Nutrients: Nitrogen (N), Sulfur (S), Phosphorus (P), Potassium (K)

Essential for all life, their availability (or lack thereof) controls the distribution of flora and fauna.

Look into their:

Sources  Pools (sinks)  Fluxes

Nutrients must be in a specific form – **specie** - for use by organisms.
Nutrient Cycling: N, S, P, K

Soil Organic Matter (CHONPS)
Minerals (P, S, K)

Primary Productivity
photosynthesis

Leaves & Roots

Decomposition
Heterotrophic respiration

Gas loss

SOM/Minerals
Microbes

Gas loss

leaching of nutrients

plant nutrient uptake
Nutrients: natural & anthropogenic sources (IN) and outputs (OUT)

N₂
fertilizers (chemical, manure, sludge)
pesticides
wet and dry deposition (acid rain, aerosols)
plant tissue/residues

SOIL
Pools (sinks)
(SOM/clays/oxides)
Fluxes (transformations)

IN
OUT

IN
OUT

ions and molecules in solution (leaching)
colloidal transport
erosion
runoff
gases and particulates to atmosphere
(fossil fuel combustion (coal/oil); cycles; trees)
harvesting
root uptake

roots (exudates, biomass)
bedrock (1̊/2̊ minerals in parent material)
The Nitrogen Cycle

Terrestrial soils
Organic matter
Clay-fixed NH₄⁺

N Content, × 10¹⁶ kg
0.022
0.002

Atmospheric nitrogen gases, mainly N₂ (N ≡ N), with traces of NO, NO₂, N₂O, and NH₃

Symbiotic biological N fixation

Fossil fuel combustion

Fertilizers
NH₃, NH₄, NO₃

Plant tissue N

Animals

People

Erosion and runoff losses

Mineralization

Nitrification

Nitrate NO₃⁻

Nitrite NO₂⁻

Ammendment NH₄⁺ Immobilization

Soil Organisms (SO)

Soluble Organic Nitrogen (SON)

Adsorbed & fixed by clay colloids

Leaching loss

Adsorption or fixation

Desorption

Immobilization

Wet and dry deposition

Denitrification

Vacuolation

Plant uptake
The Nitrogen Cycle

- **Oxic zone:**
  - NO$_3^-$ is the most stable chemical form of N in aerated soil solutions
  - N$_2$ (g) is prevalent in the air of soil pores
  - N fixation: enzyme-catalyzed reaction (occurs only in living organisms)

- **Suboxic zone:**
  - Organic-N (~-90% of soil N)
  - Nitrification: NH$_3$ to oxidized forms of N (NO$_2^-$, NO$_3^-$) (energy-releasing)
  - Oxidation of N$_2$ does not occur except in a few organisms (N-N triple bond)

- **Nitrogen evolution (gases):**
  - Denitrification: reduction of NO$_3^-$ to reduced forms of N (N$_2$) (energy-consuming)

- **Atmospheric N deposition**
- **Fertilizer additions**

- **E$_h$(mV):**
  - Oxic zone: 700
  - Suboxic zone: 236
  - (-3) to (+5)

- **N oxidation state:**
  - (-3)
  - (+1)
  - (+2)
  - (+3)
  - (+5)
The Sulfur Cycle

Sulfur undergoes dramatic changes in redox cycling

Oxidation states range from +6 to -2

Oxic zone

Suboxic zone

Anoxic zone

Sulfate found in oxidized environments

degradation of organic materials (plant/animal)

Oxidation/reduction

biological reduction

mineralization

sorption

$O_2$

$SO_4^{2-}$

$S^{2-}$

$H_2S$

$M^{2+} + S^{2-} = MS$

(pptation of metal sulfides)

A large variety of organic forms of S

reduced organic S (thiol)

H2S

M2+ + S2- = MS

(pptation of metal sulfides)

metal sulfides tend to be “insoluble” (Hg, Ag, Cd, Cu, Pb, Zn, Fe(II))

Oxic zone

Suboxic zone

Anoxic zone

M2+ + S2- = MS

(pptation of metal sulfides)
In soil, $\text{SO}_4^{2-}$ originates from

- Organic matter mineralization
- Weathering of soil minerals
- Sulfur inputs from atmosphere
The Phosphorus Cycle

Land
Soil
Mineable rock
Biota
Fresh water (dissolved)

Total P × 10^{12} kg

96–160
19
2.6
0.090

Fertilizer

Plant tissue

Soil

Soil solution

Im mobilization

Mineralization

Plant residues, manure, sludge

Root uptake enhanced by mycorrhizae

Animals

Humans

Loss down runoff

Loss on eroded particles

Inorganic forms of phosphorus

Organic forms of phosphorus

P retained by clay & by iron & aluminum oxides

P excluded in iron and aluminum minerals extremely insoluble.

Dominant forms of inorganic P in low pH, highly weathered soils

Very slowly soluble Ca-P minerals

Readily soluble Ca-P

Dominant forms of inorganic P in high pH and calcareous soils
Mostly in organic P and inorganic P forms

$PO_4^{3-}$ is strongly retained by soils but can be transported in colloidal forms.

$PO_4^{3-}$ sorption onto Al and Fe oxides is strong.

Phosphate minerals (low solubility):

- Al and Fe phosphates (acid mineral soils)
  - (variscite, $AlPO_4 \cdot 2H_2O$)
  - (strengite, $FePO_4 \cdot 2H_2O$)

- Ca phosphates (non acid soils)
  - (hydroxyapatite, $Ca_5(PO_4)_3OH$)
The Potassium Cycle
Potassium as $K^+$ with no changes in oxidation state

$K^+$ flux controlled by CEC & chemical weathering ~ no organisms

Sources: Primary and Secondary Minerals