Plant-Microbe Interactions and Mineral Nutrition

Food Chain – Trophic Levels

•**Producers**
– autotrophs
– manufacture their own food by photosynthesis or chemosynthesis
•**Consumers**
– heterotrophs
– get food by eating producers or other consumers
– their "leftovers" still have nutritional value
•**Decomposers**
– heterotrophs
– get food by eating the remains of producers or consumers
– microorganisms (bacteria, fungi) called saprobes because they live off of dead organisms
– break down organic matter to a form from which elements can be re-assimilated by the producers

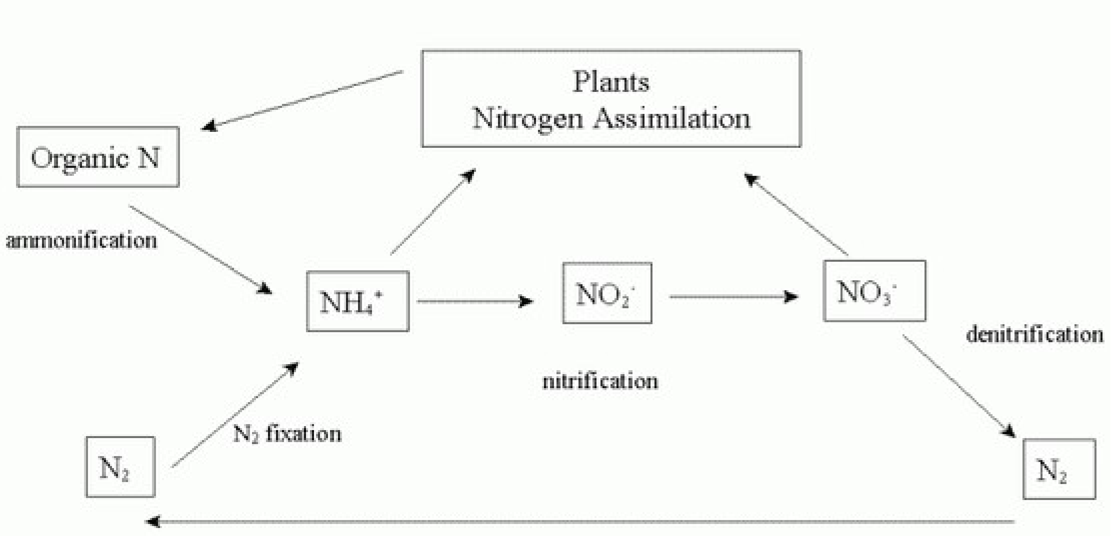
The primary emphasis in food chains is on energy flow and the carbon cycle. Available energy enters the system at the producer level when light or inorganic chemical energy is captured in the form of carbon (organic) compounds. As the available energy is transferred to subsequent organisms in the food chain, so is carbon in the form of carbohydrates, proteins, lipids, etc. Organisms obtain other chemical elements in these molecules, such as N, P, and S. These other chemical elements are also part of the food chain, and these elements enter at the same point as carbon does, producers. So, photosynthesis isn't the only important activity of plants in their ecosystem role as producers. Plants also take in various elements as soil minerals and incorporate those elements into key organic molecules (assimilation) that are then available to subsequent feeders in the food chain.

Symbiosis

•two (or more) different species living in close association; at least one member of the symbiosis benefits from the association
•The association could be:
– beneficial to both (mutualism)
– beneficial to one but harmful to the other (parasitism)
– beneficial to one with the other unaffected by the association (commensalism)

Biological Nitrogen Cycle

The diagram below shows just the biological reactions involving plants, bacteria, and fungi.



