Nutrient Cycling & Soils

tutorial by Paul Rich

Outline

1. Nutrient Cycles
   What are nutrient cycles? major cycles
2. Water Cycle
3. Carbon Cycle
4. Nitrogen Cycle
5. Phosphorus Cycle
6. Sulfur Cycle
7. Soil
   layers/profiles, texture & porosity, acidity
8. Nutrient Cycling & Sustainability

1. Nutrient Cycles

nutrient cycles (= biogeochemical cycles): natural processes that involve the flow of nutrients from the nonliving environment (air, water, soil, rock) to living organisms (biota) & back again.

Nutrient cycles involve one–way flow of high–quality energy from the sun through the environment & recycling of crucial elements.

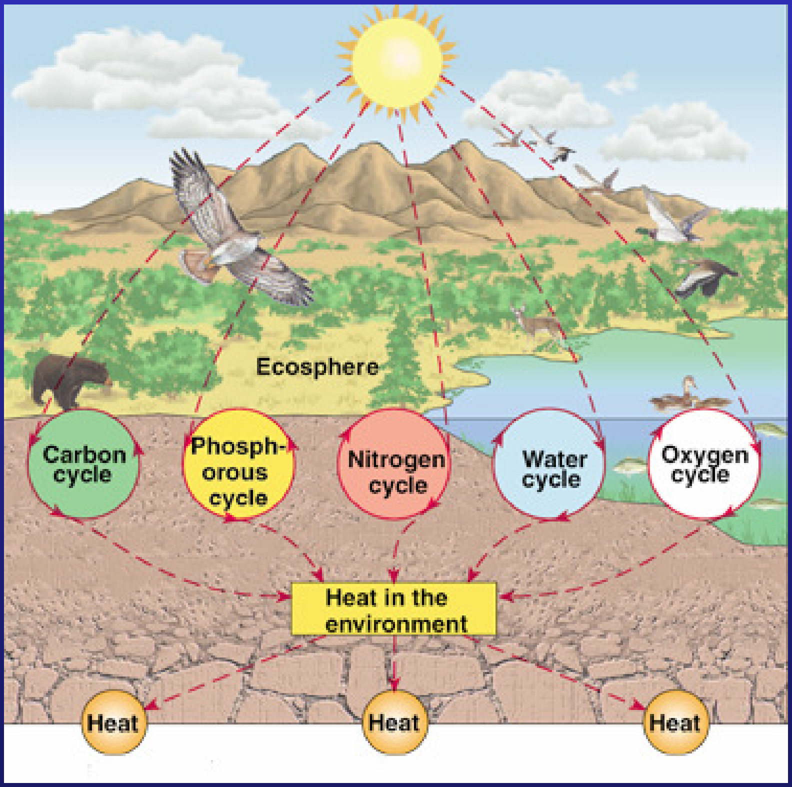

Fig. 4–6

Major Types of Nutrient Cycles

three major types:

- **hydrologic** – involving flows through the hydrosphere, in the form of liquid water, compounds dissolved in water, & sediments carried by water.
- **atmospheric** – involving flows through the atmosphere, as gases or airborne particles (particulates).
- **sedimentary** – involving flows through the lithosphere (Earth's crust = soil & rock), as solid minerals.

Nutrient Storehouses

Major nonliving & living storehouses of elemental nutrients.

Element	Main nonliving storehouse	Main forms in living organisms	Other nonliving storehouse
Carbon (C)	Atmospheric: carbon dioxide (CO_2)	Carbohydrates $(CH_2O)_n$ and all other organic molecules	Hydrologic: dissolved carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) Sedimentary: carbon containing minerals in rocks
Nitrogen (N)	Atmospheric: nitrogen gas (N_2)	Proteins and other nitrogen-containing organic molecules	Hydrologic: dissolved ammonium (NH_4^+), nitrate (NO_3^-), and nitrate (NO_2^-) in water and soils
Phosphorus (P)	Sedimentary: phosphate (PO_4^{3-}) containing minerals in rocks	DNA, other nucleic acids (e.g, ATP), and phospholipids	Hydrologic: dissolved phosphate (PO_4^{3-})
Sulfur (S)	Sedimentary: rocks (e.g., iron disulfide and pyrite) and minerals (e.g., sulfate [SO_4^{2-}])	Sulfur-containing amino acids in most proteins, some vitamins	Atmospheric: hydrogen sulfide (HgS), sulfur dioxide (SO_2), sulfur trioxide (SO_3), and sulfuric acid (H_2SO_4) Hydrologic: sulfate (SO_4^{2-}) and sulfuric acid (H_2SO_4)

Fig. 5–3

2. Water Cycle

Role of Water?

- terrestrial ecosystems – major factor determining distribution of organisms;
- aquatic ecosystems – literally matrix that surrounds & serves as environment of aquatic organisms;
- flows of water are major means material & energy transport;
- water is critical for human activities – agriculture, industry, & municipal use.

Water is the driver of nature.
— Leonardo da Vinci

Water Cycle

How is Water Cycled?

