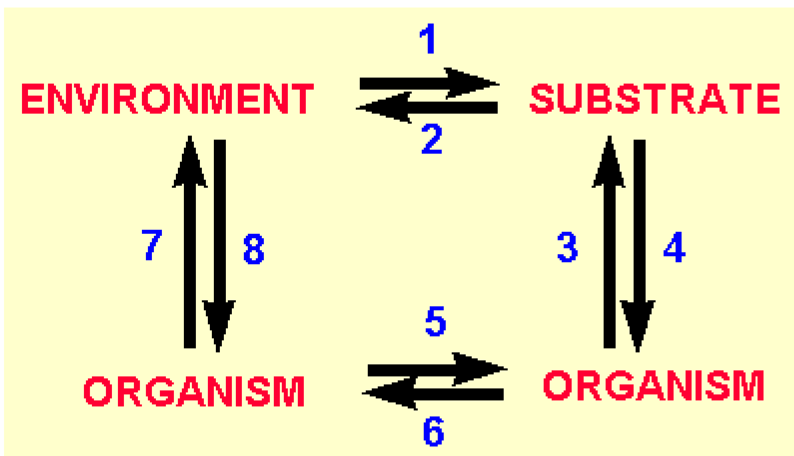
Soil Microbial Population Ecology

Ecology is the study of the relationships between organisms and their environment.

Soil population ecology: is the interaction between the following 3:

- Organisms (microbes, plants and animals)
- Substrates (dead roots, leaves, dead organisms, pesticides)
- Environment (water, air and soil particles)

The interaction of these three groups can be shown diagrammatically in the following schematic figure. The arrows denote one factor influencing another. In summary all the factors can influence one another making the study of soil population ecology very difficult and complex. Examples for each of the arrows are given underneath.



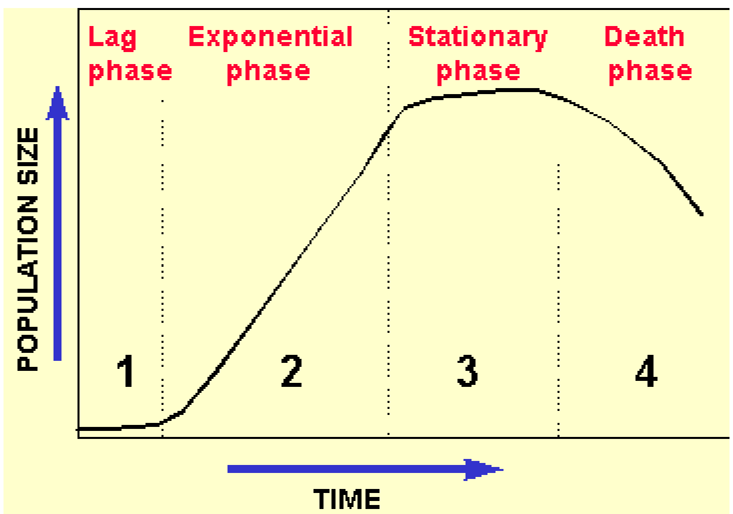
1. e.g. Pesticide adsorption by clay particles preventing breakdown and movement
2. e.g. Plant mucilage binding soil particles together (improves the soil's water retention and structure)
3. e.g. Decomposition of the substrate
4. e.g. Some chemicals are toxic to organisms (e.g. pesticides)
5. e.g. Predation
6. e.g. Mutualism, symbiosis
7. e.g. Earthworms increasing soil porosity and aeration
8. e.g. Compaction preventing earthworm burrowing

Why is microbial population ecology important?

Basically because few soil processes are carried out by a single organism alone. Most are carried out by a group of microbes living together within a dynamic community. Examples of soil processes involving more than one organism are:

- Inorganic nutrient cycling (N, P, S)
- Substrate decomposition (plant litter)

The 4 Phases of Microbial Population Growth



1. Lag phase

This is the time needed to switch on the necessary cell machinery to (a). transport the substrate into the cell, and (b), process the substrate once inside. It normally requires the *de novo* synthesis of new enzymes and therefore requires gene transcription and translation which will take at least a few hours.

2. Exponential phase

The necessary machinery for substrate use are now in place (the enzymes required to transport the substrate into the cell and the enzymes required to turn this into energy or new cell material). The substrate is in plentiful supply. Growth is very rapid and goes in the following exponential pattern

1 cell…. 2 cells...4 cells….8 cells….16 cells….32 cells

3. Stationary phase

At this point either the substrate or another nutrient (e.g. P or N) has become limiting so that growth is now slowing rapidly as it becomes harder and harder to obtain the limiting factor.

4. Death phase

The cell starts to run out of energy so they start to die.

Example calculation (to put things in perspective)

If a single bacterium kept dividing exponentially every hour this is how many microbes (clones) you would have after 4 days:

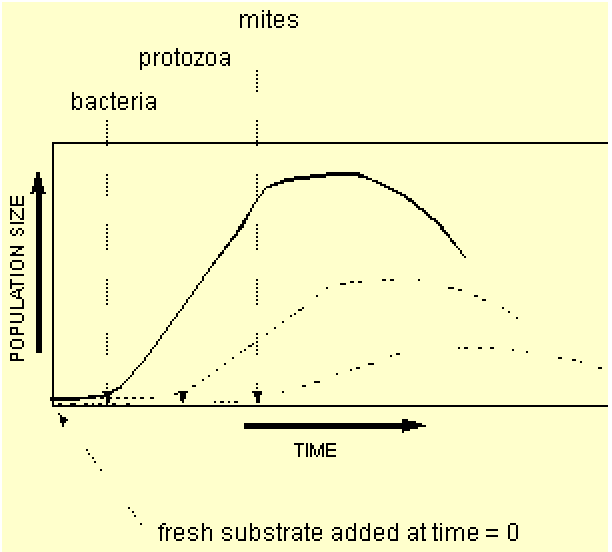
Time (hours)	Bacteria Population Size
0	1
24	16 million
48	280,000,000 million
72	4,700,000,000,000,000 million
96	79,000,000,000,000,000,000,000 million

If a bacterium dimensions are 2μm by 0.5μm then its volume is 3.14 x 10^{-12} m^3, so after 96 h you have 2.48 x 10^{17} $m^3$of bugs. This is equal to 2.48 x 10^{11} cubic kilometers i.e. nearly a million times a million km^3. Therefore as microbes have not taken over the earth and sunk us into a black hole, it is because the amount of substrate in soil must be limiting