1. Ammonification

the release of ammonium (NH_4^+) from organic matter
performed by decomposers (saprobes): bacteria, fungi
the ammonium can be taken up by plants and assimilated into organic compounds again

$$\text{organic N} \xrightarrow{\text{decomposers}} NH_4^+$$

(urea, proteins, amino acids)

2. Nitrification

conducted by chemosynthetic bacteria (also called chemotrophic bacteria)
the chemosynthetic bacteria use the energy present in ammonium and nitrite to power their synthesis reactions
bacteria in the genus *Nitrosomonas* do the first reaction; bacteria in the genus *Nitrobacter* do the second reaction
plants can take up nitrate, reduce it to ammonium, and assimilate the N into organic compounds

$$NH_4^+ \xrightarrow{\textit{Nitrosomonas}} NO_2^- \xrightarrow{\textit{Nitrobacter}} NO_3^-$$

(ammonium) (nitrite) (nitrate)

3. Nitrogen Fixation

done by symbiotic or free-living N_2-fixing bacteria
the reaction has been found only in bacteria
a single-step reaction, catalyzed by the enzyme nitrogenase
a very-energy intensive reaction; each reaction uses 16 ATP, roughly half the yield from the aerobic respiration of one glucose molecule
nitrogenase is irreversibly inactivated by exposure to O_2; therefore, N-fixing bacteria must have a way

to control or avoid free O_2

$$N_2 \text{ ------------------> } 2\ NH_4^+$$

N_2, nitrogen gas, accounts for almost 80% of the gas in air. Molecular nitrogen (N_2) is chemically inert. This abundant form of nitrogen is biologically unavailable unless bacteria convert it to ammonium.

Symbiotic Nitrogen Fixation:
Probably the most well known symbiotic nitrogen fixation occurs with *Rhizobium* bacteria that live in the roots of legumes (soy, lentils, peanuts, peas, various beans, clover, alfalfa). A specific *Rhizobium* enters the root of a specific legume. A special structure called a nodule forms in the cortex of a root. The bacteria live in the cells of the nodule. Once the nodule is "mature," the bacteria are called bacteroids and they start fixing nitrogen. This symbiosis is a mutualism. The legume provides *Rhizobium* with organic carbon; *Rhizobium* provides the legume with useable N. To maintain an O_2-free environment for nitrogenase activity, both organisms cooperate in the synthesis of an oxygen-binding protein called leghemoglobin. (Nodules often appear pink due to the leghemoglobin.) The plant makes the amino acid chain of the protein and the bacterium makes the heme part.
The nodulation process (Figures 29-9, 29-10):

1. Recognition between legume root and *Rhizobium*
2. *Rhizobium* bacteria attaches to the root hairs; root hairs curl
3. Formation of infection thread
4. *Rhizobium* bacteria enter cells of the cortex and form nodules
5. *Rhizobium* bacteria convert to bacteroids and begin nitrogen fixation via the enzyme nitrogenase
6. Legume provides *Rhizobium* with organic carbon; *Rhizobium* provides legume with useable N
7. Legume provides leghemoglobin to maintain O_2-free environment for nitrogenase
8. *Rhizobium* genes needed for nitrogen fixation are on a plasmid

Free-living N-fixing soil bacteria:
Clostridium (anaerobic bacteria). Some species give the genus a bad name (*C. botulinum*, *C. tetani*), but many species are important as N-fixers.
Azospirillum, *Azotobacter*: often found in the rhizosphere of tropical grasses. Maintain low O_2 levels by their rapid respiration rates.

Cyanobacteria:
Photosynthetic bacteria as well as N-fixing. Nitrogen fixation occurs in special cells called heterocysts. Heterocysts have PSI, but not PSII. So, heterocysts can use light energy to make ATP, but they lack the ability to use light energy to split H_2O and evolve O_2 (photolysis). The cell wall of heterocysts also keeps free O_2 out. So, heterocysts can generate high amounts of ATP in an anaerobic environment. Heterocysts account for 5-10% of cells in a bacterial filament. The rest of the cells (called vegetative cells) have a full set of photosynthesis reactions.

Cyanobacteria can fix N as free-living organisms in soils and aquatic environments, both fresh water and marine. They also fix N in symbiotic relationships with fungi in lichens, in fresh water with *Azolla* (water fern), and with all known cycads (a group of gymnosperms).

