Ch. 5 - Nutrient Cycles and Soils

Matter Cycling in Ecosystems

What are Nutrient (biogeochemical) Cycles?

Processes by which nutrients are recycled between living organisms and the nonliving environment.

The three general types of nutrient cycles:

Hydrologic Cycle – the Water Cycle; Water is recycled through nature driven by the Sun's energy and gravity. The major steps include evaporation, precipitation, condensation, runoff, permeation, infiltration, transpiration.

Atmospheric Cycle – A large portion of the element exists in a gaseous form (N_2, CO_2); These cycles operate, locally, regionally and globally.

Sedimentary Cycle – The element does not have a gaseous form or gaseous compounds making up a significant portion of its supply.

The Water Cycle

Role of Water - terrestrial: major factor that determines types of organisms that can live there: rain forests and deserts.

Aquatic ecosystems: water flow influences temperature, salinity, and availability of nutrients.

How is water cycled in the Ecosphere?

Driven by the Sun's energy and gravity

evaporation – conversion of water into water vapor

transpiration – evaporation from leaves of plants

condensation – conversion of water vapor into liquid water droplets

precipitation – rain, sleet, hail, snow

infiltration – movement of water into the soil

percolation – downward flow of water through the soil and permeable rock formations to groundwater storage areas call aquifers.

Runoff – downslope surface movement of water back to the sea.

Humidity - the amount of water in the air - depends on the temperature of the air.

Absolute humidity (g/kg) – amount of water vapor in a certain mass of air.

Relative humidity (%) – amount of water vapor in a certain mass of air expressed as a percentage of the maximum amount it can hold.

Precipitation - requires the presence of condensation nuclei (volcanic ash, smoke, sea salts, any particulate matter)

Dew Point - the temperature at which condensation will occur; i.e., the temperature at which the air would be saturated.

Aquifer – water-laden rock (porous)

Aquitard – impermeable rock

Water Table – upper layer of the zone of saturation

Zone of Aeration – soil that is not saturated with water.

Circulation rate - underground water (300-4600 yrs), lakes (13 years), streams (13 days), atmosphere (9 days), ocean (37,000 yrs) and glaciers (16,000 yrs).

Many natural processes act to purify the water (a natural distillation/filtration processes).

How people affect the water cycle:

We withdraw large quantities of fresh water from lakes, rivers, groundwater, ...

We clear vegetation from land for agriculture and other uses (increasing runoff and reducing infiltration)

We modify water quality by adding nutrients (phosphates) and other pollutants

The Carbon Cycle

Carbon - the currency of energy exchange (energy is stored in chemical bonds); it is the basic building block of all organic chemicals including carbohydrates, fats, proteins, nucleic acids (DNA and RNA)

The flow of energy follows the flow of carbon (temp. is proportional to the conc. of CO_2)

See pp.114-115 (Miller, 11th edition; R&B, p. 106) for conceptual model of the carbon cycle.

Average residence time: atmosphere (3 yrs), soils (25-30 yrs), oceans (1500 yrs).

How people affect the carbon cycle:

forest and brush removal - less vegetation to remove CO2 through photosynthesis

burning fossil fuels

The Nitrogen Cycle

Role of nitrogen: used by organisms to make vital organic compounds: amino acids, proteins, DNA and RNA.

Nitrogen is usually in short supply and limits the rate of primary production.

Nitrogen (N_2) cannot be absorbed and used directly by plants or animals.

most complex of the nutrient cycles.

Nitrogen fixation - bacteria convert N_2 into NH_3 [$N_2 + 3\ H_2 \longrightarrow 2\ NH_3$]; cyanobacteria in soil and water and by the Rhizobium bacteria living in small nodules on the roots of legumes (soybeans, alfalfa, and clover).

Nitrification - NH_3 is converted to NO_2^- (nitrite, toxic to plants) and then to NO_3^- (nitrate, readily used by plants).

Assimilation - roots absorb NH_3, NH_4^+ and nitrate to make the nitrogen containing compounds.

