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.*

<table>
<thead>
<tr>
<th>Organisms</th>
<th>Number Per m(^2)</th>
<th>Number Per gram</th>
<th>Biomass (^b) kg/ha</th>
<th>Biomass (^b) g/m(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Microflora</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bacteria</td>
<td>(10^{13} - 10^{14})</td>
<td>(10^8 - 10^9)</td>
<td>400-5000</td>
<td>40-500</td>
</tr>
<tr>
<td>Actinomycetes</td>
<td>(10^{12} - 10^{13})</td>
<td>(10^7 - 10^8)</td>
<td>400-5000</td>
<td>40-500</td>
</tr>
<tr>
<td>Fungi</td>
<td>(10^{10} - 10^{11})</td>
<td>(10^5 - 10^6)</td>
<td>1,000-15,000</td>
<td>100-1500</td>
</tr>
<tr>
<td>Algae</td>
<td>(10^9 - 10^{10})</td>
<td>(10^4 - 10^5)</td>
<td>10-500</td>
<td>1-50</td>
</tr>
<tr>
<td><strong>Fauna</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protozoa</td>
<td>(10^9 - 10^{10})</td>
<td>(10^4 - 10^5)</td>
<td>20-200</td>
<td>2-20</td>
</tr>
<tr>
<td>Nematodes</td>
<td>(10^6 - 10^7)</td>
<td>(10 - 10^2)</td>
<td>10-150</td>
<td>1-15</td>
</tr>
<tr>
<td>Mites</td>
<td>(10^3 - 10^6)</td>
<td>1-10</td>
<td>5-150</td>
<td>.5-1.5</td>
</tr>
<tr>
<td>Collembola</td>
<td>(10^3 - 10^6)</td>
<td>1-10</td>
<td>5-150</td>
<td>.5-1.5</td>
</tr>
<tr>
<td>Earthworms</td>
<td>(10 - 10^3)</td>
<td>1-10</td>
<td>100-1500</td>
<td>10-150</td>
</tr>
<tr>
<td>Other fauna</td>
<td>(10^2 - 10^4)</td>
<td></td>
<td>10-100</td>
<td>1-10</td>
</tr>
</tbody>
</table>

\(^a\) 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
Secondary Consumers
Tertiary Consumers
Herbivores
Carnivores
Detritivore
Classification Based on Trophic Level

Based on Size
- Macrofauna/flora (>2mm)
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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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<table>
<thead>
<tr>
<th>Generalized grouping (width in mm)</th>
<th>Major specific groups</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Macrofauna (&gt;2mm)</strong></td>
<td>Vertebrates</td>
<td>Gophers, mice, moles</td>
</tr>
<tr>
<td>all heterotrophs, largely herbivores and detritivores</td>
<td>Arthropods</td>
<td>Ants, beetles and their larvae, centipedes, grubs, maggots, millipedes, spiders, termites, woodlice</td>
</tr>
<tr>
<td></td>
<td>Annelids</td>
<td>Earthworms</td>
</tr>
<tr>
<td></td>
<td>Mollusks</td>
<td>Snails, slugs</td>
</tr>
<tr>
<td><strong>Macroflora</strong></td>
<td>Vascular plants</td>
<td>Feeder roots</td>
</tr>
<tr>
<td>largely autotrophs</td>
<td>Bryophytes</td>
<td>Mosses</td>
</tr>
<tr>
<td><strong>Mesofauna (0.1–2 mm)</strong></td>
<td>Arthropods</td>
<td>Mites, collombola (springtails)</td>
</tr>
<tr>
<td>all heterotrophs, largely detritivores</td>
<td>Annelids</td>
<td>Enchytraeid (pot) worms</td>
</tr>
<tr>
<td>all heterotrophs, largely predators</td>
<td>Arthropods</td>
<td>Mites, protura</td>
</tr>
<tr>
<td><strong>Microfauna (&lt;0.1 mm)</strong></td>
<td>Nematodes</td>
<td>Nematodes</td>
</tr>
<tr>
<td>detritivores, predators, fungivores, bacterivores</td>
<td>Rotifera*</td>
<td>Rotifers</td>
</tr>
<tr>
<td></td>
<td>Protozoa*</td>
<td>Amoebae, ciliates, flagellates</td>
</tr>
<tr>
<td><strong>Microflora (&lt;0.1 mm)</strong></td>
<td>Vascular plants</td>
<td>Root hairs</td>
</tr>
<tr>
<td>largely autotrophs</td>
<td>Algae</td>
<td>Greens, yellow-greens, diatoms</td>
</tr>
<tr>
<td>largely heterotrophs</td>
<td>Fungi</td>
<td>Yeasts, mildews, molds, rusts, mushrooms</td>
</tr>
<tr>
<td>heterotrophs and autotrophs</td>
<td>Actinomycetes</td>
<td>Many kinds of actinomycetes</td>
</tr>
<tr>
<td></td>
<td>Bacteria* (and Archaea*)</td>
<td>Aerobes, anaerobes</td>
</tr>
<tr>
<td></td>
<td>Cyanobacteria</td>
<td>Blue-green algae</td>
</tr>
</tbody>
</table>

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*Generally classified in the kingdom Protista.

