Soil Organisms and Soil Ecology

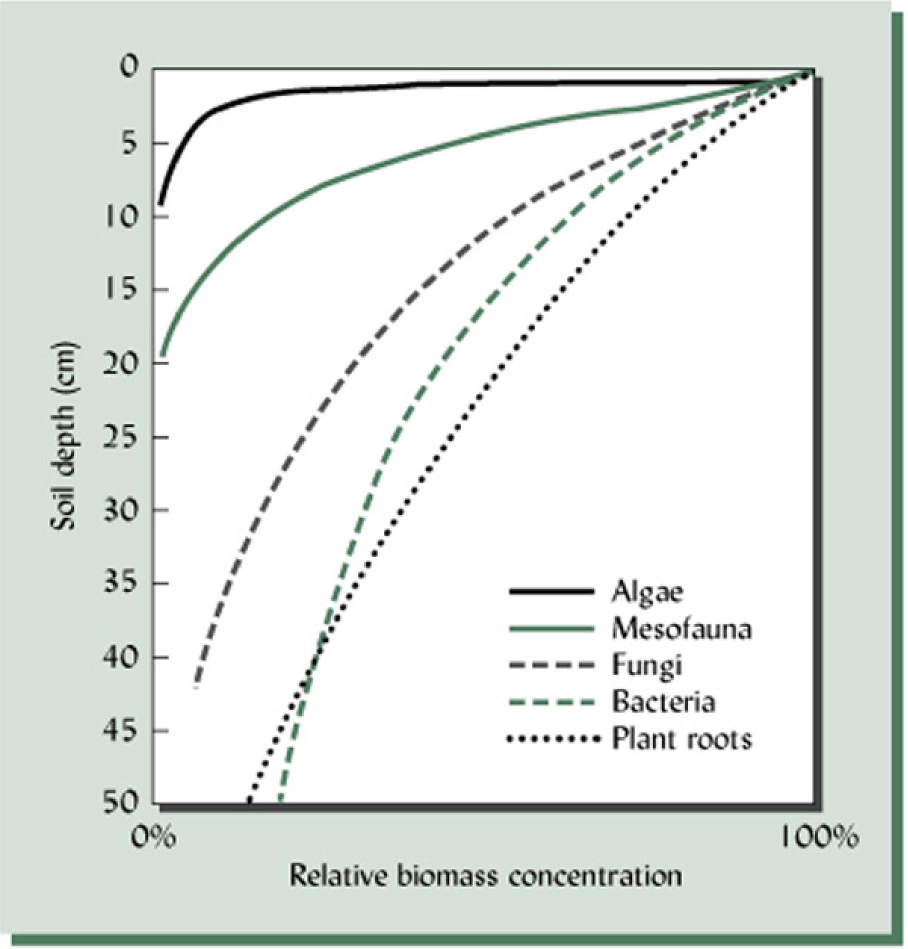


TABLE 11.4 Relative Numbers and Biomass of Fauna and Flora Commonly Found in the Surface 15 cm of Soil[a]

Since metabolic activity is generally related to biomass, microflora and earthworms dominate the life of most soils.

	Number		*Biomass*[b]	
Organisms	*Per* m^2	*Per gram*	*kg/ha*	g/m^2
Microflora				
Bacteria	10^{13}–10^{14}	10^{8}–10^{9}	400–5000	40–500
Actinomycetes	10^{12}–10^{13}	10^{7}–10^{8}	400–5000	40–500
Fungi	10^{10}–10^{11}	10^{5}–10^{6}	1,000–15,000	100–1500
Algae	10^{9}–10^{10}	10^{4}–10^{5}	10–500	1–50
Fauna				
Protozoa	10^{9}–10^{10}	10^{4}–10^{5}	20–200	2–20
Nematodes	10^{6}–10^{7}	10–10^{2}	10–150	1–15
Mites	10^{3}–10^{6}	1–10	5–150	.5–1.5
Collembola	10^{3}–10^{6}	1–10	5–150	.5–1.5
Earthworms	10–10^{3}		100–1500	10–150
Other fauna	10^{2}–10^{4}		10–100	1–10

[a] A greater depth is used for earthworms.
[b] Biomass values are on a liveweight basis. Dry weights are about 20 to 25% of these values.