Ammonification - specialized decomposed bacteria convert the nitrogen rich organic compounds (waste, etc.) into simpler nitrogen containing inorganic compounds (NH_3 and NH_4^+).

Denitrification - bacteria convert NH_3 and NH_4^+ back into nitrite and nitrate and then into N_2 and nitrous oxide (N_2O). The N_2O is released into the atmosphere and the process starts all over again.

See p. 117, Miller (11th) or R&B p.107 for a schematic diagram of the nitrogen cycle.

How people affect the Nitrogen Cycle:

We react nitrogen with hydrogen to make ammonia (the Haber Process)- revolutionizing agriculture.

We emit large quantities of NO when we burn fuel. The NO is produced when nitrogen and oxygen molecules combine at high temperatures:
$N2 + O2 \longrightarrow 2\ NO$ The NO produces HNO_3 (acid rain) and creates ozone (O_3) and photochemical smog.

We emit heat-trapping nitrous oxide (N_2O) into the atmosphere through the action of anaerobic bacteria on livestock waste

We remove nitrogen from the earth's crust when we mine nitrogen-containing mineral deposits for fertilizers.

We remove nitrogen from topsoil when we burn grasslands and clear forests.

We add excess nitrogen compounds to aquatic systems in agricultural runoff, discharge of municipal sewage and deposition of nitrogen compounds from the atmosphere.

We add excess nitrogen compounds to terrestrial ecosystems through atmospheric deposition involving HNO_3 and NO_2.

The Phosphorus Cycle

Phosphorus is an essential nutrient for plants and animals (as PO_4^{3-} and HPO_4^{2-})

How is Phosphorus Cycled in the Ecosphere?

Water, crust and in living organisms.

In Sedimentary Cycle: phosphate deposits on land and forms shallow ocean deposits to living organisms and then back to the land and ocean. Phosphorus is found as phosphate salts in rock and is released by weathering of the rock, is dissolved in soil water and taken up by plant roots.

Phosphorus and its compounds are not gaseous, so P is not circulated in the atmosphere.

Phosphorus cycle is very slow.

Most soils are low in phosphorus, so P is the limiting factor for plant growth (so fertilizer is needed).

How people affect the Phosphorus Cycle (3):

we mine large quantities of phosphate rock for fertilizers and detergents

cutting down the rain forests reduces available Phosphate. In rain forests, all phosphate is found in the plants and animals, not the soil. P is washed away when forests are cut and burned.

we add excessive phosphate to aquatic ecosystems in runoff of animal wastes from livestock feedlots, runoff of commercial fertilizers

The Sulfur Cycle

Sulfur is a component of most proteins and some vitamins.

Sulfur enters the atmosphere from several natural sources. H_2S from active volcanoes and breakdown of organic matter in swamps, bogs, tidal flats.

SO_2 (from volcanoes)

SO_4^{2-} (sulfate) salts from sea spray.

How people affect the Sulfur Cycle:

burning sulfur-containing coal and oil to produce electricity

refining petroleum

using smelting to convert sulfur compounds of metallic minerals into free metals (Cu, Pb, Zn),

other industrial processes.

Rock Cycle - How rocks change over time

Slowest of all Earth's cycles

Three types of rocks:

- Igneous
- Sedimentary
- Metamorphic

Soil - mixture of eroded rock, minerals, organic matter, water, air, living organisms (decomposers) - very slow to renew

Soil Horizons

O – organic matter; leaf litter

A - topsoil

B - subsoil

C - parent material

Soil Profiles

Soil Texture

Clay = silt = sand = gravel --- Relative amounts determine texture of the soil; Soil triangle

porosity - volume of the pores

permeability - determined by the average size of the pores in the soil

See soil triangle in text (Miller, p.128)

Soil texture, porosity and permeability determine a soil's 1) water-holding capacity, 2) aeration or oxygen content, and 3) workability. (ease of cultivation)

Soil acidity (pH) - influences the uptake of nutrients

Nutrient Cycling

Rainfall - can erode soil, dissolve soil nutrients

Wind - can blow away topsoil and deposits nutrients elsewhere

Nutrients lost from one ecosystem must enter another ecosystem