B. PHARMACY 1st SEMESTER - REMEDIAL BIOLOGY

UNIT – 4 🌱

POINTS TO BE COVERED IN THIS TOPIC

- ➤ PLANTS AND MINERAL NUTRITION
- ➤ ESSENTIAL MINERALS
- ➤ MACRO AND MICRONUTRIENTS
- ➤ NITROGEN METABOLISM
- ➤ NITROGEN CYCLE
- ➤ BIOLOGICAL NITROGEN FIXATION
- ➤ PHOTOSYNTHESIS
- ➤ AUTOTROPHIC NUTRITION
- ➤ PHOTOSYNTHETIC PIGMENTS
- ➤ FACTORS AFFECTING PHOTOSYNTHESIS

PLANTS AND MINERAL NUTRITION 🌿

Plants require various mineral nutrients for their proper growth, development, and metabolic processes. Mineral nutrition refers to the study of minerals required by plants and their role in plant physiology. Plants absorb these minerals from the soil through their root systems in the form of ions.

The availability of minerals in soil depends on various factors including soil pH, temperature, moisture content, and the presence of organic matter. Plants have developed sophisticated mechanisms to absorb, transport, and utilize these minerals efficiently.

Mineral deficiency in plants leads to various physiological disorders, reduced growth, poor yield, and increased susceptibility to diseases. Understanding mineral nutrition is crucial for optimizing plant growth in agricultural and pharmaceutical applications.

ESSENTIAL MINERALS ⚡

Essential minerals are those elements that are absolutely necessary for the normal growth and reproduction of plants. These minerals cannot be replaced by any other element and their deficiency leads to specific symptoms.

Criteria for Essential Minerals:

- The element must be absolutely necessary for normal growth and reproduction
- The deficiency of the element must cause specific abnormalities
- The element must be directly involved in plant metabolism
- The requirement must be specific and cannot be replaced by another element

Classification Based on Requirement:

1. Macronutrients (Required in large quantities)

- Primary macronutrients: Nitrogen (N), Phosphorus (P), Potassium (K)
- Secondary macronutrients: Calcium (Ca), Magnesium (Mg), Sulfur (S)

2. Micronutrients (Required in trace amounts)

- Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Boron (B), Molybdenum (Mo), Chlorine (Cl), Nickel (Ni)

MACRO AND MICRONUTRIENTS 📊

MACRONUTRIENTS	Functions	Deficiency Symptoms
Nitrogen (N)	Protein synthesis, chlorophyll formation, nucleic acid synthesis	Yellowing of leaves (chlorosis), stunted growth, poor flowering
Phosphorus (P)	Energy transfer (ATP), nucleic acid synthesis, root development	Purple discoloration of leaves, poor root development, delayed maturity
Potassium (K)	Enzyme activation, osmotic regulation, stomatal movement	Marginal leaf burn, weak stems, reduced disease resistance
Calcium (Ca)	Cell wall formation, membrane stability, enzyme activation	Tip burn, poor root development, blossom end rot
Magnesium (Mg)	Chlorophyll center, enzyme cofactor, protein synthesis	Interveinal chlorosis, premature leaf drop
Sulfur (S)	Amino acid synthesis, oil formation, chlorophyll synthesis	General yellowing, reduced protein content

MACRONUTRIENTS 🔋

Nitrogen (N) Nitrogen is the most important macronutrient required by plants. It is a component of amino acids, proteins, nucleic acids, and chlorophyll. Plants absorb nitrogen in the form of nitrate (NO_3^-) and ammonium (NH_4^+) ions. Nitrogen deficiency is characterized by chlorosis of older leaves, starting from the tips and margins.

Phosphorus (P) Phosphorus is essential for energy transfer in the form of ATP and ADP. It is also a component of nucleic acids, phospholipids, and several coenzymes. Plants absorb phosphorus as phosphate ions (PO_4^{3-}). Phosphorus deficiency results in poor root development and purple discoloration of leaves.

Potassium (K) Potassium plays a crucial role in maintaining osmotic balance, enzyme activation, and stomatal regulation. It is absorbed as K^+ ions. Potassium deficiency causes marginal leaf burn and reduces the plant's resistance to diseases and environmental stress.