- The lichen symbiosis seems to be mutualistic; benefits to both the fungus and cyanobacterium are apparent.
- The symbiosis with *Azolla* could be a mutualism or a commensalism. The plant partner benefits from ready access to ammonium, but the benefit to the cyanobacterium is less clear. (Figure 29-

12)

- In cycads, the cyanobacteria live in specialized roots called coralloid roots, tinting the roots a blue-green color. When a corolloid root is cross-sectioned, a green-ish ring of cyanobacteria is visible. Because of the limited amount of light available to cyanobacteria in roots, the cycads provide fixed carbon and a stable environment to the cyanobacteria in exchange for fixed nitrogen.

4. Denitrification

NO_3^- -----------------> N_2

Denitrifying bacteria use nitrate (NO_3^-)in place of O_2 as the terminal electron receptor in respiration. The nitrate is reduced to nitrogen gas, which is not bioavailable.

5. N assimilation by plants

NO_3^- ---------> NO_2^- ------------> NH_4^+ ------------> organic molecules
↑ ↑
↑ ↑
↑ ↑
soil soil

Plants take up either nitrate or ammonium from the soil solution. If nitrogen is obtained as nitrate, it is converted first to nitrite and then to ammonium by the plant. Ammonium is attached to organic acids to form amino acids (assimilation). Once the nitrogen is in amino acids, further reactions can change these to other N-containing molecules, like chlorophyll, nitrogen bases for DNA and RNA, and alkaloids.

Mycorrhizae = "fungus root"

symbiotic relationship between fungi and roots
generally viewed as a mutualistic relationship
multiple fungal species can inhabit the root system of a single tree; for orchids, a specific fungus is required
mycorrhizae are very common, could be present in as high as 90% of all plants
found in natural and agricultural conditions
Found throughout the Plant Kingdom: seed plants, seedless vascular plants, and non-vascular plants

Endomycorrhizae

fungi live inside the cells of the root cortex

1. Orchids

the fungal partner is usually a basidiomycete (this is the fungal phylum that includes mushrooms, puffballs, and rusts)

orchid seeds are minute; there is no food supply, only an embryo; cannot germinate unless fungus is present to feed the orchid

fungi are saprobes, getting food from dead organic matter; the fungus in the orchid makes

trehalose (a sugar) from the organic matter and feeds the trehalose to the orchid
even after the plant is established, the fungus does not seem to get much in the way of organic material from the plant

some orchids never become photosynthetic; they depend on the fungus to tap into adjacent photosynthetic plants as a source of food for the orchid (mycotrophic)

2. Vesicular Arbuscular Mycorrhizae

the fungal partner is a zygomycete (this phylum includes bread mold); the association seems to be obligate for the fungus

enhance water and mineral uptake in general, phosphate uptake in particular

also seem to provide some protection for the plant from some diseases and other stresses

Ectomycorrhizae

the fungi are ususally basidiomycetes; some ascomycetes (truffles, morels – this is why people look for their fruiting bodies under trees and shrubs)

mostly found on woody plants (hardwoods and conifers) in temperate areas

a single plant can host many fungal species simultaneously

the fungus grows between the cells of the root cortex; the fungus also grows out from the root, branching and extending into soil for mineral collection

the fungi are saprobes/decomposers; they break down leaf litter and pick up released mineral nutrients; some release proteases to mobilize N from decomposing leaf litter

the plant makes specific sugars for the fungus (mannitol, trehalose)

increase the tree's hardiness to cold and dry conditions (winter)

Mycotrophic Plants
dependent on fungi their entire lives
fungi gets sugar from trees and passes them to the plant
examples: some orchids, Indian pipe (*Monotropa uniflora*), snow plant (*Sarcodes sanguinea*)

Parasitic Plants
dodder (*Cuscuta spp.*)

Partially Parasitic Plants
Indian paintbrush (*Castilleja*), mistletoe (*Phoradendron*)

Fairy Rings
basidiomycetes
diameter expands over time
grown into new thatch zones, release N, and the grass greens up behind the advancing rings
for some, the youngest hyphae make the soil water repellent, resulting in a dead zone of grass