Based on Size

Macrofauna/flora (>2mm)

Mesofauna (0.1 – 2 mm)

Microfauna/flora (< 0.1 mm)

Based on RNA Sequencing (Phylogeny)

Eukaryotes

Eubacteria

Archaebacteria

Based on Energy Source

Autotrophs

Heterotrophs

Lithotrophs

Methylotrophs

Chemolithotrophs

Based on Trophic Level

Primary Producers

Primary Consumers Herbivores

Secondary Consumers Carnivores

Tertiary Consumers Detritivore

Classification Based on Trophic Level

Based on Size	Based on RNA Sequencing
Macrofauna/flora (>2mm)	Eukaryotes
Mesofauna (0.1 – 2 mm)	Eubacteria
Microfauna/flora (< 0.1 mm)	Archaebacteria

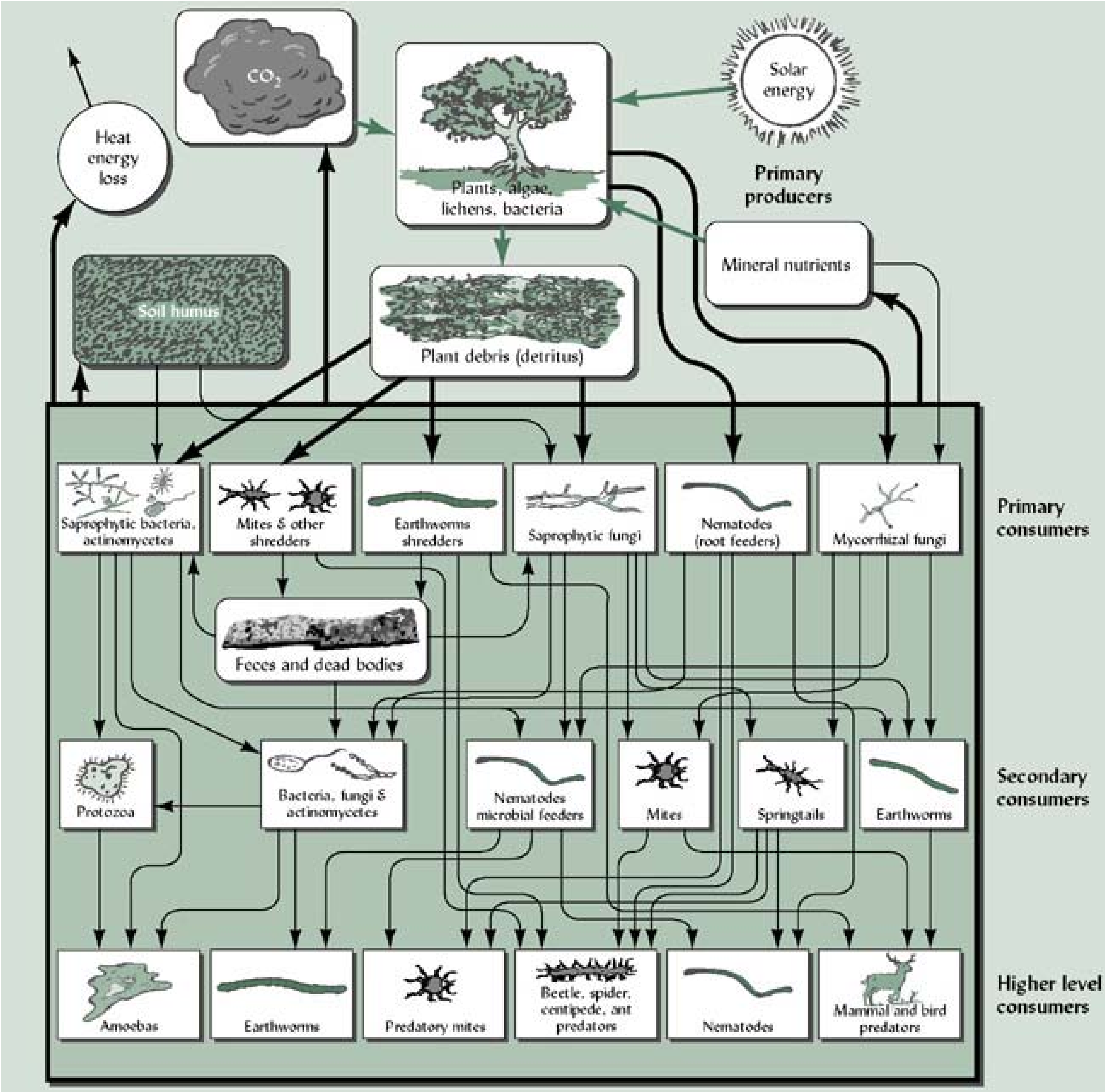
Based on Energy

- Autotrophs
- Heterotrophs
- Lithotrophs
- Methylotrophs
- Chemolithotrophs

Based on Trophic Level

Primary Producers

Primary Consumers	Herbivores
Secondary Consumers	Carnivores
Tertiary Consumers	Detritivore



Organizes are understanding of the system using a very simple ecosystem structure

and

raises questions into form/function, ecosystem dynamics and process oriented relationships in the soil.

Classification Based on Size

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Based on Trophic Level