Succession and Competition

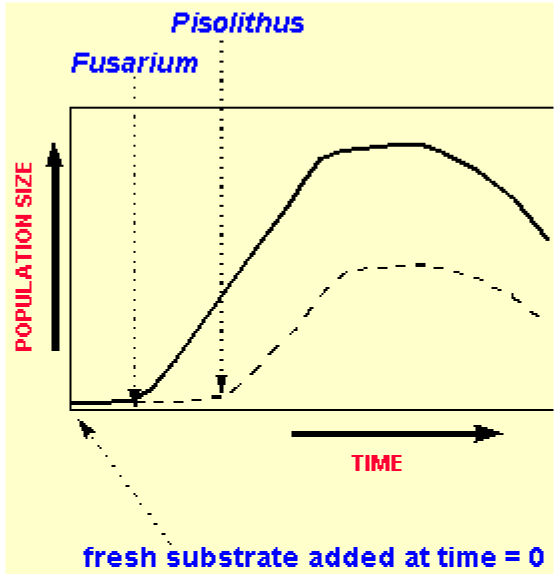
Succession

Below is a graph showing succession of three groups of organisms. Substrate has been added as time = 0 and bacteria have responded by growing (in 4 phases as described above). As protozoa are triggered into action by bacteria, they don't start growing until the bacteria are in exponential phase. They then go through four phase growth. This is followed similarly by protozoan predators mites. Note that all go through 4 phases of growth and that the population numbers are lower at each stage. Secondly note that the curves start and finish at different times. i.e. the time of death is not the same for bacteria and mites. The 3 curves represent from left to right, bacteria, protozoa and mites respectively.



Competition

Here we have on the surface similarly looking graphs for two fungal species. However, it is subtly different and is characteristic of competition. *Fusarium* is the top curve and *Pisolithus* the botton curve. Here the substrate has been added at time =0 and *Fusarium* has reacted first. *Pisolithus*, however, can also use this substrate but it takes longer to turn on the necessary apparatus for transport (maybe it has only a few membrane receptors for this substrate). The important point to note, however, is that they both go into stationary phase and death phase at the same time. This indicates that they are both using the substrate and that *Pisolithus* is not using *Fusarium* as a substrate. Basically *Fusarium* has out-competed (higher population) *Pisolithus* for the substrate.


Pisolithus
Fusarium
POPULATION SIZE
TIME
fresh substrate added at time = 0

MODULE TWO

Soil microbiological terms to describe fast and slow growers in soil

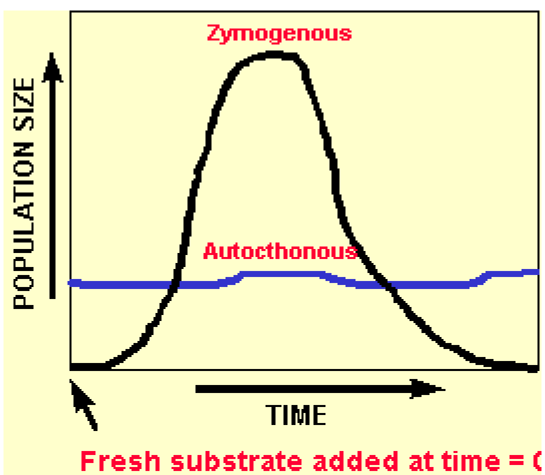
Zymogenous organisms

- Organisms which grow extremely rapidly when a new substrate arrives
- They are 'boom' and 'bust' (i.e. big fluctuations in pop'n numbers)
- They are not long lived
- They spend most of their time in hibernation (waiting for substrate)
- They are more adapted to taking up substrate at high concentrations
- They are uncommon in soil (as soil is normally substrate limiting)
- They are analogous to 'r strategists'

Autochthonus organisms

- Organisms which grow slowly when new substrate is added
- Their populations tend to be more stable
- They are longer lived
- They are more adapted to taking up substrate at low concentrations
- They are common in soil
- They are analogous to 'K strategists'

Below is a graph of the population numbers versus time for each group



Substrates, microbes and the environment

Inputs of substrate to the soil

Example: Mixed Temperate Forest Ecosystem

- Leaves and needles constitute 25-60 % of the net primary production
- Roots constitute 40-75 % of net primary production
- Over 60 % of most fine tree roots die each year

	Tropics	**Temperate**
Net Primary production (g/m^2)	2200	1200
Soil Organic Carbon (g/m^2)	1900	7000
Total Microbial Carbon (g/m^2)	80	90
Active Microbial Biomass Carbon (g/m^2)	8	9

Substrate Quality

- Most substrates are 90 % water (10 % dry matter)
- Substrate quality determines how fast it's broken down
- Generally the more nutrients the substrate contains - the faster it is broken down
- Microbes need not just C but other nutrients as well

Here is a table of the typical macronutrient content (% of dry weight) of two groups of organisms and two substrates.

Macronutrient	**Bacterial cells**	**Fungal cells**	**Green Shoots**	**Cereal Straw**
C	50	40	40	40
N	6.25	2.5	1	0.4
P	3	0.6	0.2	0.1
S	1	0.4	0.2	0.1
C:N Ratio	8	16	40	100

Oxygen and Hydrogen makes up most of the rest.

- One important point is the carbon to nitrogen ration (C:N ratio). These are the two nutrients most needed by microbial cells for growth as they are used to make proteins, cell walls etc. From the C: N ratio we can guess at which organisms might decompose it

- Note the C:N ration of fungi (16) is much greater than that for bacteria (8), and that both are lower than that of crop residues (40-100).

C:N of microbe > C:N substrate = Excretion on N into soil
C:N of microbe < C:N substrate = Uptake of N from soil

N- rich residues (e.g. dead animal cells C:N =10)

- Bacteria will rapidly degrade these as they have a low C:N ratio (the C:N ratio of the substrate is still greater than that of the microbe so the bacteria may still need to take up a small amount of external N from the soil)
- Fungi will also rapidly degrade these. As the C:N ratio of fungi is greater than the residue they will excrete the excess N into the soil.

N- poor residues (e.g. cereal straw C:N = 100)

- Bacteria will be poor at degrading this as they will be N starved
- Fungi will be OK (they will still need to take up some external N from the soil)

MODULE THREE

Introduction to soil microbial ecology and interactions in the rhizosphere

Microorganisms play an essential role in maintaining soil fertility: cycling nutrients, influencing their availability; improving soil structure; supporting healthy plant growth; degrading organic pollutants. Some soil bacteria and fungi cause plant diseases; others are antagonistic to plant pathogens and invertebrate pests. The rhizosphere provides a region of increased microbial activity in which certain groups of bacteria and fungi are more likely to proliferate than in the bulk soil.

Some rhizosphere microorganisms originate from the seed but the majority is derived from the soil, in which a plant is growing, and they will be returned to the soil, thus bulk soil and rhizosphere reciprocate impact on microbial communities. This is especially important in the case of plant pathogenic microorganisms and microbial antagonists to pests and pathogens.