MICRONUTRIENTS 🔬

MICRONUTRIENTS	Functions	Deficiency Symptoms
Iron (Fe)	Chlorophyll synthesis, electron transport, enzyme activation	Interveinal chlorosis in young leaves
Manganese (Mn)	Enzyme activation, chloroplast structure, photosynthesis	Interveinal chlorosis, brown spots
Zinc (Zn)	Enzyme activation, protein synthesis, auxin metabolism	Small leaves, short internodes, rosetting
Copper (Cu)	Enzyme activation, lignin synthesis, electron transport	Wilting, chlorosis, necrosis
Boron (B)	Cell wall formation, membrane function, sugar transport	Growing point death, hollow stem
Molybdenum (Mo)	Nitrogen fixation, nitrate reduction	Nitrogen deficiency symptoms, leaf cupping

Iron (Fe) Iron is essential for chlorophyll synthesis and functions as a cofactor for many enzymes involved in respiration and photosynthesis. Iron deficiency causes interveinal chlorosis, particularly in young leaves, as iron is relatively immobile in plants.

Manganese (Mn) Manganese is involved in the activation of several enzymes and plays a crucial role in photosynthesis, particularly in the oxygen-evolving complex of photosystem II. Deficiency results in interveinal chlorosis with brown necrotic spots.

Zinc (Zn) Zinc is essential for enzyme activation and auxin metabolism. It plays a role in protein synthesis and carbohydrate metabolism. Zinc deficiency is characterized by small leaves, short internodes, and rosette growth patterns.

NITROGEN METABOLISM 🔄

Nitrogen metabolism encompasses all biochemical processes involving nitrogen compounds in plants. It includes nitrogen uptake, assimilation, and the synthesis of nitrogen-containing compounds such as amino acids, proteins, and nucleic acids.

Nitrogen Uptake:

- Plants primarily absorb nitrogen as nitrate (NO_3^-) and ammonium (NH_4^+) ions from soil
- Root hairs and mycorrhizal associations enhance nitrogen uptake
- Active transport mechanisms are involved in nitrogen absorption
- Nitrogen uptake is influenced by soil pH, temperature, and moisture

Nitrogen Assimilation:

- **Nitrate Reduction:** Nitrate is reduced to nitrite by nitrate reductase enzyme
- **Nitrite Reduction:** Nitrite is further reduced to ammonium by nitrite reductase
- **Ammonium Assimilation:** Ammonium is incorporated into amino acids through glutamine synthetase and glutamate synthase pathways
- **Protein Synthesis:** Amino acids are polymerized to form proteins

Nitrogen Transport:

- Nitrogen compounds are transported through xylem and phloem

- Amino acids and amides serve as transport forms of nitrogen
- Asparagine and glutamine are major transport compounds
- Nitrogen is remobilized from older tissues to younger growing parts

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NITROGEN CYCLE ♻️

The nitrogen cycle is a biogeochemical cycle that describes the transformation of nitrogen and nitrogen-containing compounds in nature. It is essential for maintaining the nitrogen balance in ecosystems and making nitrogen available to plants.

Stages of Nitrogen Cycle:

1. Nitrogen Fixation 🔧

- Conversion of atmospheric nitrogen (N_2) into ammonia (NH_3)
- Carried out by nitrogen-fixing bacteria (free-living and symbiotic)
- Industrial nitrogen fixation through Haber-Bosch process
- Lightning also contributes to nitrogen fixation

2. Nitrification ⚡

- Conversion of ammonia to nitrite (NO_2^-) by Nitrosomonas bacteria
- Conversion of nitrite to nitrate (NO_3^-) by Nitrobacter bacteria
- Two-step oxidation process that releases energy
- Makes nitrogen available to plants in usable form

3. Assimilation 🌱

- Uptake and incorporation of nitrogen compounds by plants
- Formation of amino acids, proteins, and nucleic acids
- Nitrogen becomes part of food chain through plant consumption
- Primary pathway for nitrogen entry into biological systems

4. Mineralization (Ammonification) 🔄

- Decomposition of organic nitrogen compounds by decomposer bacteria
- Release of ammonia from dead plant and animal tissues
- Conversion of complex nitrogen compounds to simple forms
- Returns nitrogen to soil for reuse

5. Denitrification 💨

- Conversion of nitrate back to nitrogen gas by denitrifying bacteria
- Occurs in anaerobic conditions in waterlogged soils
- Results in loss of nitrogen from soil system
- Completes the nitrogen cycle by returning nitrogen to atmosphere

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BIOLOGICAL NITROGEN FIXATION 🦠

Biological nitrogen fixation is the process by which certain microorganisms convert atmospheric nitrogen (N_2) into ammonia (NH_3) using the enzyme nitrogenase. This process is crucial for maintaining nitrogen availability in ecosystems.