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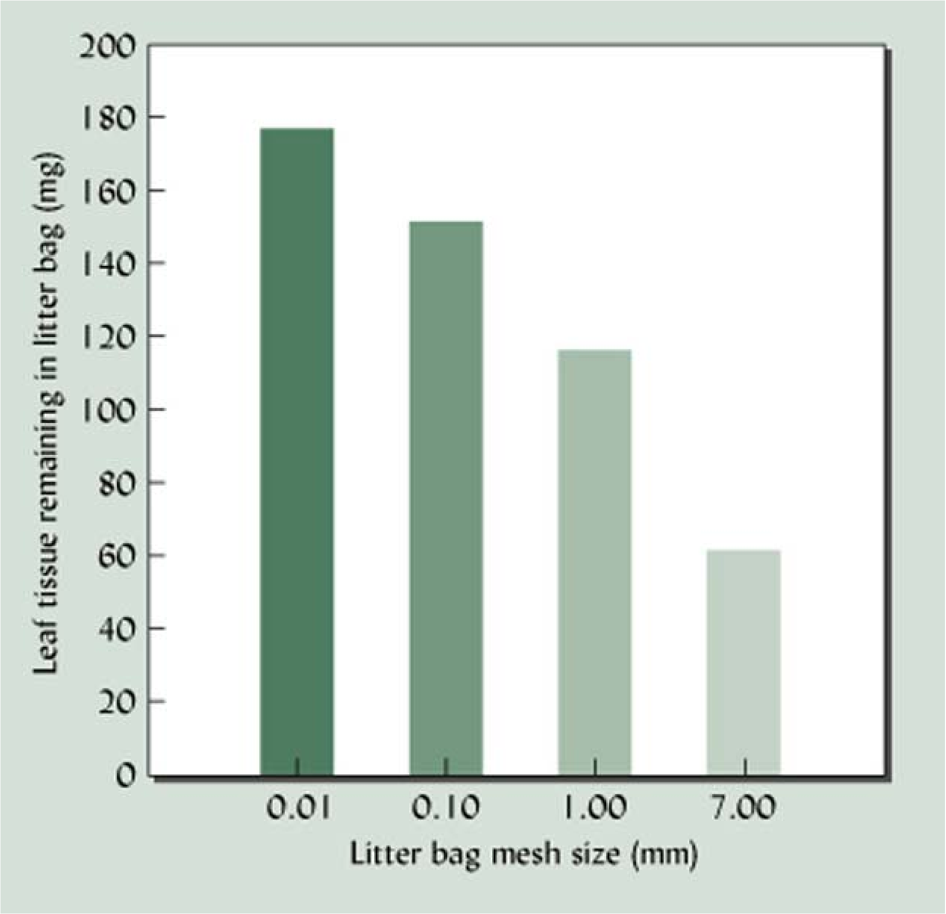
Generalized grouping (width in mm)	*Major specific groups*	*Examples*
Macrofauna (>2mm)		
All heterotrophs, largely herbivores and detritivores	Vertebrates	Gophers, mice, moles
	Arthropods	Ants, beetles and their larvae, centipedes, grubs, maggots, millipedes, spiders, termites, woodlice
	Annelids	Earthworms
	Mollusks	Snails, slugs
Macroflora		
Largely autotrophs	Vascular plants	Feeder roots
	Bryophytes	Mosses
Mesofauna (0.1–2 mm)		
All heterotrophs, largely detritivores	Arthropods	Mites, collembola (springtails)
	Annelids	Enchytraeid (pot) worms
All heterotrophs, largely predators	Arthropods	Mites, protura
Microfauna (<0.1 mm)		
Detritivores, predators, fungivores, bacterivores	Nematodes	Nematodes
	Rotifera[a]	Rotifers
	Protozoa[a]	Amoebae, ciliates, flagellates
Microflora (<0.1 mm)		
Largely autotrophs	Vascular plants	Root hairs
	Algae	Greens, yellow-greens, diatoms
Largely heterotrophs	Fungi	Yeasts, mildews, molds, rusts, mushrooms
	Actinomycetes	Many kinds of actinomycetes
Heterotrophs and autotrophs	Bacteria[b] (and Archaea[b])	Aerobes, anaerobes
	Cyanobacteria	Blue-green algae