Any one group of microbes is unlikely to perform with maximum efficiency under all circumstances so genetically diverse populations are needed to provide continuation of important soil processes. Since the relationship between the size, diversity and activity of microbial populations and soil 'quality' is unclear, also how these properties fluctuate throughout the seasons, with crop rotations, and the scale (temporal, spatial) on which they vary, it is difficult to predict effects of changes in agricultural practice, land use, climate, introduction of novel plants, microbial inoculants and pollution on soil quality.

Baseline studies are needed to demonstrate the significance of any observed changes in response to unusual stress. Some functions undertaken by specific groups of bacteria can be measured in situ and may indicate the size of the active population, but cannot describe its diversity or indicate if there is a related, inactive population. Advances in molecular techniques mean that more detailed examination of individual groups and of the total microbial population is possible, whether or not they can be isolated from the soil and be grown in laboratory culture. Because the genetic material defines organism identity, profiles based on DNA are the most reliable method of identification, including difficult-to-culture microbes.

The available DNA sequence information on environmental bacteria is increasing exponentially, enabling design of many group- and species-specific primers. PCR techniques can be used to amplify sequences from individual or related strains in nucleic acids (DNA or RNA) isolated from soil providing estimates of activity, diversity and relative abundance. Quantitative PCR can estimate the frequency of sequences and reverse transcriptase PCR can amplify ribosomal sequences and functional genes identifying which populations are active. However, to assess and compare whole populations, DNA arrays offer great future possibilities.

The application of modern molecular techniques to study the ecology of soil fungi lags behind bacteria. Several groups of soil fungi are known to attack plant pathogenic nematodes, and have potential as biological control agents. To exploit fungal agents, or to manage the development of naturally suppressive soils, further understanding of fungal biology and ecology, especially genetic diversity and population dynamics, is important.

Soil microorganisms exist in large numbers in the soil as long as there is a carbon source for energy. A large number of bacteria in the soil exists, but because of their small size, they have a smaller biomass. Actinomycetes are a factor of 10 times smaller in number but are larger in size so they are similar in biomass to bacteria. Fungus population numbers are smaller but they dominate the soil biomass when the soil is not disturbed. Bacteria, actinomycetes, and protozoa are hardy and can tolerate more soil disturbance than fungal populations so they dominate in tilled soils while fungal and nematode populations tend to dominate in untilled or no-till soils.

There are more microbes in a teaspoon of soil than there are people on the earth. Soils contain about 8 to 15 tons of bacteria, fungi, protozoa, nematodes, earthworms, and arthropods. See fact sheets on Roles of Soil Bacteria, Fungus, Protozoa and Nematodes.

Relative number and biomass of microbial species at 0–6 inches (0–15 cm) depth of soil

Microorganisms	Number/g of soil	Biomass (g/m^2)
Bacteria	10^8–10^9	40–500
Actinomycetes	10^7–10^8	40–500
Fungi	10^5–10^6	100–1500
Algae	10^4–10^5	1–50
Protozoa	10^3–10^4	Varies
Nematodes	10^2–10^3	Varies

MODULE FOUR

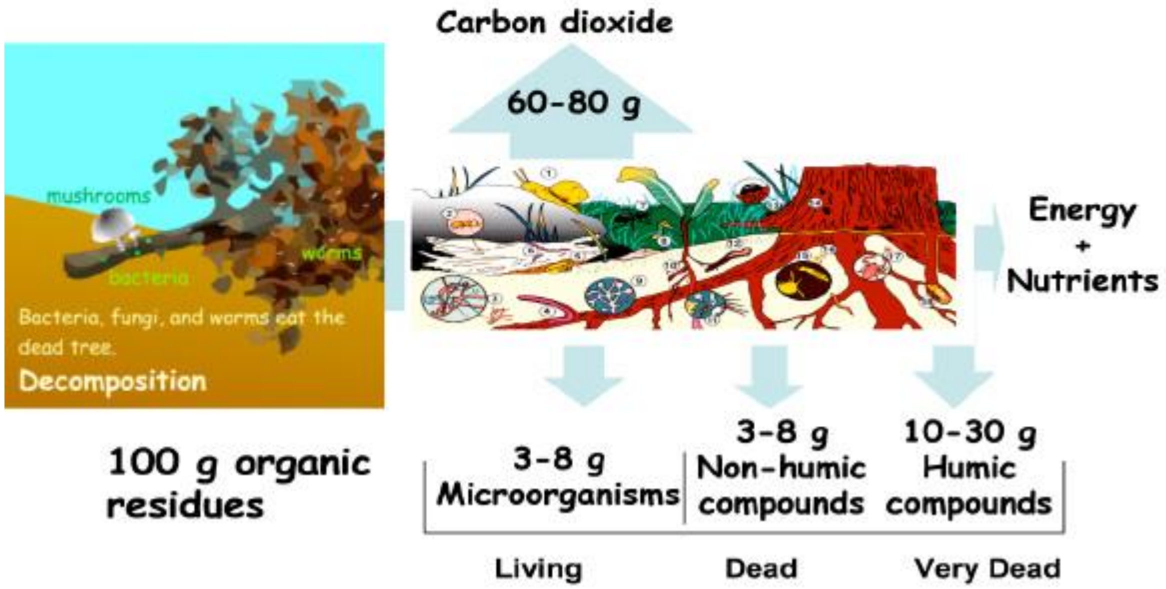
Microbial Soil Organic Matter Decomposition

Organic matter decomposition serves two functions for the microorganisms, providing energy for growth and supplying carbon for the formation of new cells. Soil organic matter (SOM) is composed of the "living" (microorganisms), the "dead" (fresh residues), and the "very dead" (humus) fractions. The "very dead" or humus is the long-term SOM fraction that is thousands of years old and is resistant to decomposition. Soil organic matter has two components called the active (35%) and the passive (65%) SOM. Active SOM is composed of the "living" and "dead" fresh plant or animal material which is food for microbes and is composed of easily digested sugars and proteins. The passive SOM is resistant to decomposition by microbes and is higher in lignin.

Microbes need regular supplies of active SOM in the soil to survive in the soil. Long-term no-tilled soils have significantly greater levels of microbes, more active carbon, more SOM, and more stored carbon than conventional tilled soils. A majority of the microbes in the soil exist under starvation conditions and thus they tend to be in a dormant state, especially in tilled soils.

Dead plant residues and plant nutrients become food for the microbes in the soil. Soil organic matter (SOM) is basically all the organic substances (anything with carbon) in the soil, both living and dead. SOM includes plants, blue green algae, microorganisms (bacteria, fungi, protozoa, nematodes, beetles, springtails, etc.) and the fresh and decomposing organic matter from plants, animals, and microorganisms.

