SOIL FERTILITY MANAGEMENT
(SST 3603)

LECTURE 2
Nutrient cycling plays an extremely significant role in maintaining ecosystem’s general functioning.

Nutrients are central to the function and growth of organisms, and in an ecosystem decomposer organisms are essential in breaking down biomass matter and cycling nutrients.

Animal waste and dead organic matter are broken down by bacteria and fungi into their constituent elements.
CARBON CYCLE

- The cycle consists of several storage pools of carbon and the processes by which the various pools exchange carbon.

- If more carbon enters a pool than leaves it, that pool is considered a net carbon sink.

- If more carbon leaves a pool than enters it, that pool is considered net carbon source.

Global carbon cycle is divided into two:

- Geological carbon cycle
- Biological carbon cycle
The Geological Carbon Cycle

- The geological component of the carbon cycle is where it interacts with the rock cycle in the processes of weathering and dissolution, precipitation of minerals, burial and subduction, and volcanism.

The Biological Carbon Cycle

- Biology plays an important role in the movement of carbon between land, ocean, and atmosphere through the processes of photosynthesis and respiration.
Plants take in carbon dioxide (CO$_2$) from the atmosphere during photosynthesis, and release CO$_2$ back into the atmosphere during respiration through the following chemical reactions:

**Respiration:**
$$C_6H_{12}O_6 \text{ (organic matter)} + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

**Photosynthesis:**
$$\text{energy (sunlight)} + 6CO_2 + H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$
NITROGEN CYCLE

• The nitrogen cycle refers to the sequence of chemical and biological changes undergone by nitrogen as it moves from the atmosphere into water, soil and living organisms and upon death of these organisms (plants and animals) is recycled through a part of all of the entire process.
Five main processes of the nitrogen cycle are:
1. Nitrogen fixation.
4. Nitrification.
5. Denitrification.

- Microorganisms, particularly bacteria, play major roles in all of the principal nitrogen transformations.
Nitrogen Fixation

A. Biological N fixation processes include:

• **Symbiotic bacteria**: Symbiotic bacteria of genus *Rhizobium* can fix nitrogen when in combination with cells from the roots of legumes like pea, bean and alfalfa. Nodule bacteria can fix 50-100 kilograms per acre per year.

• **Non-symbiotic N fixation**: This is a $N_2$ fixation process that is performed by free-living bacteria (e.g. *Azotobacter*) and blue-green algae in the soil. The amount of $N_2$ fixed by these organisms is much lower than that fixed by symbiotic $N_2$ fixation.
B. Non-biological N fixation processes include:

- **Lightening:** High-energy natural events such as lightning, forest fires, and even hot lava flows can cause the fixation of smaller, but significant amounts of nitrogen. The high energy of these natural phenomena can break the triple bonds of N\textsubscript{2} molecules, resulting in ammonia (NH\textsubscript{3}) and nitrates (NO\textsubscript{3}\textsuperscript{-}). These forms are carried to Earth in precipitation.

- **Synthetic or industrial processes of N Fixation:** The industrial fixation of N is the most important source of N as a plant nutrient. The production of N by industrial processes is based on the Haber-Bosch process where hydrogen (H\textsubscript{2}) and N\textsubscript{2} gases react to form NH\textsubscript{3}.
Mineralization of nitrogen

• When soil microbes attack compounds, simple amine compounds are formed. Then the amine groups are hydrolyzed and the nitrogen is released as ammonium ions ($\text{NH}_4^+$), which can be oxidized to nitrate form. This enzymatic process is called **mineralization**.

• The opposite of mineralization is immobilization. **Immobilization** is the conversion of inorganic nitrogen ions ($\text{NO}_3^-$ and $\text{NH}_4^+$) into organic forms.
Nitrification

- Nitrification is the conversion ammonium into nitrate. Nitrification requires the presence of oxygen.
- Biochemical processes of nitrification are in two stages:
  - **Step 1:** \( \text{NH}_4^+ + \text{O}_2 \xrightarrow{\text{Nitrosomonas}} \text{NO}_2^- + 2\text{H}^+ + \text{H}_2\text{O} + 275 \text{ kj} \)
    - Ammonium
    - Nitrite
  - **Step 2:** \( \text{NO}_2^- + \text{O}_2 \xrightarrow{\text{Nitrobacter}} \text{NO}_3^- + 76 \text{ kj energy} \)
    - Nitrite
    - Nitrate
Denitrification

- Denitrification is the reduction of nitrates back into nitrogen gas (N\textsubscript{2}).
- This process is performed by bacterial species such as *pseudomonas* and *clostridium* in anaerobic conditions.

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\begin{align*}
\text{Nitrate gas} & \rightarrow \text{Nitrite} & \rightarrow \text{Nitric oxide} & \rightarrow \text{Nitrous oxide} & \rightarrow \text{Dinitrogen gas}
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The phosphorus cycle is the biogeochemical cycle that describes the movement of phosphorus through the lithosphere, hydrosphere, and biosphere.

Unlike many other biogeochemical cycles, the atmosphere does not play a significant role in the movements of phosphorus, because phosphorus and phosphorus-based compounds are usually solids at the typical ranges of temperature and pressure found on Earth.
The Phosphorus Cycle

- Animal manures and biosolids
- Crop harvest
- Atmospheric deposition
- Mineral fertilizers
- Runoff and erosion
- Primary minerals (apatite)
- Mineral surfaces (clays, Fe and Al oxides, carbonates)
- Secondary compounds (CaP, FeP, MnP, AlP)

Organic phosphorus
- Microbial
- Plant residue
- Humus

Plant residues
- Soil solution phosphorus
  - $\text{HPO}_4^{2-}$
  - $\text{H}_2\text{PO}_4^{-1}$

Plant uptake

Mineral surfaces

Leaching (usually minor)

Mineralization

Immobilization

Weathering

Adsorption

Desorption

Dissolution

Precipitation
• Phosphates move quickly through plants and animals; however, the processes that move them through the soil or ocean are very slow, making the phosphorus cycle overall one of the slowest biogeochemical cycles.