*bTraditionally 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
Classification Based on RNA Sequencing

Based on Size
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Eukaryotes
Eubacteria
Archaebacteria
Eukaryotes

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

large
- Plants (roots)
- Algae
- Fungi
  - Mushrooms
  - Molds
  - Yeasts
- Slime molds
  - Cellular
  - Acellular

small
- Protozoa

Animals

large
- Gophers, moles, prairie dogs
- Earthworms
- Slugs
- Ants, termites
- Spiders
- Mites
- Nematodes

small
**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 \[ \text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O} \]

also: formate (HCOOH)
Carbon monoxide (CO)
Methyl substances (contain \text{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 $N_2$ 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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<table>
<thead>
<tr>
<th>Source of carbon</th>
<th>Source of energy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Biochemical oxidation</strong></td>
</tr>
<tr>
<td>Combined organic carbon</td>
<td>Chemoheterotrophs: All animals, fungi, actinomycetes, and most bacteria</td>
</tr>
<tr>
<td></td>
<td>Examples: Earthworms, Aspergillus, Azotobacter, Pseudomonas</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>Chemoautotrophs</td>
</tr>
<tr>
<td></td>
<td>Examples: Ammonia oxidizers—Nitrosomonas, Sulfur oxidizers—Thiobacillus denitrificans</td>
</tr>
</tbody>
</table>
Phototrophs - contain chlorophyll, assimilate CO₂

Organotrophs - feed on organic matter
  - aerobic - aerobic respiration, produces CO₂
  - anaerobic - anaerobic respiration, fermentation, produces smaller organic molecules

Methylotrophs - oxidize single carbon compounds e.g.
  methane (CH₄)
  methanol (CH₃OH)
  carbon monoxide (CO)

Methanotrophs - oxidize methane (CH₄)
cannot use compounds with C-C bonds
ENERGY (LIGHT or OXIDATION)

PHOTOTROPHS (mostly plants) PRODUCE

ORGANIC MATTER

IONS OF N, S, P, K, Ca, Mg, Fe, etc.....

CO_2 + H_2O \rightarrow CH_2O + O_2

C^+4 + 4e \rightarrow C^0

2O^-2 - 4e \rightarrow O_2^0

ORGANOTROPHS (mostly fungi, bacteria) USE

CO_2 GAS
Classification by oxygen requirements

**Aerobes** - use only $O_2$ as electron acceptor in respiration

$$\text{CH}_2\text{O} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$$
$$C^0 - 4e^- \rightarrow C^{+4}$$
$$O_2^0 + 4e^- \rightarrow 2O^{-2}$$

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

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

**Facultative anaerobes** - use $O_2$ if available, if not will use other elements
Anaerobic Soils -

Once $O_2$ is consumed, other substances become reduced.

- $MnO_2 + 4H^+ \rightarrow Mn^{2+} + H_2O$
- $Fe(OH)_3 + 3H^+ \rightarrow Fe^{2+} + 3H_2O$
- $NO_3^- + nH^+ \rightarrow N_2, N_2O + H_2O$
- $SO_4^{2-} + 10H^+ \rightarrow H_2S + 4H_2O$
- $CH_3OH + H^+ \rightarrow CH_4 + H_2O$

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 $\sim O$ (as little as 1/2 day after flooding in warm weather)

2. Anaerobic microbes take over $\rightarrow$ 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: $\text{NH}_3 + 1\ 1/2 \text{O}_2 \rightarrow \text{NO}_2^- + \text{H}_2\text{O} + \text{H}^+$

(nitrosifyer) $\text{N}^-{}^3 - 6\text{e}^- \rightarrow \text{N}^+{}^3$

$1\ 1/2 \text{O}_2 + 6\text{e}^- \rightarrow 3\text{O}^-{}^2$

Nitrosononas $\text{NO}_2^- + 1/2 \text{O}_2 \rightarrow \text{NO}_3^-$

(nitrofyer) $\text{N}^+{}^3 - 2\text{e}^- \rightarrow \text{N}^+{}^5$

$\text{O}^0 + 2\text{e}^- \rightarrow \text{O}^-{}^2$
Sulfur oxidizing bacteria

\[ \text{H}_2\text{S}, \text{sulfides}, S^0, S_2\text{O}_3^{-2}, \text{SO}_3^{-} \]
are oxidized to \( \text{SO}_4^{-2} \)

\[
\begin{align*}
S^{-2} - 8e^- & \rightarrow S^{+6} \\
S^0 - 6e^- & \rightarrow S^{+6} \\
S^{+2} - 4e^- & \rightarrow S^{+6} \\
S^{+5} - 1e^- & \rightarrow S^{+6} \\
\hline
O^0 + 2e^- & \rightarrow O^{-2}
\end{align*}
\]

Hydrogen oxidizing bacteria

facultative lithotrophs, are also
organothrophic

\[
\begin{align*}
\text{H}_2^0 - 2e^- & \rightarrow 2\text{H}^+ \\
1/2\text{O}_2^0 + 2e & \rightarrow \text{O}^{-2}
\end{align*}
\]

\( \text{H}_2^0 \) is a product of fermentation

interesting -- CO is oxidized by a facultative \( \text{H}_2^0 \) oxidizer
in soils