Soil organic matter can be broken down into its component parts. One hundred grams (g) or 100 pounds (lbs) of dead plant material yields about 60–80 g (lbs) of carbon dioxide, which is released into the atmosphere. The remaining 20–40 g (lbs) of energy and nutrients is decomposed and turned into about 3–8 g (lbs) of microorganisms (the living), 3–8 g (lbs) of non-humic compounds (the dead), and 10–30 g (lbs) of humus (the very dead matter, resistant to decomposition). The molecular structure of SOM is mainly carbon and oxygen with some hydrogen and nitrogen and small amounts of phosphorus and sulfur. Soil organic matter is a by-product of the carbon and nitrogen cycles.



Soil Organic Matter Nutrients

The nutrients in the soil have a current value of $680 for each 1% SOM or $68 per ton of SOM based on economic values for commercial fertilizer (see Table 2). SOM is composed of mostly carbon but associated with the carbon is high amounts of nitrogen and sulfur from proteins, phosphorus, and potassium. SOM should be considered like an investment in a certificate of deposit (CD). Soils that are biologically active and have higher amounts of active carbon recycle and release more nutrients for plant growth than soils that are biologically inactive and contain less active organic matter. Under no-till conditions, small amounts of nutrients are released annually (like interest on a CD) to provide nutrients slowly and efficiently to plant roots. However, with tillage, large amounts of nutrients can be released since the SOM is consumed and destroyed by the microbes. Since SOM levels are slow to build, the storage capacity for nutrients is decreased and excess nutrients released are often leached to surface waters. SOM is a storehouse for many plant nutrients.

Value of Soil Organic Matter

Assumptions: 2,000,000 pounds soil in top 6 inches	
Nutrients	1% organic matter = 20,000# 50% Carbon, C:N ratio = 10:1
Nitrogen:	1000# * $0.50/#N = $500
Phosphorus:	100# * $.70/#P = $70
Potassium:	100# * $0.40/#K = $40
Sulfur:	100# * $0.50/#S = $50
Carbon:	10,000# or 5 ton * $4/Ton = $20
Value of 1% SOM Nutrients/Acre	= $680
Relative Ratio of Nutrients:	100 Carbon/10 Nitrogen/ 1 Phosphorus/1 Potassium/1 Sulfur

MODULE FIVE
Climate, Temperature, and pH Effects on SOM

SOM is affected by climate and temperature. Microbial populations double with every 10°F change in temperature. If we compare the tropics to colder arctic regions, we find most of the carbon is tied up in trees and vegetation above ground. In the tropics, the topsoil has very little SOM because high temperatures and moisture quickly decompose SOM. Moving north or south from the equator, SOM increases in the soil. The tundra near the Arctic Circle has a large amount of SOM because of cold temperatures. Freezing temperatures change the soil so that more SOM is decomposed then in soils not subject to freezing.

Moisture, pH, soil depth, and particle size affect SOM decomposition. Hot, humid regions store less organic carbon in the soil than dry, cold regions due to increased microbial decomposition. The rate of SOM decomposition increases when the soil is exposed to cycles of drying and wetting compared to soils that are continuously wet or dry. Other factors being equal, soils that are neutral to slightly alkaline in pH decompose SOM quicker than acid soils; therefore, liming the soil enhances SOM decomposition and carbon dioxide evolution. Decomposition is also greatest near the soil surface where the highest concentration of plant residues occur. At greater depths there is less SOM decomposition, which parallels a drop in organic carbon levels due to less plant residues. Small particle sizes are more readily degraded by soil microbes than large particles because the overall surface area is larger with small particles so that the microbes can attack the residue.

A difference in soil formation also occurs traveling east to west across the United States. In the east, hardwood forests dominated and tree tap roots were high in lignin, and deciduous trees left large amounts of leaf litter on the soil surface. Hardwood tree roots do not turn over quickly so organic matter levels in the subsoil are fairly low. In forest soils, most of the SOM is distributed in the top few inches. As you move west, tall grassland prairies dominated the landscape and topsoil formed from deep fibrous grass root systems. Fifty percent of a grass root dies and is replaced every year and grass roots are high in sugars and protein (higher active organic matter) and lower in lignin. So soils that formed under tall grass prairies are high in SOM throughout the soil profile. These prime soils are highly productive because they have higher percentage of

SOM (especially active carbon), hold more nutrients, contain more microbes, and have better soil structure due to larger fungal populations.

Carbon to Nitrogen Ratio

The breakdown of organic residues by microbes is dependent upon the carbon to nitrogen (C:N) ratio. Microbes in a cow's rumen, a compost pile, and soil microbes rely on the C:N ratio to break down organic (carbon-based) residues. Consider two separate feed sources, a young tender alfalfa plant and oat or wheat straw. A young alfalfa plant has more crude protein, amino acids, and sugars in the stalk so it is easily digested by microbes whether it is in a cow's rumen, a compost pile, or in the soil. Young alfalfa has a high nitrogen content from protein (amino acids and proteins are high in nitrogen and sulfur), so it has a lower carbon to nitrogen ratio (less carbon, more nitrogen). However, oat and wheat straw (or older mature hay) has more lignin (which is resistant to microbial decomposition), lower crude protein, and less sugars in the stalk and a higher C:N ratio. Straw is decomposed by microbes but it takes additional time and nitrogen to break down this high carbon source.

A low nitrogen content or a wide C:N ratio is associated with slow SOM decay. Immature or young plants have a higher nitrogen content, lower C:N ratios and faster SOM decay. For good composting, a C:N ratio less than 20 allows the organic materials to decompose quickly (4 to 8 weeks) while a C:N ratio greater than 20 requires additional N and slows down decomposition. So if we add a high C based material with low N content to the soil, the microbes will tie up soil nitrogen. Eventually, the soil N is released but in the short-term the N is tied up. The conversion factor for converting N to crude protein is 16.7, which relates back to why it is so important to have a C:N ratio of less than 20.

The C:N ratio of most soils is around 10:1 indicating that N is available to the plant. The C:N ratio of most plant residues tends to decrease with time as the SOM decays. This results from the gaseous loss of carbon dioxide. Therefore, the percentage of nitrogen in the residual SOM rises as decomposition progresses. The 10:1 C:N ratio of most soils reflects an equilibrium value associated with most soil microbes (Bacteria 3:1 to 10:1, Fungus 10:1 C:N ratio).

Bacteria are the first microbes to digest new organic plant and animal residues in the soil. Bacteria typically can reproduce in 30 minutes and have high N content in their cells (3 to 10 carbon atoms to 1 nitrogen atom or 10 to 30% nitrogen). Under the right conditions of heat, moisture, and a food source, they can reproduce very quickly. Bacteria are generally less efficient at converting organic carbon to new cells. Aerobic bacteria assimilate about 5 to 10 percent of the carbon while anaerobic bacteria only assimilate 2 to 5 percent, leaving behind many waste carbon compounds and inefficiently using energy stored in the SOM.