Nitrogen-Fixing Organisms:

1. Free-Living Nitrogen Fixers

- **Azotobacter:** Aerobic, free-living soil bacteria
- **Clostridium:** Anaerobic, spore-forming bacteria
- **Beijerinckia:** Aerobic, acid-tolerant bacteria
- **Rhizobium:** Free-living form in soil

2. Symbiotic Nitrogen Fixers

- **Rhizobium-Legume Symbiosis:** Most important agricultural symbiosis
- **Frankia-Actinorhizal Symbiosis:** With non-leguminous plants like Alnus
- **Azolla-Anabaena Symbiosis:** Important in rice cultivation
- **Lichens:** Symbiosis between fungi and cyanobacteria

Mechanism of Nitrogen Fixation:

Nitrogenase Enzyme Complex:

- Contains iron-molybdenum cofactor (FeMoCo)
- Consists of two main components: Fe protein and MoFe protein
- Requires ATP and reducing power (electrons) for activity
- Extremely sensitive to oxygen and requires anaerobic conditions

Reaction: $N_2 + 8H^+ + 8e^- + 16ATP \rightarrow 2NH_3 + H_2 + 16ADP + 16Pi$

Rhizobium-Legume Symbiosis:

Steps in Nodule Formation:

- **Recognition:** Chemical signaling between Rhizobium and legume roots
- **Infection:** Formation of infection thread for bacterial entry
- **Nodule Development:** Cortical cell division and nodule differentiation
- **Nitrogen Fixation:** Bacteroids fix nitrogen within nodule cells
- **Senescence:** Nodule aging and nitrogen remobilization

Benefits:

- Plants receive fixed nitrogen from bacteria
- Bacteria receive carbohydrates and protection from plant
- Reduces dependence on nitrogen fertilizers
- Improves soil fertility for subsequent crops

PHOTOSYNTHESIS 🌞

Photosynthesis is the biological process by which plants convert light energy into chemical energy, producing glucose and oxygen from carbon dioxide and water. It is the foundation of all food chains and responsible for oxygen production in the atmosphere.

Overall Equation:

$6CO_2 + 6H_2O + \text{Light Energy} \rightarrow C_6H_{12}O_6 + 6O_2$

Significance of Photosynthesis:

- Primary source of energy for all living organisms
- Converts inorganic carbon into organic compounds
- Produces oxygen essential for respiration
- Maintains atmospheric CO_2 levels
- Forms the basis of food webs and ecosystems

Types of Photosynthesis:

C3 Photosynthesis:

- First stable product is 3-carbon compound (3-phosphoglyceric acid)
- Calvin cycle operates in mesophyll cells
- Most common type found in temperate plants
- Less efficient in hot, dry conditions due to photorespiration

C4 Photosynthesis:

- First stable product is 4-carbon compound (oxaloacetic acid)
- Spatial separation of CO_2 fixation and Calvin cycle
- Found in tropical grasses like maize, sugarcane
- More efficient in hot, dry conditions

CAM Photosynthesis:

- Crassulacean Acid Metabolism
- Temporal separation of CO_2 fixation (night) and Calvin cycle (day)
- Adaptation to arid conditions
- Found in succulents like cacti and pineapple

AUTOTROPHIC NUTRITION 🌿

Autotrophic nutrition is the process by which organisms produce their own food using simple inorganic substances. Plants are the primary autotrophs in most ecosystems, converting light energy into chemical energy through photosynthesis.

Types of Autotrophic Nutrition:

1. Photoautotrophic Nutrition ☀️

- Uses light energy for food synthesis
- Primary mode of nutrition in green plants
- Requires chlorophyll and other photosynthetic pigments
- Converts CO_2 and H_2O into glucose using light energy

2. Chemoautotrophic Nutrition ⚗️

- Uses chemical energy from oxidation of inorganic compounds
- Found in certain bacteria (chemosynthetic bacteria)
- Does not require light energy
- Important in deep-sea ecosystems and soil nitrogen cycling

Adaptations for Autotrophic Nutrition:

Structural Adaptations:

- Large leaf surface area for maximum light capture
- Thin leaves for efficient gas exchange

- Chloroplast arrangement for optimal light absorption
- Vascular system for transport of materials

Physiological Adaptations:

- Multiple photosynthetic pigments for broad spectrum light absorption
- Efficient CO_2 fixation mechanisms (C3, C4, CAM)
- Stomatal regulation for gas exchange and water conservation
- Integration of light and dark reactions

PHOTOSYNTHETIC PIGMENTS 🎨

Photosynthetic pigments are molecules that absorb light energy and convert it into chemical energy during photosynthesis. Different pigments absorb different wavelengths of light, allowing plants to utilize a broader spectrum of solar radiation.