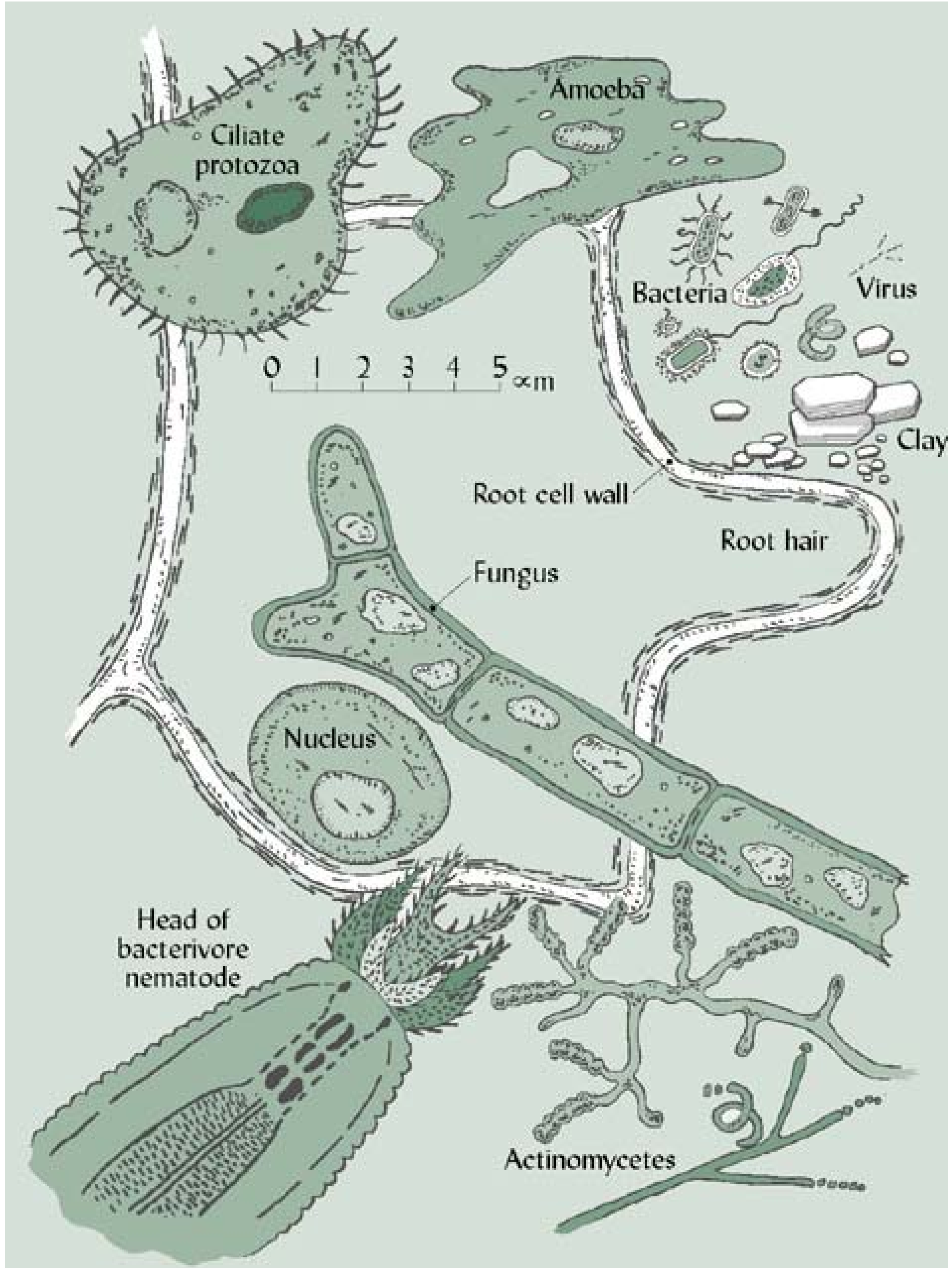
[a] Generally classified in the kingdom *Protista*.