Alfalfa

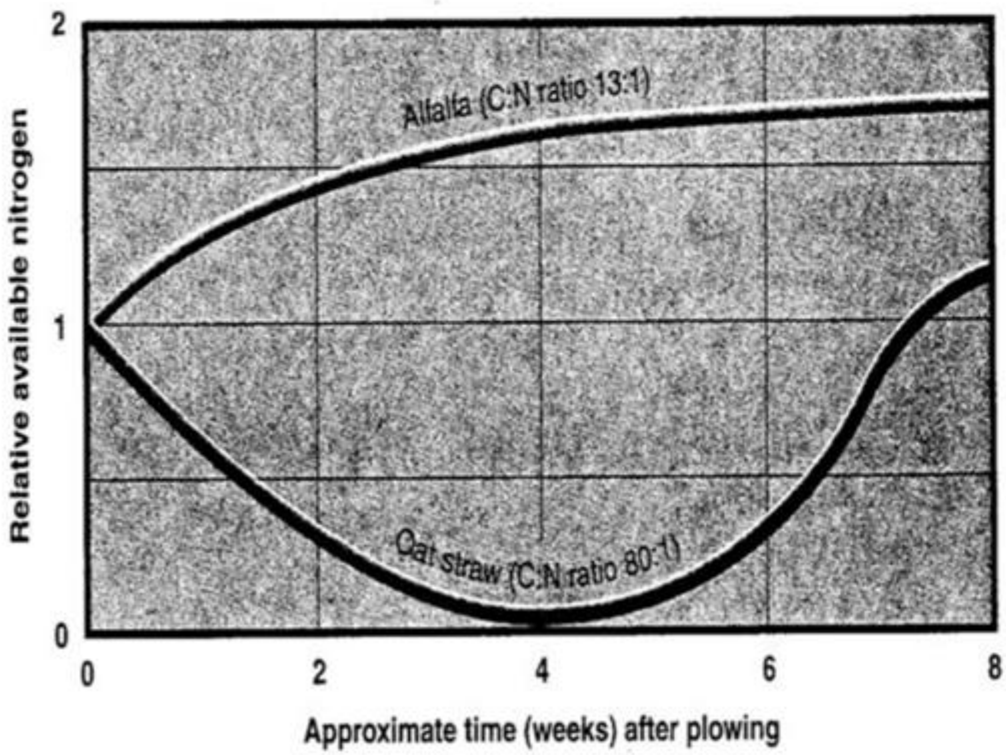
Low C:N Ratio

C:N = 13:1

Oat Straw

High C:N Ratio

C:N = 80:1



Graph of Relative Available N with Length of Time for Decomposition

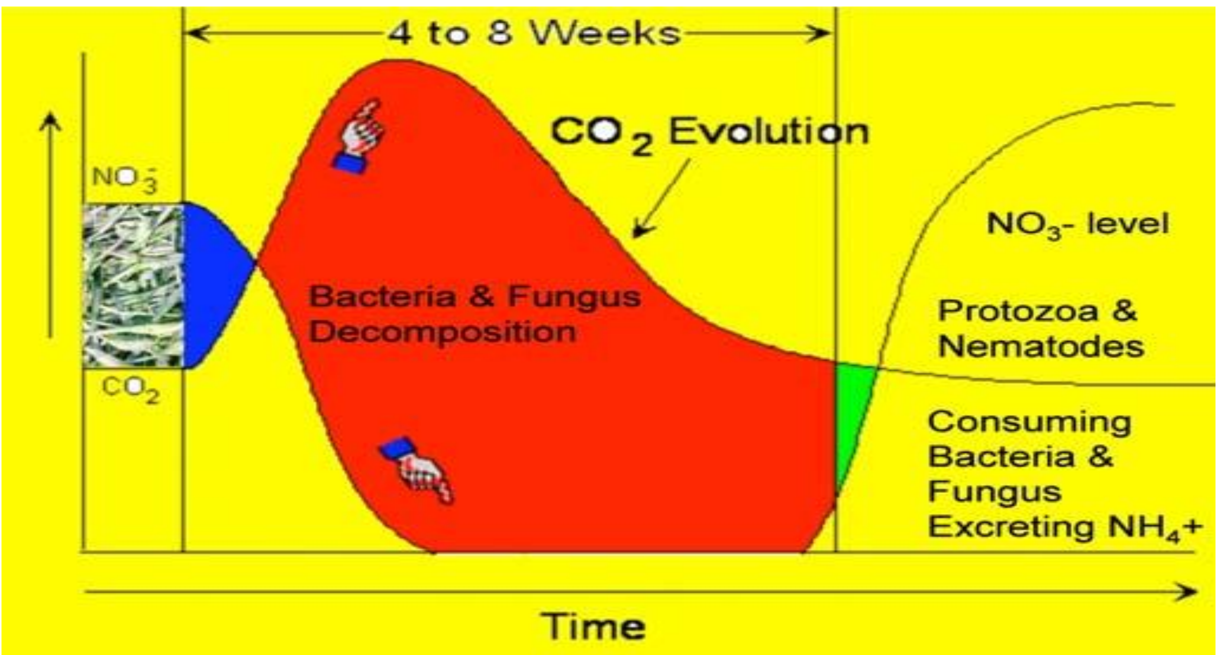
Fungus generally release less carbon dioxide into the atmosphere and are more efficient at converting carbon to form new cells. The fungus generally captures more energy from the SOM as they decompose it, assimilating 40 to 55 percent of the carbon. Most fungi consume organic matter higher in cellulose and lignin, which is slower and tougher to decompose. The lignin content of most plant residues may be of greater importance in predicting decomposition velocity than the C:N ratio.

Mycorrhizal fungi live in the soil on the surface of or within plant roots. The fungi have a large surface area and help in the transport of mineral nutrients and water to the plants. The fungus life cycle is more complex and longer than bacteria. Fungi are not as hardy as bacteria, requiring a more constant source of food. Fungi population levels tend to decline with conventional tillage. Fungi have a higher carbon to nitrogen ratio (10:1 carbon to nitrogen or 10% nitrogen) but are more efficient at converting carbon to soil organic matter. With high C:N organic residues, bacteria and fungus take nitrogen out of the soil (see the graph on net immobilization).

Protozoa and nematodes consume other microbes. Protozoa can reproduce in 6–8 hours while nematodes take from 3 days to 3 years with an average of 30 days to reproduce. After the protozoa and nematodes consume the bacteria or other microbes (which are high in nitrogen), they release nitrogen in the form of ammonia (see the graph on net mineralization). Ammonia (NH_4+) and soil nitrates (NO_3-) are easily converted back and forth in the soil. Plants absorb ammonia and soil nitrates for food with the help of the fungi mycorrhizal network.