• Phosphorus moves slowly from deposits on land and in sediments, to living organisms, and then much more slowly back into the soil and water sediment.

• Phosphorus availability and mobility is influenced by several factors such as pH. In acid soils, P precipitates as relatively insoluble Fe and Al phosphate minerals. In neutral and calcareous soils, P precipitates as relatively insoluble Ca phosphate minerals.
POTASSIUM CYCLE

• Potassium is present in relatively large quantities in most soils, but only a small percentage of the total soil K is readily available for plant uptake. Potassium exists in the soil as dissolved K+ ions (solution K), exchangeable K, non-exchangeable K, and mineral K.

• In the soil, weathering releases K from a number of common minerals including feldspars and micas. The released K+ can be taken up easily by plant roots, adsorbed by the cation exchange complex of clay and organic matter, or “fixed” in the internal structure of certain 2:1 clay minerals. Potassium that is “fixed” by these clay minerals is very slowly available to the plant.
The Potassium Cycle

- Crop harvest
- Plant residues
- Animal manures and biosolids
- Runoff and erosion
- Leaching
- Soil solution potassium (K⁺)
- Plant uptake
- Mineral potassium
- Exchangeable potassium
- Fixed potassium
Potassium availability and mobility

- **Plant available K**: Although mineral K accounts for 90 to 98% of the total soil K, readily and slowly available K represent only 1 to 10% of the total soil K. Plant available K (K that can be readily absorbed by plant roots) includes the portion of the soil K that is soluble in the soil solution and exchangeable K held on the exchange complex.

- **Exchangeable K**: is that portion of soil K which is in equilibrium with K in the soil solution:

  Exchangeable K ↔ Solution K
INTEGRATED NUTRIENT SYSTEM AND NUTRIENT BALANCE

• **Balanced fertilization** refers to the practice of applying the required plant nutrients after taking into account available nutrients in the soil, crop requirement, cropping sequence and crop management practices like weed control, irrigation etc.

• **Integrated nutrient management (INM)** refers to the practice of integrated use of all natural and man-made resources of plant nutrients so that the crop productivity increases efficiently and environmentally friendly manner without sacrificing the soil productivity of the future generations.
Nutrients can be lost in the following processes:

- Removal of the harvest (all of the nutrients)
- Volatilization (especially N)
- Run-off (especially N)
- Fixation (especially P)
- Leaching
- Erosion (all nutrients)
Nutrients are added in the following processes:

- Decomposition of organic matter (all nutrients)
- Nitrogen fixation (only N)
- Weathering (mostly K and Mg)
- Chemical fertilizer (mostly N, P, and K)
- Rain and solid matter deposits.
• Most soils in the tropical region are highly weathered and infertile. A sustainable crop production system must adopt an ecological approach, using balanced nutrient inputs from inorganic, organic and biological sources.
Management of Crop Residues

• Organic nutrient sources include plant residues, leguminous cover crops, mulches, green manure, animal manure, and household wastes.

• Organic matter in soil exists as partially decomposed plant and animal residues, living and dead microorganisms, and humidified organic matter or humus. Stable humus constitutes 50 to 75% of the total soil carbon and is little affected by management.

• Rates of decomposition of both fresh plant residues and humidified soil organic matter are three to five times greater in the humid tropical environment than under temperate conditions (Mueller-Harvey et al., 1985).
Strategies and practices for integrated nutrient management include

1. **Composting and addition of Organic Matter:**

   Organic nutrient sources include plant residues, leguminous cover crops, mulches, green manure, animal manure, and household wastes. Organic matter in soil exists as partially decomposed plant and animal residues, living and dead microorganisms, and humidified organic matter or humus.
Advantages of organic matter

- Physically, it improves soil structure and increases water holding capacity.

- Chemically, it increases the capacity of the soil to buffer changes in pH, increases the cation retention capacity (CEC), reduces phosphate fixation, and serves as a reservoir of secondary nutrients and micronutrients.

- Biologically, organic matter is the energy source for soil fauna and microorganisms, which are the primary agents that manipulate the decomposition and release of mineral nutrients in soil ecosystems.
2. Farm Yard manure:
   • Farmyard manure such as cattle dung are major sources of nutrients for food crops in many parts of the tropics and reduce the need for fertilizer.

3. Green Manure crops:
   • Timely applications of organic materials with a low C/N ratio, such as green manure and compost, could synchronize nutrient release with plant demand and minimize the amount of inorganic fertilizer needed to sustain high crop yields.
Advantages of Leguminous green manures and cover crops

- Enrich the soil with biologically fixed N.
- Conserve and recycle soil mineral nutrients.
- Provide ground cover to minimize soil erosion.
- Require little or no cash input.
- However, additional labor is required for timely establishment, maintenance and incorporation.
4. **Mulching and conservation tillage practices:**
   - The role of mulches and tillage practices in conserving soil moisture, with the subsequent effect on crop yields, has long been recognized.

5. **Agroforestry:**
   - Agroforestry refers to all forms of land-use systems in which trees or woody perennials are deliberately planted on the same land management unit in association with livestock and/or annual crops, with significant ecological interactions.
6) **Chemical fertilizers and soil amendments:**

- Judicious use (i.e. lower dose) of inorganic fertilizers is needed on infertile soils, to sustain high crop yields and maintain an optimum balance of nutrients. Liming should also be practiced under acidic conditions.