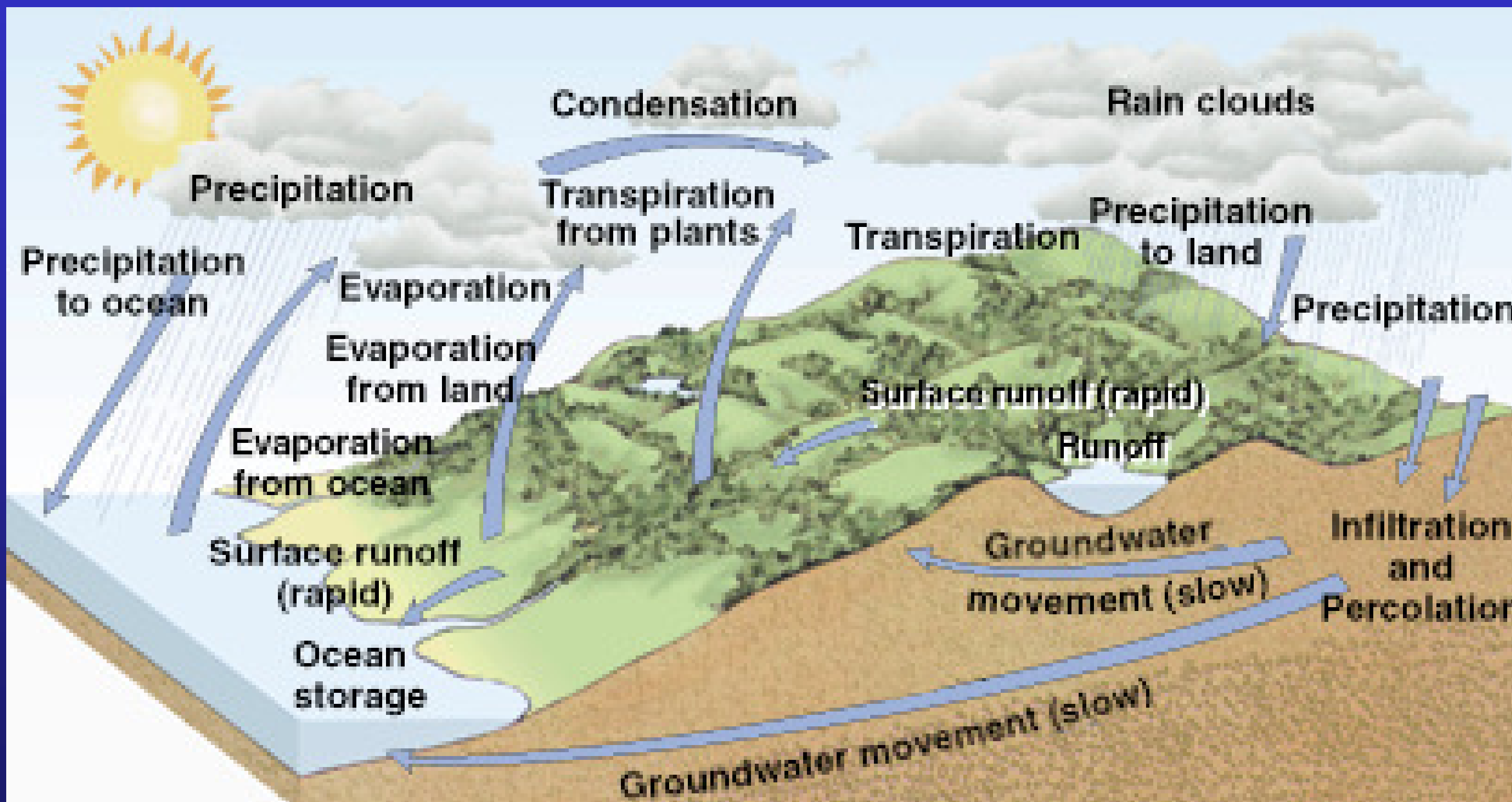

Fig. 5–4

Water Cycle

main processes:

- **evaporation:** conversion from liquid to vapor form (surface to atmosphere).
- **transpiration:** evaporation from leaves of water extracted from soil by roots & transported through the plant (surface to atmosphere).
- **movement in atmosphere:** transport as vapor.
- **condensation:** conversion of vapor to liquid droplets.
- **precipitation:** movement as rain, sleet, hail, & snow (atmosphere to surface).
- **infiltration:** movement into soil.
- **percolation:** downward flow through soil to aquifers.
- **flow in aquifers:** belowground flow of water.
- **runoff:** surface flow downslope to ocean.

Water Cycle

Human Influences?

- withdraw large quantities of fresh water – water diversion, groundwater depletion, wetland drainage (see Chapter 13);
- clear vegetation – increase runoff, decrease infiltration & groundwater recharge, increase flooding & soil erosion;
- modify water quality – add nutrients (P, N…) & pollutants (see Chapter 20).

3. Carbon Cycle

Role of Carbon?

- building block of organic molecules (carbohydrates, fats, proteins, & nucleic acid) – essential to life;
- currency of energy exchange – chemical energy for life stored as bonds in organic compounds;
- carbon dioxide (CO_2) greenhouse gas – traps heat near Earth's surface & plays a key role as "nature's thermostat".

Carbon Cycle

How is Carbon Cycled?

Carbon cycling between the atmosphere & terrestrial ecosystems.

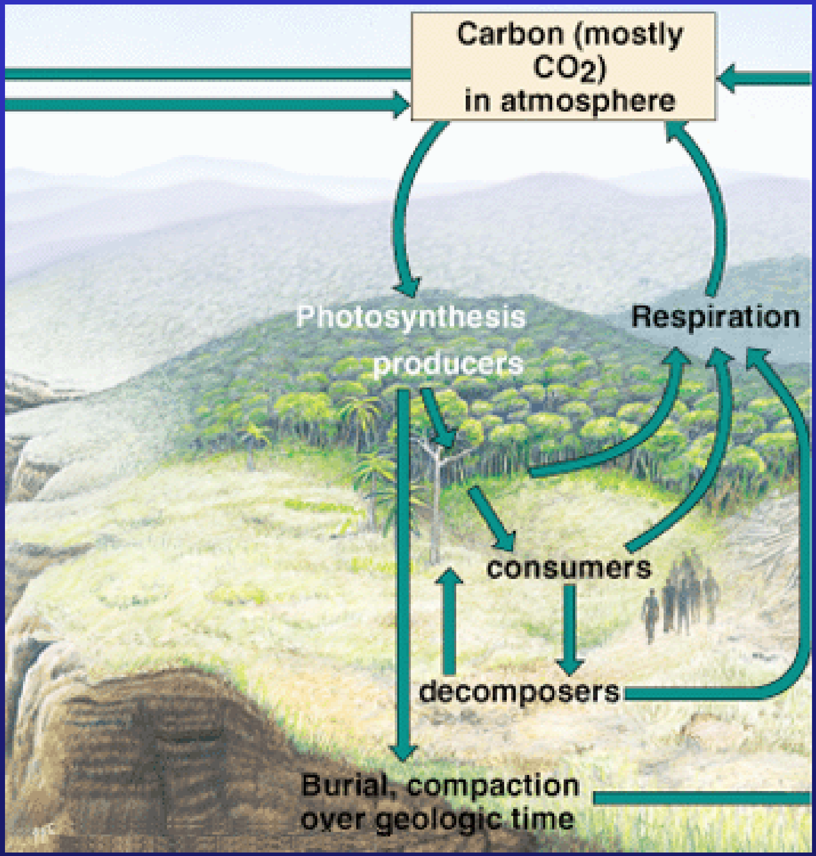

Fig. 5–5

Carbon Cycle

Humans now play a major role in the carbon cycle through burning of fossil fuels. Natural inputs include volcanoes & wildfires.