[b] Traditionally classified together in the kingdom *Monera*, these organisms have prokaryotic cells but are classed in the domains Bacteria or Archaea based on differences in RNA.

Size Matters!



Bags started with 558 mg


Ciliate protozoa
Amoeba
Bacteria
Virus
0 1 2 3 4 5 ∝m
Clay
Root cell wall
Root hair
Fungus
Nucleus
Head of bacterivore nematode
Actinomycetes

Classification Based on RNA Sequencing

Based on Size

Macrofauna/flora (>2mm)

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Based on Energy

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Based on Trophic Level

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Eukaryotes

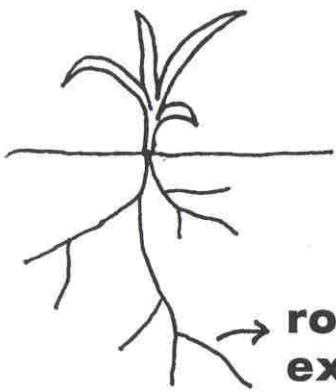
- Plants
- Fungi
- Animals
- Ciliates
- Flagellates
- Slime molds

Non-animals		Animals	
large	Plants (roots)	Gophers, moles, prairie dogs	large
	Algae	Earthworms	
	Fungi	Slugs	
	Mushrooms	Ants, termites	
	Molds	Spiders	
	Yeasts	Mites	
	Slime molds	Nematodes	small
	Cellular		
	Acellular		
small	Protozoa		

EUCARYA

Plants - feed microbes

Rhizosphere - zone of root's influence on soil.



root exudates (organic acids, sugars, etc.)

- exudates stimulate fungi & bacteria

--> 10-100x more microbes than in bulk soil

- root hosts harmless, parasitic and symbiotic organisms

Soil Animals - nematodes, insects, slugs, earthworms, etc.

- heterotrophic, aerobic, mobile, mostly in topsoil and litter, few in compacted or very wet soil.

Protozoa and Algae - active & abundant in wet soil

Algae - single-celled phototrophs

Protozoa - non-photosynthetic, single-celled organotrophs

- mobile, prey on live bacteria, control population

Fungi - active and abundant in normally moist aerated soil.

- organotrophic
- include YEASTS (single-celled, sometimes anaerobic)
- include MOLDS
  - strictly aerobic
  - filamentous mycelia
  - extends cm-->m in soil
- include MUSHROOMS, bracket fungi

Importance of fungi:

--> mycelia promote aggregation
--> associate with plant roots

PATHOGENS, HARMLESS, SYMBIOTIC

--> prominent in most aerobic soils
 ---> decomposers

Archaebacteria

Extreme Halophiles – salt

Methanogens

Extreme Thermophiles

Extreme halophiles

Methanogens - methane producing
strictly anaerobic

autotrophic $CO_2 + 4H_2$ ---> $CH_4 + 2H_2O$

also: formate (HCOOH)
Carbon monoxide (CO)
Methyl substances (contain CH_3)
Acetate (CH_3COOH)

Extremely thermophilic
110°C or higher (limit to life forms?)

Eubacteria (Bacteria)

Some important and interesting kinds of bacteria:

Actinomycetes - a class of bacteria very common in soils. Rod-shaped or filamentous

The Pseudomonads - organotrophic aerobes, neutral pH, mesophiles. Some use over 100 organic compounds

N-fixing bacteria - will convert N_2^o to NH_4^+ but prefer to use NH_4^+ if available

Rhizobia and Bradyrhizobia - legume nodulators

Azotobacter - free living

Spirilla

Azospirillum lipoferum - N-fixing with loose symbiotic relationship with tropical grasses and grain crops.