Microorganism populations change rapidly in the soil as SOM products are added, consumed, and recycled. The amount, the type, and availability of the organic matter will determine the microbial population and how it evolves. Each individual organism (bacteria, fungus, protozoa) has certain enzymes and complex chemical reactions that help that organism assimilate carbon. As waste products are generated and the original organic residues are decomposed, new microorganisms may take over, feeding on the waste products, the new flourishing microbial community (generally bacteria), or the more resistant SOM. The early decomposers generally attack the easily digested sugars and proteins followed by microorganisms that attack the more resistant residues.

Decomposition of Cover Crop Residues: Cowpeas with a low C:N ratio (<20) will decompose in 4 to 8 weeks and result in net mineralization or release of N. Sudan grass or cereal rye with a higher C:N ratio (>38) will decompose slowly (3 months to 1 year or more) and will result in net immobilization or will tie up soil N.



Graph of Cowpeas (C:N<20) being decomposed by bacteria and fungus, the carbon dioxide evolution and protozoa and nematodes consuming the bacteria and fungus and excreting ammonia into the soil for plant growth. NO_3- and NH_4+ are easily converted in the soil.

Cover crops supply food (active carbon like glucose and proteins) to the microbes to feed on. In the soil, there are 1,000 to 2,000 times more microbes associated with roots than are living in bare or tilled soil. The microbes in turn build SOM and store soil nutrients. Building SOM requires soil nutrients like N-P-K-S to be tied up in the soil. Winter cover crops soak up excess soil nutrients and supply food to all the microbes in the soil during the winter months rather than microbes having to use up SOM reserves for nutrients. In a conventional tilled field, soil nutrients are quickly released as SOM is burned up and the microbes and soil organism's habitat are destroyed.

In a no-till field, high levels of SOM are reserves of soil nutrients which are slowly released into the soils. Adding a living cover crop to a no-till field increases active organic matter (sugars and proteins) for the soil microbes. Soil microbes have two crops to feed on instead of one crop per year. Microbes thrive under no-till conditions and winter cover crops. Cover crops and manure can be used to feed soil microbes and recycle soil nutrients. As soil microbes decompose organic residues, they slowly release nutrients back into the soil for the winter cover crops or for the preceding crop. Cover crops prevent the nutrients from being lost through soil erosion, leaching, volatilization, or denitrification.

MODULE SIX

Soil Microbial Communities

The soil is home to a large proportion of the world's biodiversity. The links between soil organisms and soil functions are observed to be incredibly complex. The interconnectedness and complexity of this soil 'food web' means any appraisal of soil function must necessarily take into account interactions with the living communities that exist within the soil. We know that soil organisms break down organic matter, making nutrients available for uptake by plants and other organisms. The nutrients stored in the bodies of soil organisms prevent nutrient loss by leaching. Microbial exudates act to maintain soil structure, and earthworms are important in bioturbation. However, we find that we don't understand critical aspects about how these populations function and interact. The discovery of glomalin in 1995 indicates that we lack the knowledge to correctly answer some of the most basic questions about the biogeochemical cycle in soils. We have much work ahead to gain a better understanding of how soil biological components affect us and the biosphere.

In balanced soil, plants grow in an active and steady environment. The mineral content of the soil and its structure are important for their well-being, but it is the life in the earth that powers its cycles and provides its fertility. Without the activities of soil organisms, organic materials would accumulate and litter the soil surface, and there would be no food for plants. The soil biota includes:

- Megafauna: size range - 20 mm upward, e.g. moles, rabbits, and rodents.
- macrofauna: size range - 2 to 20 mm, e.g. woodlice, earthworms, beetles, centipedes, slugs, snails, ants, and harvestmen.
- Mesofauna: size range - 100 micrometres to 2 mm, e.g. tardigrades, mites and springtails.
- Microfauna and Microflora: size range - 1 to 100 micrometres, e.g. yeasts, bacteria (commonly actinobacteria), fungi, protozoa, roundworms, and rotifers.

Of these, bacteria and fungi play key roles in maintaining a healthy soil. They act as decomposers that break down organic materials to produce detritus and other breakdown products. Soil detritivores, like earthworms, ingest detritus and decompose it. Saprotrophs, well represented by fungi and bacteria, extract soluble nutrients from delitro. The ants (macrofaunas) help by breaking down in the same way but they also provide the motion part as they move in their armies. Also the rodents, wood-eaters help the soil to be more absorbent.

Soil life table

This table is a résumé of soil life, coherent with prevalent taxonomy

Domain	Kingdom	Phylum	Class	Order	Family	Genus
Prokaryote	Bacteria	Proteobacteria	Beta Proteobacteria	Nitrosomonadales	Nitrosomonadaceae	*Nitrosomonas*
Prokaryote	Bacteria	Proteobacteria	Alpha Proteobacteria	Rhizobiales	Bradyrhizobiaceae	*Nitrobacter*
Prokaryote	Bacteria	Proteobacteria	Alpha Proteobacteria	Rhizobiales	Rhizobiaceae	*Rhizobium*
Prokaryote	Bacteria	Proteobacteria	Gamma Proteobacteria	Pseudomonadales	Azotobacteraceae	*Azotobacter*
Prokaryote	Bacteria	Actinobacteria	Actinobacteria			
Prokaryote	Bacteria	Cyanobacteria (Blue-green algae)				
Prokaryote	Bacteria	Firmicutes	Clostridia	Clostridiales	Clostridiaceae	*Clostridium*
Eukaryote	Fungi	Ascomycota	Eurotiomycetes	Eurotiales	Trichocomaceae	*Penicillium*
Eukaryote	Fungi	Ascomycota	Eurotiomycetes	Eurotiales	Trichocomaceae	*Aspergillus*
Eukaryote	Fungi	Ascomycota	Sordariomycetes	Hypocreales	Nectriaceae	*Fusarium*
Eukariote	Fungi	Ascomycota	Sordariomycetes	Hypocreales	Hypocreaceae	*Trichoderma*
Eukaryote	Fungi	Basidiomycota	Agaricomycetes	Cantharellales	Ceratobasidiaceae	*Rhizoctonia*
Eukaryote	Fungi	Zygomycota	Zygomycetes	Mucorales	Mucoraceae	*Mucor*
Eukaryote	Chromalveolata	Heterokontophyta	Bacillariophyceae (Diatomea algae)			
Eukaryote	Chromalveolata	Heterokontophyta	Xanthophyceae (Yellow-green algae)			
Eukaryote	Chromalveolata	Ciliophora				
Eukaryote	Amoebozoa					
Eukaryote	Plantae	Chlorophyta (green algae)	Chlorophyceae			