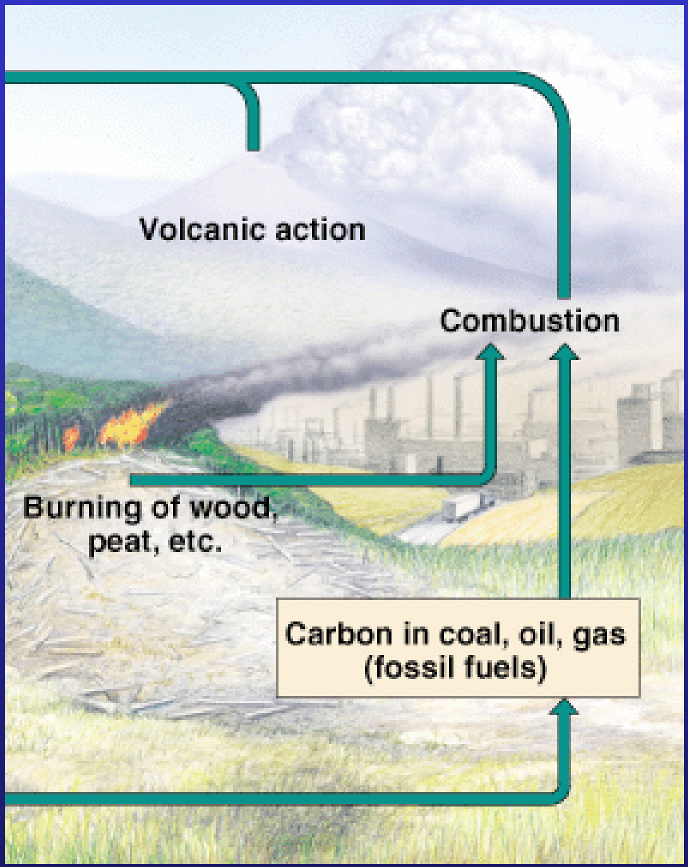

Fig. 5–5

Carbon Cycle

The oceans play a major role in the carbon cycle. Large amounts of carbon are buried in sediments in the form of calcium carbonate ($CaCO_3$)

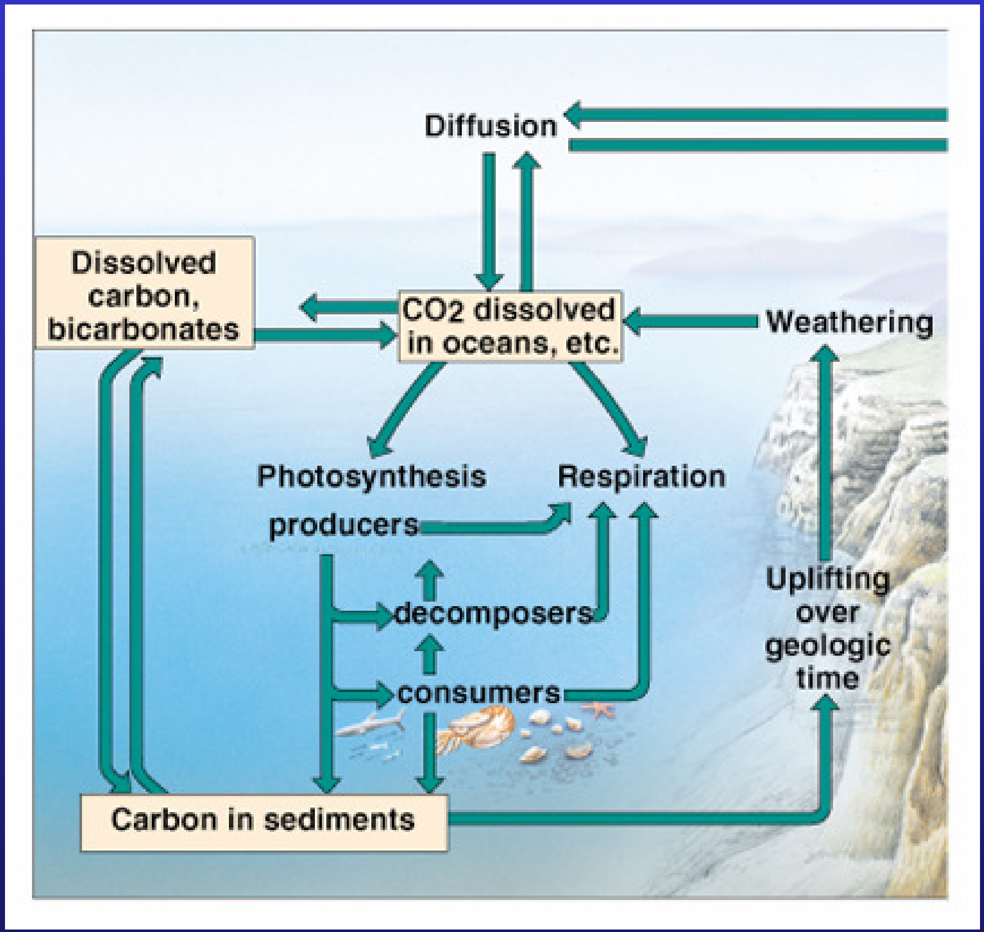

Fig. 5–5

Carbon Cycle

main processes:

- **movement in atmosphere:** atmospheric C as CO_2 (0.036% of troposphere);
- **primary production:** photosynthesis (= carbon fixation) moves C from atmosphere to organic molecules in organisms;
- **movement through food web:** C movement in organic form from organism to organism;
- **aerobic respiration:** organic molecules broken down to release CO_2 back to atmosphere;
- **combustion:** organic molecules broken by burning down to release CO_2 back to atmosphere;
- **dissolving in oceans:** C enters as to form carbonate (CO_3^{2-}) & bicarbonate (HCO_3^-);
- **movement to sediments:** C enters sediments, primarily as calcium carbonate ($CaCO_3$);

Carbon Cycle

Human Influences?

- removal of vegetation – decreases primary production (decreases carbon fixation);
- burning fossil fuels & biomass (wood) – increase movement of carbon into the atmosphere;
- the resulting increased concentration of atmospheric CO_2 is believed to be sufficient to modify world climate through global warming (see Chapter 19).

4. Nitrogen Cycle

Role of Nitrogen?

- **building block of various essential organic molecules** – especially proteins & nucleic acids;
- **limiting nutrient in many ecosystems** – typically, addition of N leads to increased productivity.

Nitrogen Cycle

How is Nitrogen Cycled?