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Based on Trophic Level

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TABLE 11.5 Metabolic Grouping of Soil Organisms According to Their Source of Metabolic Energy and Their Source of Carbon for Biochemical Synthesis

	Source of energy	
Source of carbon	*Biochemical oxidation*	*Solar radiation*
Combined organic carbon	**Chemoheterotrophs**: All animals, fungi, actinomycetes, and most bacteria Examples: Earthworms *Aspergillus* *Azotobacter* *Pseudomonas*	**Photoheterotrophs**: A few algae
Carbon dioxide	**Chemoautotrophs** Examples: Ammonia oxidizers—*Nitrosomonas* Sulfur oxidizers—*Thiobacillus denitrificans*	**Photoautotrophs**: Algae and cyanobacteria Examples: *Chorella* *Nostoc*

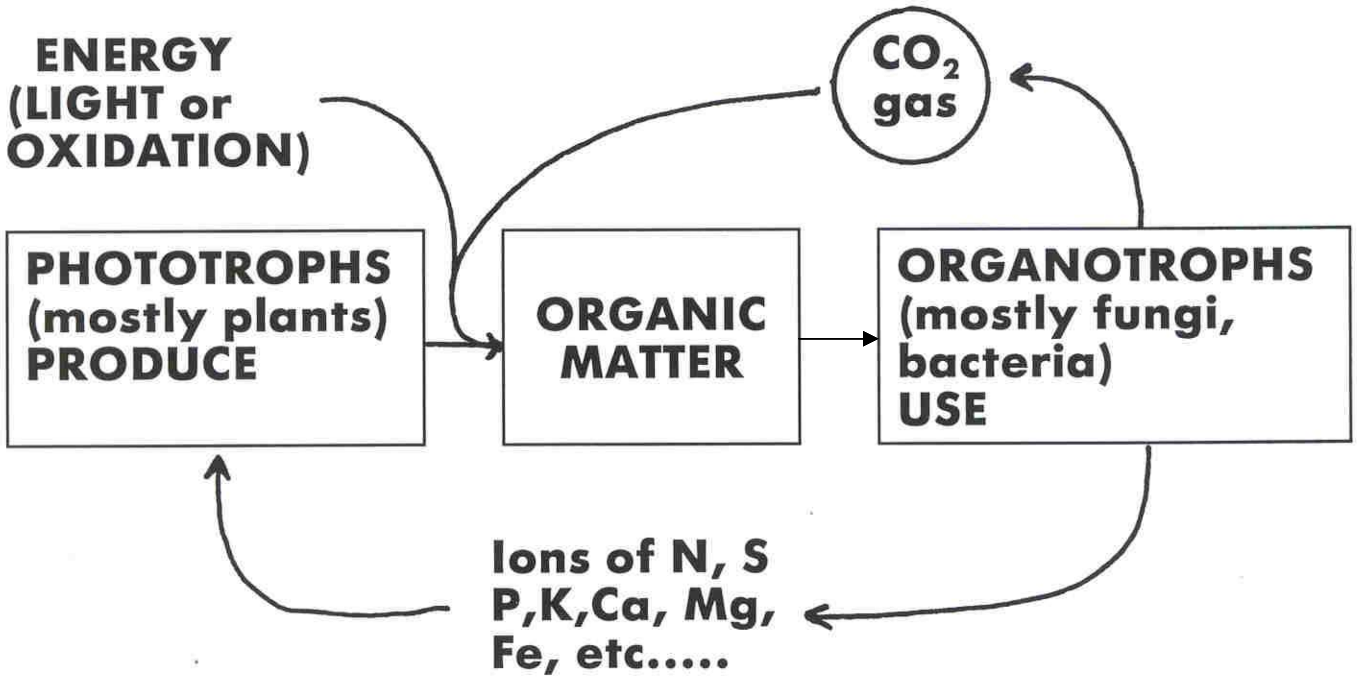
Phototrophs - contain chlorophyl, assimilate CO_2

Organotrophs - feed on organic matter

- **aerobic** - aerobic respiration, produces CO_2
- **anaerobic** - anerobic respiration, fermentation, produces smaller organic molecules