Eukaryote	Animalia	Nematoda			
Eukaryote	Animalia	Rotifer			
Eukaryote	Animalia	Tardigrada			
Eukaryote	Animalia	Arthropoda	Entognatha	Collembola	
Eukaryote	Animalia	Arthropoda	Arachnida	Acarina	
Eukaryote	Animalia	Arthropoda	Arachnida	Pseudoscorpionida	
Eukaryote	Animalia	Arthropoda	Insecta	Coleoptera (larvae)	
Eukaryote	Animalia	Arthropoda	Insecta	Coleoptera	Carabidae (Ground beetles)
Eukaryote	Animalia	Arthropoda	Insecta	Coleoptera	Staphylinidae (Rove beetle)
Eukaryote	Animalia	Arthropoda	Insecta	Diptera (larvae)	
Eukaryote	Animalia	Arthropoda	Insecta	Hymenoptera	Formicidae (Ant)
Eukaryote	Animalia	Arthropoda	Chilopoda (Centipede)		
Eukaryote	Animalia	Arthropoda	Diplopoda (Millipede)		
Eukaryote	Animalia	Arthropoda	Malacostraca	Isopoda (woodlouse)	
Eukaryote	Animalia	Annelida	Clitellata	Haplotaxida	Enchytraeidae
Eukaryote	Animalia	Annelida	Clitellata	Haplotaxida	Lumbricidae
Eukaryote	Animalia	Mollusca	Gastropoda		

MODULE SEVEN

MICROFAUNA

Bacteria

Bacteria are single-cell organisms and the most numerous denizens of agriculture, with populations ranging from 100 million to 3 billion in a gram. They are capable of very rapid reproduction by binary fission (dividing into two) in favourable conditions. One bacterium is capable of producing 16 million more in just 24 hours. Most soil bacteria live close to plant roots and are often referred to as rhizobacteria. Bacteria live in soil water, including the film of moisture surrounding soil particles, and some are able to swim by means of flagella. The majority of the beneficial soil-dwelling bacteria need oxygen (and are thus termed aerobic bacteria), whilst those that do not require air are referred to as anaerobic, and tend to cause putrefaction of dead organic matter.

Aerobic bacteria are most active in a soil that is moist (but not saturated, as this will deprive aerobic bacteria of the air that they require), and neutral soil pH, and where there is plenty of food (carbohydrates and micronutrients from organic matter) available. Hostile conditions will not completely kill bacteria; rather, the bacteria will stop growing and get into a dormant stage, and those individuals with pro-adaptive mutations may compete better in the new conditions. Some gram-positive bacteria produce spores in order to wait for more favourable circumstances, and gram-negative bacteria get into a "nonculturable" stage. Bacteria are colonized by persistent viral agents (bacteriophages) that determine gene word order in bacterial host.

Types of bacteria

Decomposers: play an important role in the early stages of decomposition of organic materials (in the later stages fungi tend to dominate).

Nitrogen fixers: extract nitrogen gas from the air and convert it into forms that plants can use, and can add the equivalent of more than 100 kg/ha per year of nitrogen to the soil. *Rhizobium* bacteria live in special root nodules on legumes and can be inoculated onto legume seeds. Other free-living nitrogen-fixing bacteria associate with non-legumes, but inoculating with these organisms has not proved effective in increasing nitrogen fixation for non-legume crops.

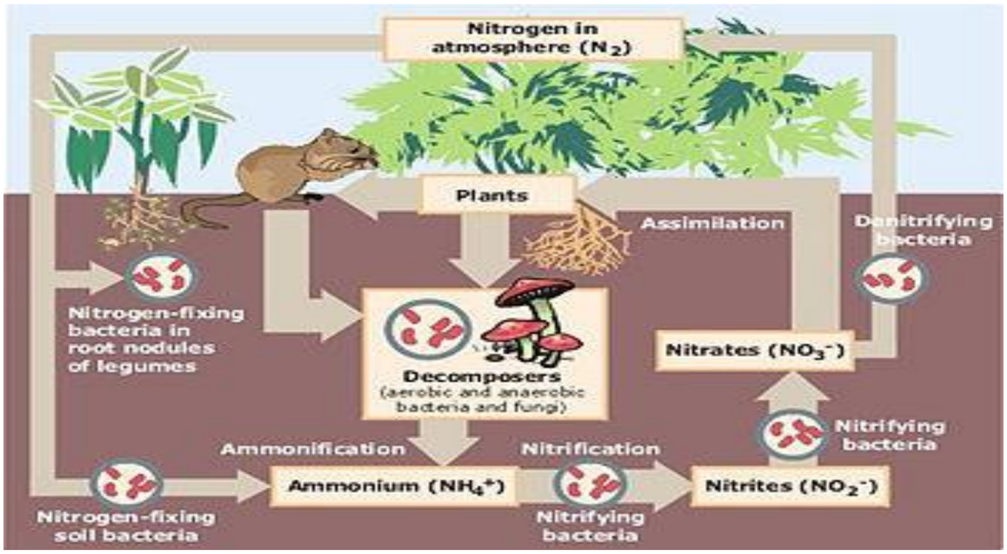
Disease suppressors: release antibiotic substances to suppress particular competitors. A number of bacteria have been commercialised for disease suppression. Their effect is often specific to particular diseases of particular crops and may only be effective in certain circumstances.

Actinobacteria: help to slowly break down humates and humic acids in soils, and prefer non-acidic soils with pH higher than 5.

Sulfur oxidisers: *Thiobacillus* bacteria can covert sulfides (common in soil minerals but largely unavailable to plants) into sulfates, a form plants can use.

Aerobes and anaerobes: Aerobic bacteria need oxygen, and dominate in well-drained soil. Anaerobic bacteria do not need oxygen, and favour wet, poorly drained soils. They can produce toxic compounds that limit root growth and predispose plants to root diseases.

From the organic gardener's point of view, the important roles that bacteria play are as follows:



The nitrogen cycle

Nitrification

Nitrification is a vital part of the nitrogen cycle, wherein certain bacteria (which manufacture their own carbohydrate supply without using the process of photosynthesis) are able to transform nitrogen in the form of ammonium, which is produced by the decomposition of proteins, into nitrates, which are available to growing plants, and once again converted to proteins.

Nitrogen fixation

In another part of the cycle, the process of nitrogen fixation constantly puts additional nitrogen into biological circulation. This is carried out by free-living nitrogen-fixing bacteria in the soil or water such as *Azotobacter,* or by those that live in close symbiosis with leguminous plants, such as rhizobia. These bacteria form colonies in nodules they create on the roots of peas, beans, and related species. These are able to convert nitrogen from the atmosphere into nitrogen-containing organic substances.