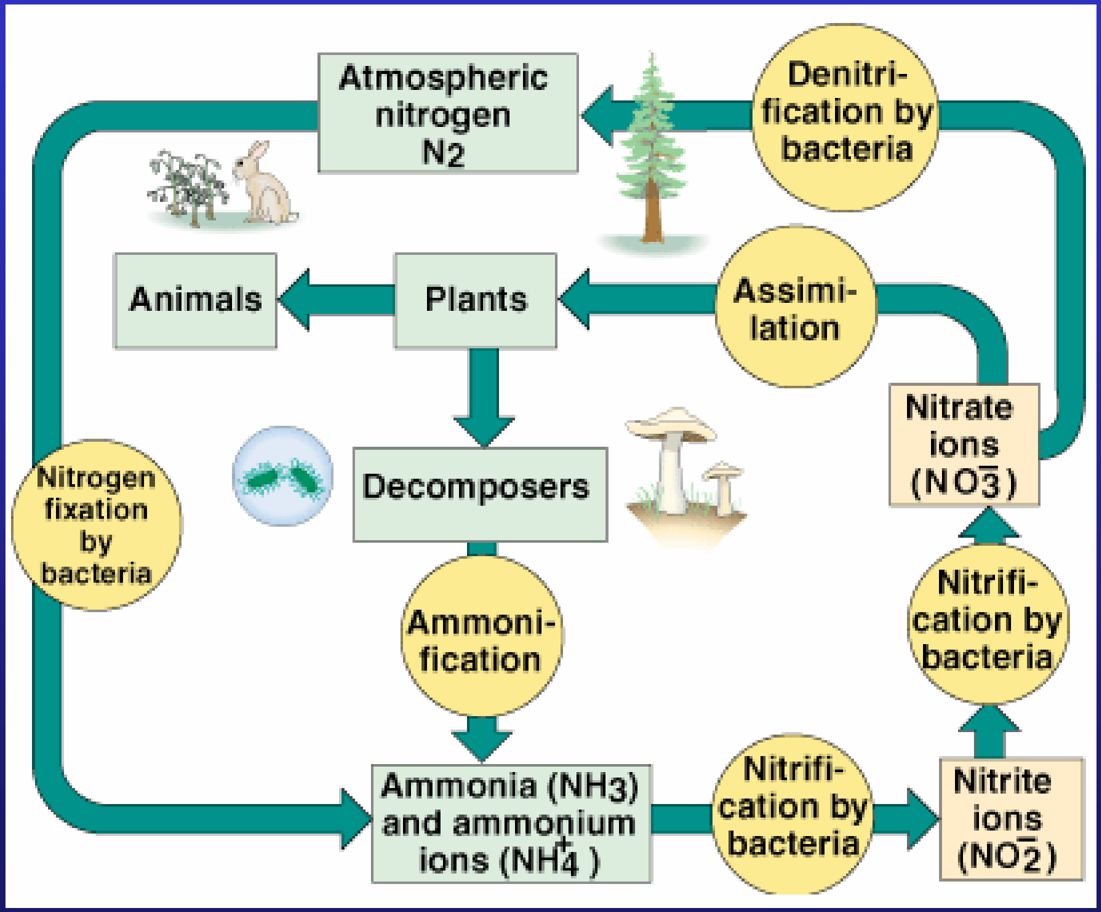

Fig. 5–6

Nitrogen Cycle

main processes:

- **nitrogen fixation**: conversion of N_2 (nitrogen gas) to NH_4^+ (ammonium), atmospheric by lightning, biological by bacteria & blue-green algae (anaerobic), e.g., Rhizobium in legumes;
- **nitrification**: conversion of NH_4^+ to NO_3^- (nitrite) to NO_3^- (nitrate) by microbes;
- **uptake** by plants, forms proteins and other N containing organic compounds, enters food chain;
- **ammonification**: returned to NH_4^+ inorganic forms by saprophytes and decomposers;
- **denitrification**: conversion of NH_4^+ to N_2 by combustion or microbes.

Nitrogen Cycle

Human Influences?

- emit nitric oxide (NO), which leads to acid rain – huge quantities of nitric oxide emitted; contributes to photochemical smog; forms nitrogen dioxide (NO_2) in atmosphere, which can react with water to form nitric acid (HNO_3) & cause acid deposition ("acid rain") (see Chapter 18);
- emit nitrous oxide into the atmosphere – nitrous oxide (N_2O) is a potent greenhouse gas & also depletes ozone in stratosphere (see Chapter 19);

Nitrogen Cycle

Human Influences? (continued)

- mine nitrogen–containing fertilizers, deplete nitrogen from croplands, & leach nitrate from soil by irrigation – leads to modification of nitrogen distribution in soils;
- remove N from soil by burning grasslands & cutting forest – leads to decreased N in soils;
- add excess N to aquatic systems – runoff of nitrates & other soluble N–containing compounds stimulates algal blooms, depletes oxygen, & decreases biodiversity;
- add excess N to terrestrial systems – atmospheric deposition increases growth of some species (especially weeds) & can decrease biodiversity;

5. Phosphorus Cycle

Role of Phosphorus?

- **essential nutrient for plants & animals** – especially building block for DNA, other nucleic acids (including ATP; ATP stores chemical energy), various fats in cell membranes (phospholipids), & hard calcium–phosphate compounds (in bones, teeth, & shells);
- **limiting nutrient in many ecosystems** – typically, addition of P leads to increased productivity, especially for fresh water aquatic systems.

Phosphorus Cycle

How is Phosphorus Cycled?