Methylotrophs - oxidize single carbon compounds e.g.
- methane (CH_4)
- methanol (CH_3OH)
- carbon monoxide (CO)

Methanotrophs - oxidize methane (CH_4) cannot use compounds with C-C bonds



$$CO_2 + H_2O \dashrightarrow CH_2O + O_2$$

$$C^{+4} + 4e \dashrightarrow C^{\circ}$$

$$2O^{-2} - 4e \dashrightarrow O_2^{\circ}$$

Classification by oxygen requirements

Aerobes - use only O_2 as electron acceptor in respiration

$$CH_2O + O_2 \text{ ---> } CO_2 + H_2O$$
$$C^o - 4e^- \text{ ---> } C^{+4}$$
$$O_2^o + 4e^- \text{ ---> } 2O^{-2}$$

Anaerobes - cannot use O_2 as electron acceptor, use the next most easily reduced element.

Oxidized form	Reduced form	E_h at which change of form occurs (V)
O_2	H_2O	0.38 to 0.32
NO_3-	N_2	0.28 to 0.22
Mn^{4+}	Mn^{2+}	0.22 to 0.18
Fe^{3+}	Fe^{2+}	0.11 to 0.08
SO_4^{2-}	S^{2-}	-0.14 to -0.17
CO_2	CH_4	-0.2 to -0.28

Facultative anaerobes - use O_2 if available, if not will use other elements

Anaerobic Soils -

Once O_2 is consumed, other substances become reduced.

FAIRLY WET

$$MnO_2 + 4H^+ \text{-----}> Mn^{2+} + H_2O$$

$$Fe(OH)_3 + 3H^+ \text{-----}> Fe^{2+} + 3H_2O$$

$$NO_3^- + nH^+ \text{-----}> N_2, N_2O + H_2O$$

$$SO_4^{-2} + 10H^+ \text{-----}> H_2S + 4H_2O$$

$$CH_3OH + H^+ \text{-----}> CH_4 + H_2O$$

WATER-LOGGED

ORDER OF REDUCTION

DENTRIFICATION -

- reduction of nitrate to gaseous N_2 & N_2O
- causes significant losses of N from agricultural soil
- favored by warm, wet conditions, lots of nitrate and decomposable organic matter.

Soil Flooding - Sequence:

1. Free O_2 drops to ~O (as little as 1/2 day after flooding in warm weather

2. Anaerobic microbes take over ---> fermentation produces organic acids, alcohol, methane

3. Mn^{2+} and Fe^{2+} become important soluble and exchange ions.

4. Zones of Fe reduction appear as pale blue-green or grey (mottling)

5. pH moves toward 7

6. Phosphate becomes more available

Few crops exploit "benefits" of flooding because they are not adapted. (exceptions: rice, ..)

Lithotrophs (use inorganic electron donors)

Nitrogen Oxidizing Bacteria - requires 2 steps

Nitrosomonas $NH_3 + 1\ 1/2\ O_2 \rightarrow NO_2^- + H_2O + H^+$
(nitrosifyer) $N^{-3} - 6e^- \rightarrow N^{+3}$
$1\ 1/2\ O_2 + 6e^- \rightarrow 3O^{-2}$

Nitrobacter $NO_2^- + 1/2\ O_2 \rightarrow NO_3^-$
(nitrofyer) $N^{+3} - 2e^- \rightarrow N^{+5}$
$O^\circ + 2e^- \rightarrow O^{-2}$

Sulfur oxidizing bacteria

H_2S, sulfides, S°, $S_2O_3^{-2}$, SO_3^- are oxidized to SO_4^{-2}

$$S^{-2} - 8e^- \text{ --> } S^{+6}$$
$$S^\circ - 6e^- \text{ --> } S^{+6}$$
$$S^{+2} - 4e^- \text{ --> } S^{+6}$$
$$S^{+5} - 1e^- \text{ --> } S^{+6}$$

$$O^\circ + 2e^- \text{ --> } O^{-2}$$

Hydrogen oxidizing bacteria

facultative lithotrophs, are also organothophic

$$H_2^\circ - 2e \text{ --> } 2H^+$$
$$1/2O_2^\circ + 2e \text{ --> } O^{-2}$$

H_2° is a product of fermentation

interesting -- CO is oxidized by a facultative H_2° oxidizer in soils