Denitrification

While nitrogen fixation converts nitrogen from the atmosphere into organic compounds, a series of processes called denitrification returns an approximately equal amount of nitrogen to the atmosphere. Denitrifying bacteria tend to be anaerobes, or facultatively anaerobes (can alter between the oxygen dependent and oxygen independent types of metabolisms), including *Achromobacter* and *Pseudomonas*. The purification process caused by oxygen-free conditions converts nitrates and nitrites in soil into nitrogen gas or into gaseous compounds such as nitrous oxide or nitric oxide. In excess, denitrification can lead to overall losses of available soil nitrogen and subsequent loss of soil fertility. However, fixed nitrogen may circulate many times between organisms and the soil before denitrification returns it to the atmosphere. The diagram above illustrates the nitrogen cycle.

Management of soil bacteria

Though largely unaffected by cultivation, bacteria populations are depressed by dry conditions, acidity, salinity, soil compaction and lack of organic matter. Except in the case of certain seed inoculations, it is very difficult to build desirable populations of bacteria just by adding them to the soil. If populations of soil bacteria are low, it is probably because conditions are unfavorable. Effective approaches (that have multiple benefits) to support healthy soil bacteria are to address problems of acidity and compaction, ensure good ground cover and build organic matter.

Actinobacteria

Actinobacteria are critical in the decomposition of organic matter and in humus formation, and their presence is responsible for the sweet "earthy" aroma associated with a good healthy soil. They require plenty of air and a pH between 6.0 and 7.5, but are more tolerant of dry conditions than most other bacteria and fungi.

MODULE EIGHT

Fungi

A gram of garden soil can contain around one million fungi, such as yeasts and moulds. Fungi have no chlorophyll, and are not able to photosynthesize. They cannot use atmospheric carbon dioxide as a source of carbon, therefore they are chemo-heterotrophic, meaning that, like animals, they require a chemical source of energy rather than being able to use light as an energy source, as well as organic substrates to get carbon for growth and development.

Many fungi are parasitic, often causing disease to their living host plant, although some have beneficial relationships with living plants, as illustrated below. In terms of soil and humus creation, the most important fungi tend to be saprotrophic; that is, they live on dead or decaying organic matter, thus breaking it down and converting it to forms that are available to the higher plants. A succession of fungi species will colonize the dead matter, beginning with those that use sugars and starches, which are succeeded by those that are able to break down cellulose and lignins.

Fungi spread underground by sending long thin threads known as mycelium throughout the soil; these threads can be observed throughout many soils and compost heaps. From the mycelia the fungi is able to throw up its fruiting bodies, the visible part above the soil (e.g., mushrooms, toadstools, and puffballs), which may contain millions of spores. When the fruiting body bursts, these spores are dispersed through the air to settle in fresh environments, and are able to lie dormant for up to years until the right conditions for their activation arise or the right food is made available.

Soil fungi

Soil fungi are microscopic plant-like cells that can be single celled (e.g. yeast) or grow in long threadlike structures or hyphae that make a mass called mycelium. They can be symbiotic with plant roots. Fungi are generally not as dependent on specific plant species as some bacteria, and populations are slower to develop.

Fungi groups

Decomposers: are essential for breaking down woody organic matter, they play an important role in immobilising and retaining nutrients in the soil. The organic acids they produce help create soil organic matter that is resistant to degradation.

Mutualists: develop mutually beneficial relationships with plants. Mycorrhizal fungi are the best known, and grow inside plant roots. Arbuscular mycorrhiza (AM) is the most common, especially in agricultural plant associations. These fungi have arbuscles, growths formed inside the plant root that have many small projections into root cells, as well as their hyphae outside the root. This growth pattern increases the plant's contact with the soil, improving access to water and nutrients, while their mass of hyphae protects roots from pests and pathogens.

Pathogens: (including the well-known *Verticillium, Phytophthora, Rhizoctonia* and *Pythium* fungi) penetrate the plant and decompose the living tissue, leading to weakened or dead plants. Where disease symptoms are seen, the pathogenic fungi is usually the dominant organism in the soil. Soils with high biodiversity can suppress soil-borne fungal diseases.

Management of soil fungi

You can encourage fungi in your soil by providing food (organic matter), water and minimal disturbance of the soil. Growing pastures and crops that support mycorrhizal fungi allow fungi to increase in the soil. Plant groups that do not form associations with mycorrhizal fungi are the Cruciferae family (eg mustard, canola, broccoli), Chenopodiaceae (eg spinach, beets, saltbush) and Proteaceae (banksia, macadamia). When these plants are included in a rotation, fungi numbers drop. A bare fallow has the same effect. Tillage has a disastrous effect on fungi as it physically severs the hyphae and breaks up the mycelium. Broadspectrum fungicides are toxic to most fungi and will result in a decline in beneficial types.

Mycorrhizae

Those fungi that are able to live symbiotically with living plants, creating a relationship that is beneficial to both, are known as Mycorrhizae (from *myco* meaning fungal and *rhiza* meaning root). Plant root hairs are invaded by the mycelia of the mycorrhiza, which lives partly in the soil and partly in the root, and may either cover the length of the root hair as a sheath or be concentrated around its tip. The mycorrhiza obtains the carbohydrates that it requires from the root, in return providing the plant with nutrients including nitrogen and moisture. Later the plant roots will also absorb the mycelium into its own tissues.

Beneficial mycorrhizal associations are to be found in many of our edible and flowering crops. Shewell Cooper suggests that these include at least 80% of the *brassica* and *solanum* families (including tomatoes and potatoes), as well as the majority of tree species, especially in forest and woodlands. Here the mycorrhizae create a fine underground mesh that extends greatly beyond the limits of the tree's roots, greatly increasing their feeding range and actually causing neighboring trees to become physically interconnected.

The benefits of mycorrhizal relations to their plant partners are not limited to nutrients, but can be essential for plant reproduction: In situations where little light is able to reach the forest floor, such as the North American pine forests, a young seedling cannot obtain sufficient light to photosynthesize for itself and will not grow properly in a sterile soil. But, if the ground is underlain by a mycorrhizal mat, then the developing seedling will throw down roots that can link with the fungal threads and through them obtain the nutrients it needs, often indirectly obtained from its parents or neighboring trees.

Recent research has shown that arbuscular mycorrhizal fungi produce glomalin, a protein that binds soil particles and stores both carbon and nitrogen. These glomalin-related soil proteins are an important part of soil organic matter.

MACRO AND MESO FAUNA

Earthworms, ants, and termites

Earthworms, ants and termites mix the soil as they burrow, significantly affecting soil formation. Earthworms ingest soil particles and organic residues, enhancing the availability of plant nutrients in the material that passes through and out their bodies. By aerating and stirring the soil, and by increasing the stability of soil aggregates, these organisms help assure the ready infiltration of water.