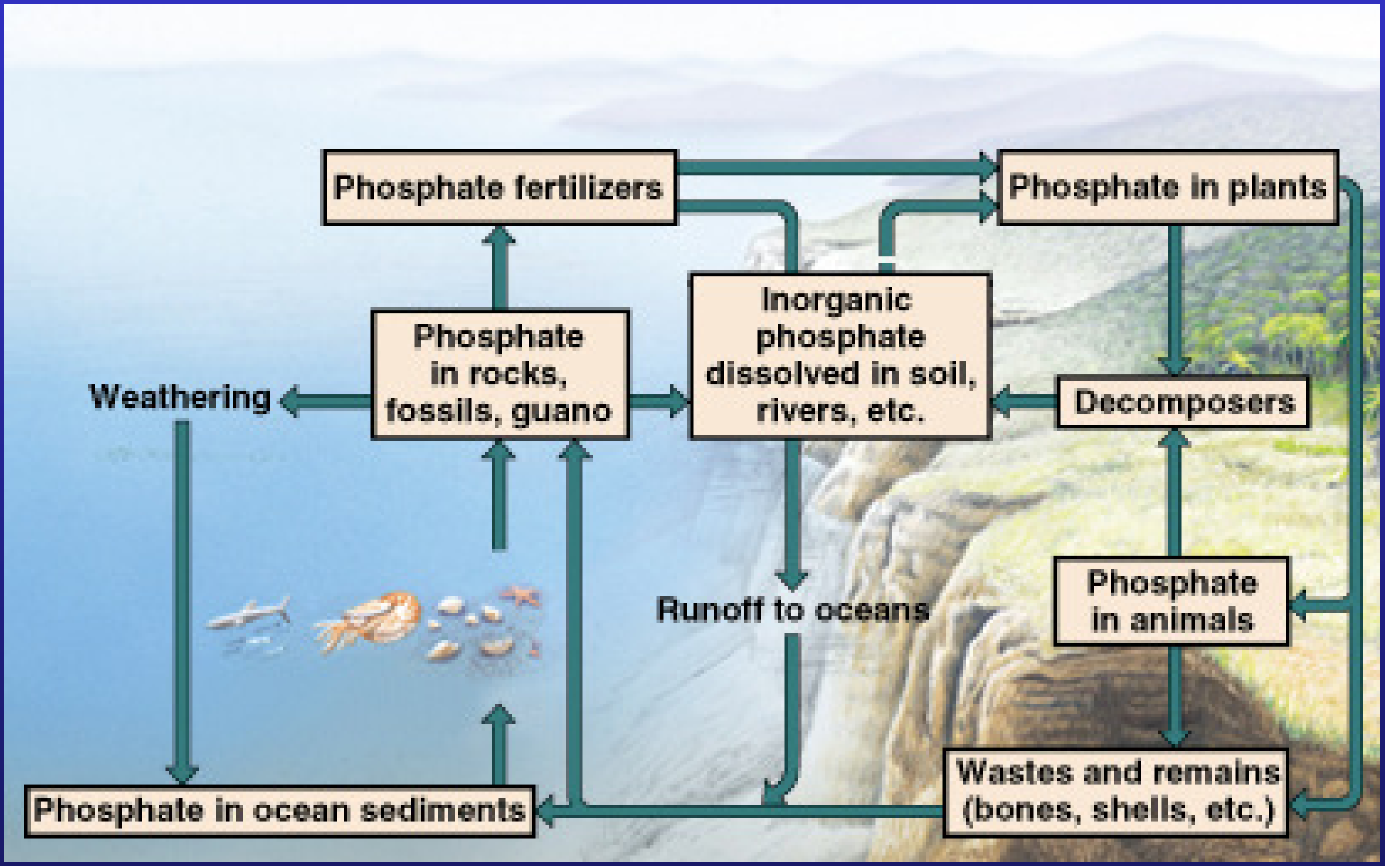

Fig. 5–8

Phosphorus Cycle

main processes:

- **weathering:** P slowly released from rock or soil minerals as phosphate ($P0_4^{3-}$), which dissolves in H_20 & is readily leached;
- **uptake:** by plants to form organic phosphates;
- **movement through food web:** nucleic acids (including DNA & ATP), certain fats in cell membranes (phospholipids), bones/teeth/shells (calcium–phosphate);
- **break down of organic forms:** to phosphate ($P0_4^{3-}$) by decomposers;
- **leaching:** $P0_4^{3-}$ from soil;
- **burial in ocean sediments:** not cycled in short time scale, only over geologic time;

Phosphorus Cycle

Human Influences?

- **mine large quantities of phosphate rock** – used for organic fertilizers & detergents; can cause local effects from mining & releases more P into environment;
- **sharply decrease P available in tropical forests & other ecosystems where P is limiting** – deforestation & certain agricultural practices decrease available P;
- **add excess P to aquatic ecosystems** – leads to excessive algal growth, depletion of oxygen, & decrease in biodiversity; such eutrophication ("over nourishment") is discussed in Chapter 20.

6. Sulfur Cycle

Role of Sulfur?

- **component of some proteins & vitamins** – essential for organisms;
- **limiting nutrient in some ecosystems**.

Sulfur Cycle

Biotic flows of sulfur through ecosystems.

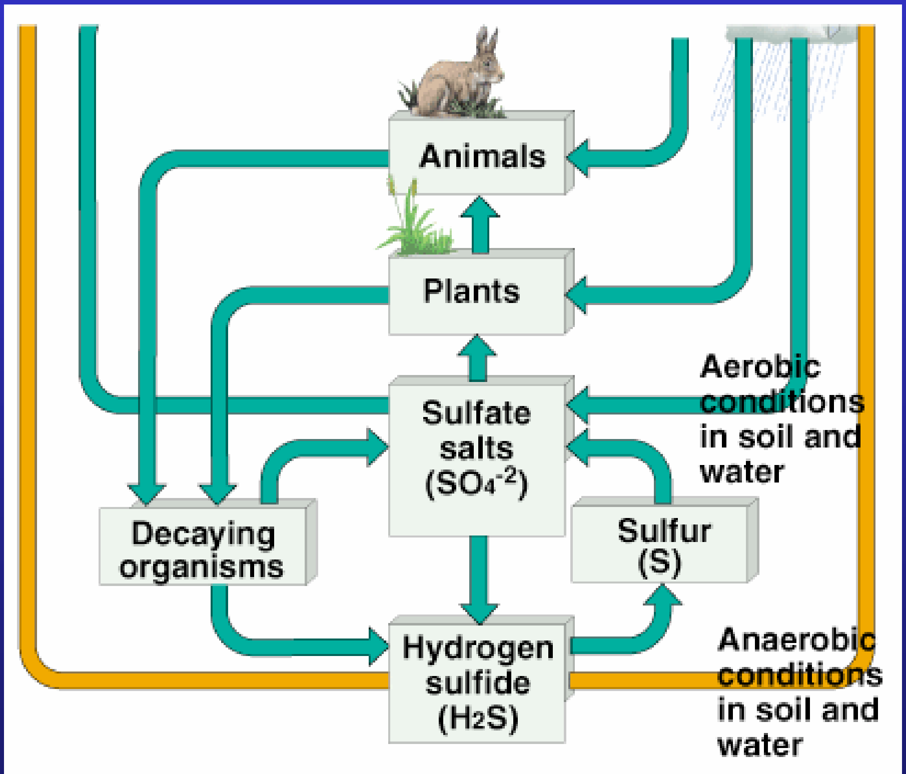

Fig. 5–9

Sulfur Cycle

Abiotic flows of sulfur through ecosystems.

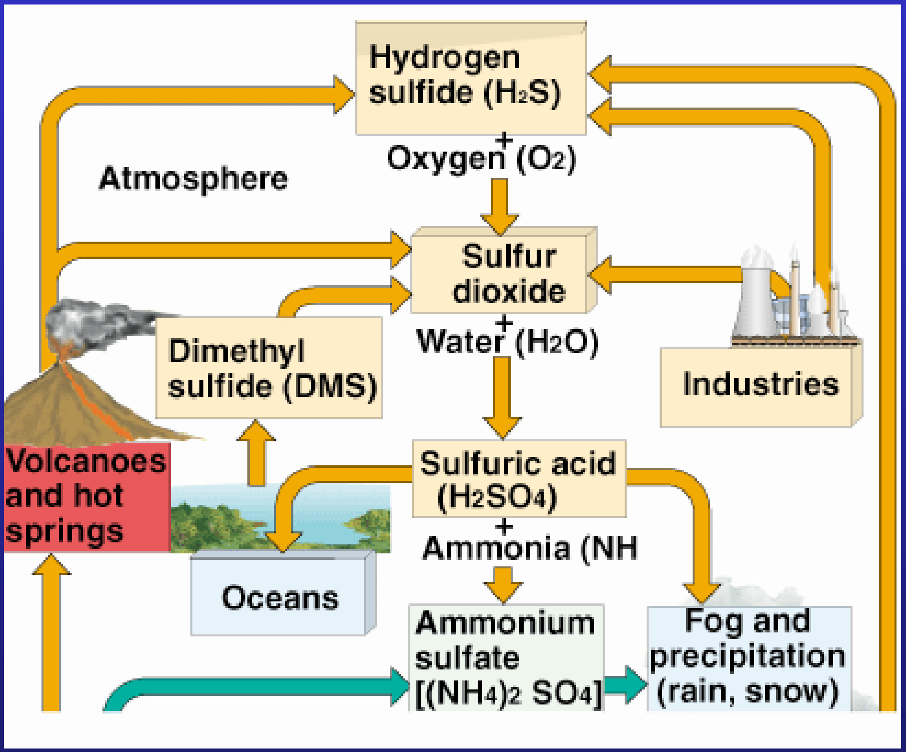

Fig. 5–9

Sulfur Cycle

main processes:

- **storage in rocks:** much of Earth's S is in rock form (e.g., iron disulfides or pyrites) or minerals (sulfates);
- **atmospheric input from volcanoes, anaerobic decay, & sea spray:** S enters atmosphere in form of hydrogen sulfide (HS) & sulfur dioxide (SO_2), & sulfates (SO_4^{2-});
- **combustion:** sulfur compounds released to the atmosphere by oil refining, burning of fossil fuels, smelting, & various industrial activities;
- **movement through food web:** movement through food web & eventual release during decay;

Sulfur Cycle

Human Influences?

contribute about one–third of atmospheric sulfur emissions:

- burning S–containing oil & coal;
- refining petroleum;
- smelting;
- other industrial processes.

7. Soils

soil: complex mixture of inorganic material (clay, silt, & sand), decaying organic matter, air, water, & living organisms;

- rich in biological life, including bacteria, fungi, & invertebrates;
- complex ecosystem;
- develop & mature slowly — can take 200 to 1,00 years to develop 2.5 cm (1 inch) or topsoil (A horizon);
- well developed soils display distinct horizons, or soil profiles.

Rock Cycle

The rock cycle involves transformations of rock over millions of years. The phosphorus cycle is part of the rock cycle.

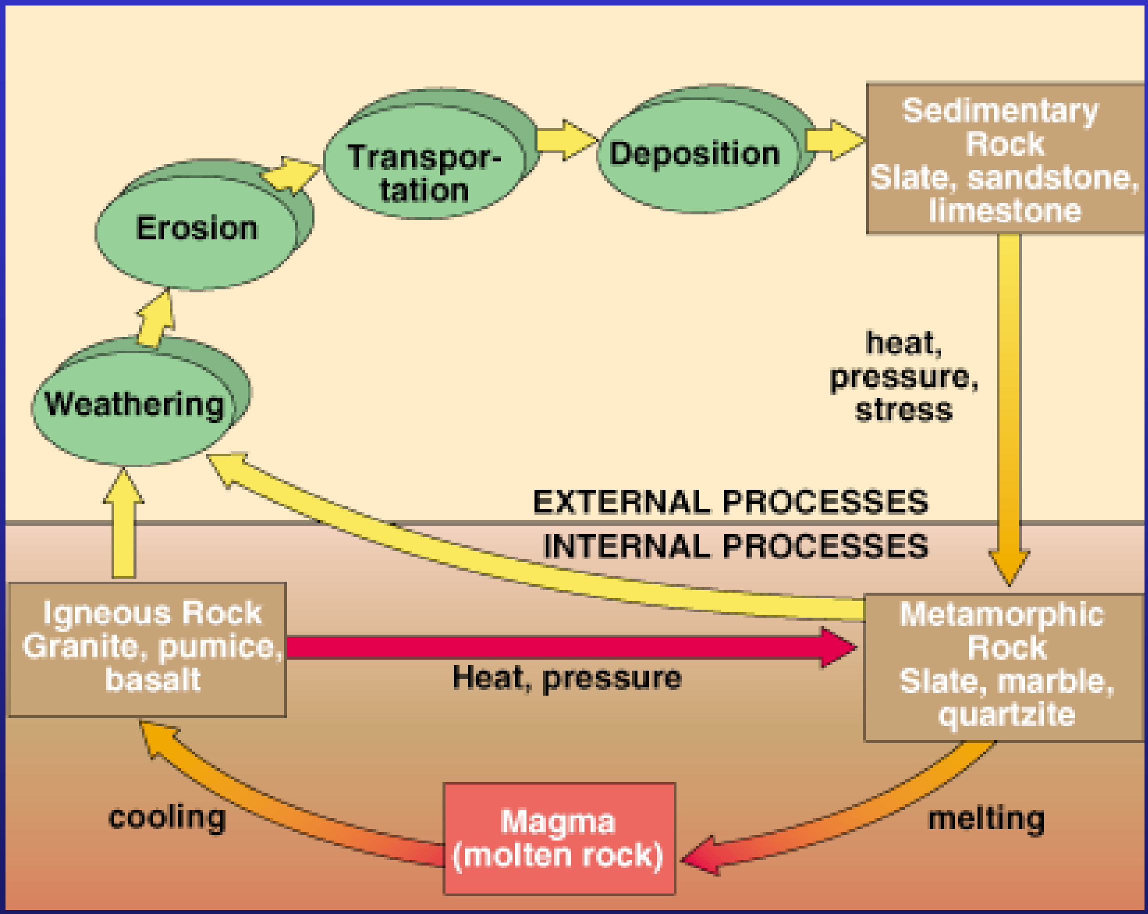

Fig. 5–10

Soil Profiles

Horizons, or layers, vary in number & composition, depending upon soil type.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

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Soil Profiles

Soils from different biomes display different profiles.

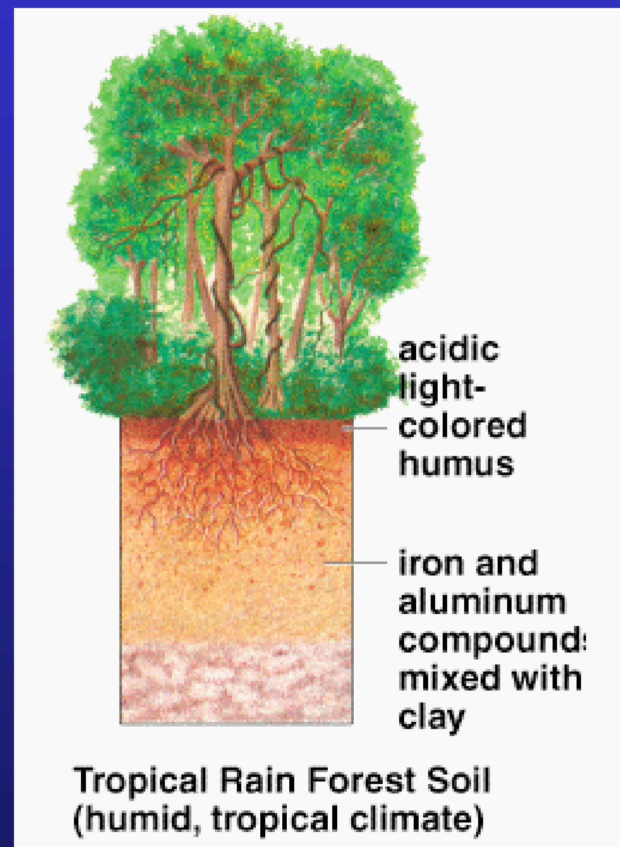
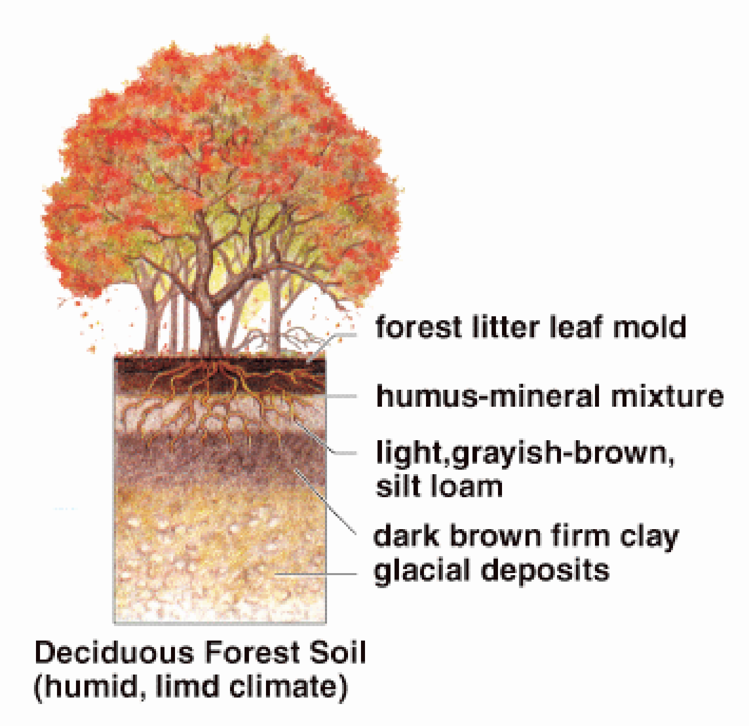


Fig. 5–16 a & b

Soil Profiles

More examples of soils from different biomes.



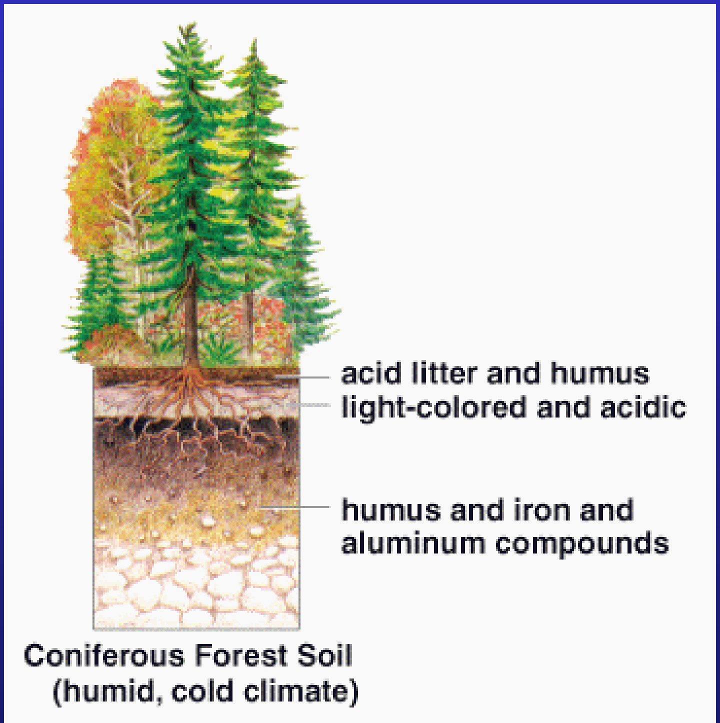


Fig. 5–16 c & d

Soil Texture

Soil texture is determined by the particular mix of clay, silt, & sand.

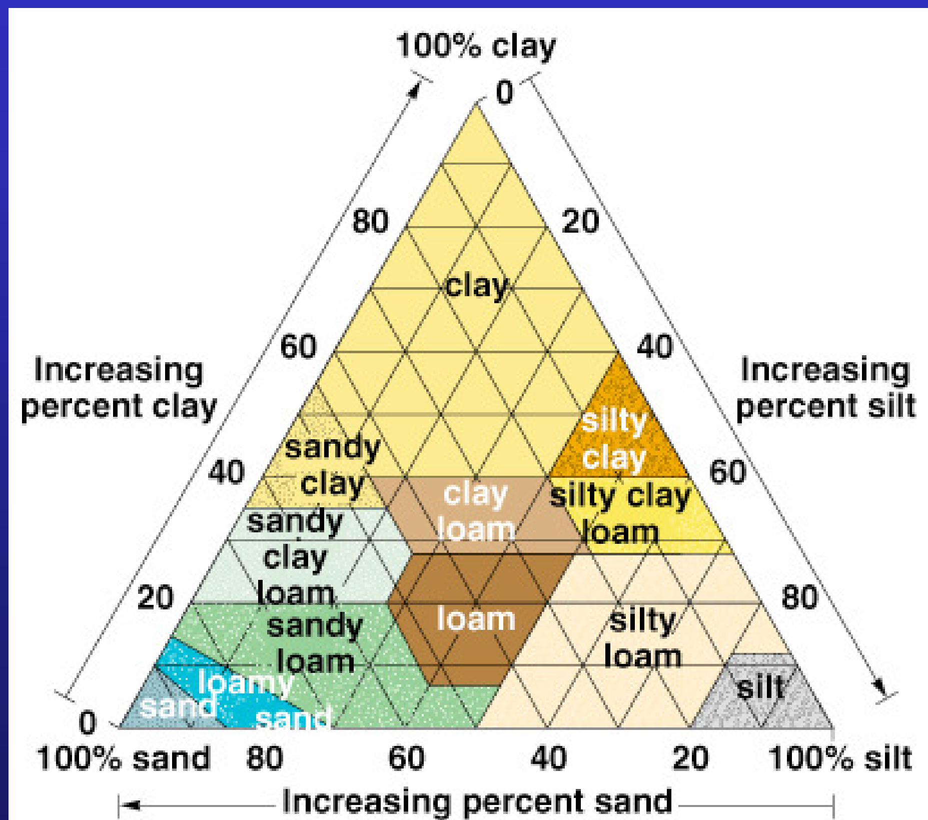


Fig. 5–17

Soil pH

The pH scale is used to measure acidity & alkalinity of water solutions. pH is an important soil property.

See Fig. 5–18

Soil Food Webs

Soil food webs are complex. The figure below shows a simplified soil food web.

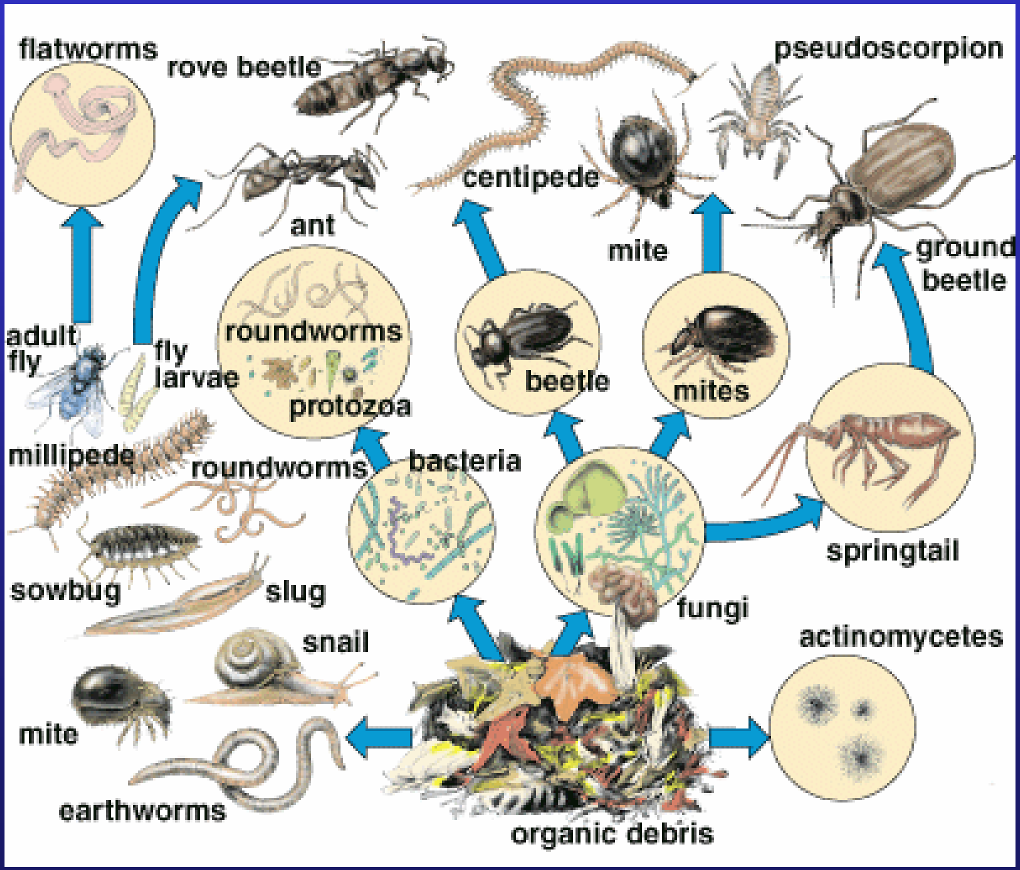


Fig. 5–14

Soil Nutrient Cycling

Pathways of nutrients in soils. Nitrogen (N), phosphorus (P), & potassium (K) are among the major nutrients.

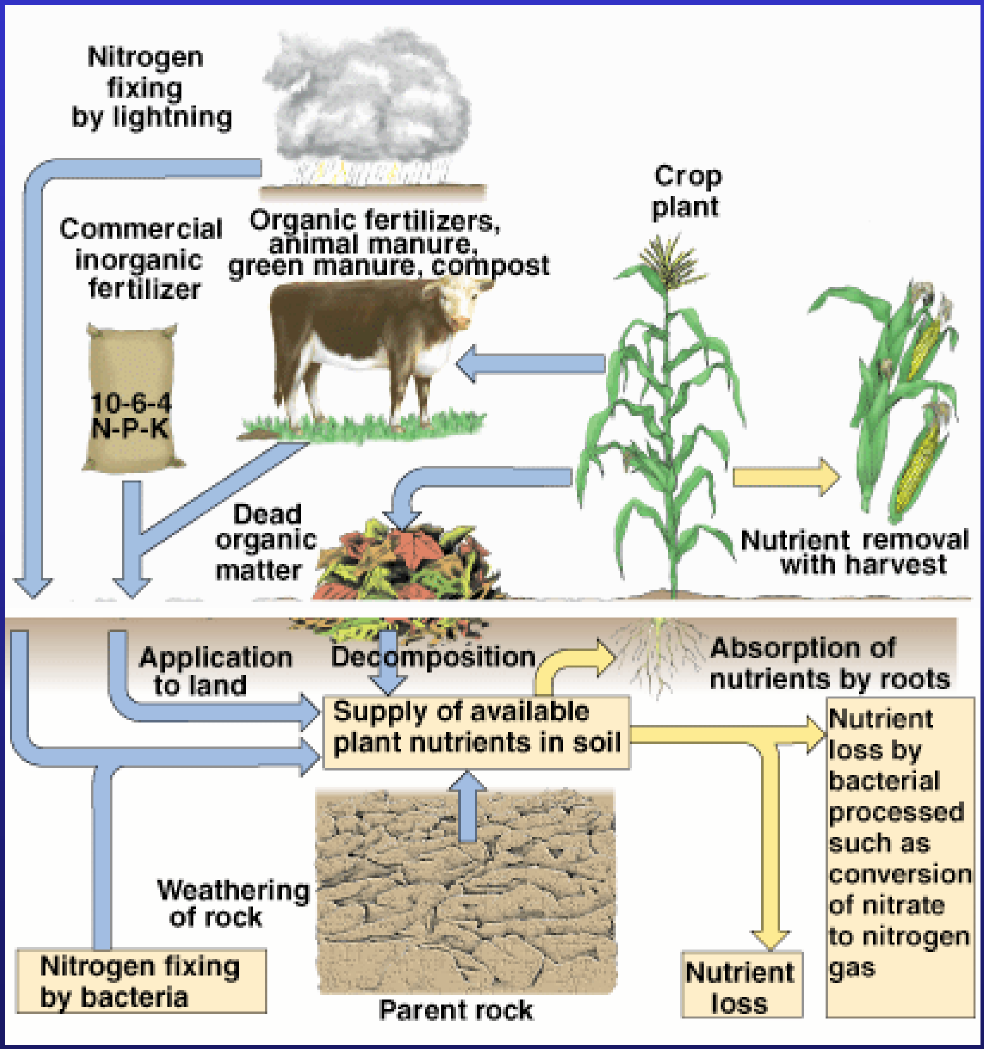


Fig. 5–15

8. Nutrient Cycling & Sustainability

Are ecosystems self–contained?

- immature natural ecosystems tend to have major shifts in energy flow & nutrient cycling;
- over time ecosystems tend to reach an equilibrium with respect to energy flow & nutrient cycling, such that these ecosystems appear self–contained;
- however, there is considerable exchange of water & nutrients of ecosystems with adjacent ecosystems;
- human disturbance (clear cutting, clearing, etc.) can cause major loss of nutrients.

Nutrient Cycling & Sustainability

How does nutrient cycling relate to ecosystem sustainability?

- the law of conservation of matter enables us to understand major nutrient cycles, and observe that given time natural ecosystems tend to come into a balance wherein nutrients are recycled with relative efficiency;
- modification of major nutrient cycles may lead to shift in ecosystems, such that current ecosystems are not sustainable;
- developing a better understanding of energy flow & nutrient cycling is critical to understanding the depth of environmental problems.

All things come from earth, and to earth they all return.
— Menander (342–290 B.C.)