Classification of Photosynthetic Pigments:

Pigment Type	Color	Absorption Peak	Location	Function
Chlorophyll a	Blue-green	430 nm, 663 nm	Reaction centers	Primary photosynthetic pigment
Chlorophyll b	Yellow-green	453 nm, 642 nm	Antenna complexes	Accessory pigment, light harvesting
Carotenoids	Yellow-orange	400-500 nm	Antenna complexes	Light harvesting, photoprotection
Phycobilins	Red-blue	550-650 nm	Phycobilisomes	Light harvesting in cyanobacteria

CHLOROPHYLLS

Chlorophyll a:

- Most abundant and essential photosynthetic pigment
- Present in all photosynthetic organisms except bacteria
- Located in reaction centers of photosystems I and II
- Directly involved in light energy conversion
- Chemical formula: $C_{55}H_{72}O_5N_4Mg$

Chlorophyll b:

- Accessory pigment found in higher plants and green algae
- Transfers absorbed light energy to chlorophyll a
- Helps expand the range of light wavelengths used

- More stable than chlorophyll a under stress conditions
- Chemical formula: $C_{55}H_{70}O_6N_4Mg$

Structure of Chlorophyll:

- Porphyrin ring system with magnesium at center
- Long hydrophobic phytol tail
- Alternating single and double bonds for light absorption
- Embedded in thylakoid membranes

CAROTENOIDS 🟡

Types of Carotenoids:

Carotenes:

- Hydrocarbon carotenoids (only C and H)
- β-carotene most common in plants
- Precursors of vitamin A in animals
- Strong antioxidant properties

Xanthophylls:

- Oxygenated carotenoids containing oxygen
- Include lutein, zeaxanthin, violaxanthin
- Important in photoprotection mechanisms
- Help dissipate excess light energy as heat

Functions of Carotenoids:

- **Light Harvesting:** Absorb light in blue-green region (400-500 nm)
- **Photoprotection:** Prevent damage from excess light energy
- **Antioxidant Activity:** Neutralize harmful reactive oxygen species
- **Structural Support:** Stabilize photosynthetic membrane complexes

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FACTORS AFFECTING PHOTOSYNTHESIS 🌡️

Photosynthesis is influenced by various environmental and internal factors. Understanding these factors is crucial for optimizing plant growth and agricultural productivity.

External Factors:

1. Light Intensity 💡

- **Low Light:** Light is limiting factor, rate increases with intensity
- **Optimal Light:** Maximum photosynthetic rate achieved
- **High Light:** May cause photoinhibition and damage
- **Compensation Point:** Light intensity where photosynthesis equals respiration
- **Saturation Point:** Light intensity beyond which rate doesn't increase

2. Carbon Dioxide Concentration 🌫️

- **Normal Atmospheric CO_2:** 0.04% (400 ppm)
- **CO_2 Enrichment:** Can increase photosynthetic rate up to 0.1%
- **CO_2 Depletion:** Below 0.01% severely limits photosynthesis

- **C4 plants:** Less sensitive to CO_2 concentration than C3 plants
- **Stomatal Limitation:** CO_2 uptake limited by stomatal aperture

3. Temperature 🌡️

- **Low Temperature:** Reduces enzyme activity and membrane fluidity
- **Optimal Temperature:** 25-30°C for most temperate plants, 30-45°C for tropical plants
- **High Temperature:** Denatures enzymes, increases photorespiration
- **Temperature Coefficient:** Rate doubles for every 10°C rise (up to optimum)
- **Thermal Adaptation:** Plants adapt to their thermal environment

4. Water Availability 💧

- **Water Stress:** Causes stomatal closure, reducing CO_2 uptake
- **Turgor Pressure:** Maintains leaf structure and stomatal function
- **Transpiration:** Creates pulling force for water and mineral transport
- **Osmotic Adjustment:** Plants adjust cell osmolarity under water stress

Internal Factors:

1. Chlorophyll Content 🟢

- Higher chlorophyll content generally increases photosynthetic capacity
- Chlorophyll a:b ratio affects light harvesting efficiency
- Chlorophyll degradation under stress reduces photosynthesis
- Genetic factors control chlorophyll synthesis and stability

2. Leaf Age and Structure 🍃

- Young leaves have higher photosynthetic rates
- Leaf thickness affects light penetration and CO_2 diffusion
- Stomatal density and size influence gas exchange
- Mesophyll cell arrangement affects internal CO_2 concentration

3. Mineral Nutrition ⚡

- Nitrogen deficiency reduces chlorophyll and enzyme content
- Phosphorus limitation affects ATP synthesis
- Magnesium deficiency directly affects chlorophyll structure
- Iron deficiency impairs chlorophyll synthesis and electron transport

Limiting Factors Principle:

- **Liebig's Law:** Growth is limited by the scarcest resource
- **Rate-Limiting Step:** Slowest step determines overall rate
- **Interactive Effects:** Multiple factors interact to affect photosynthesis
- **Compensation:** Plants can partially compensate for one limiting factor through others

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SUMMARY 📋

Plant mineral nutrition and photosynthesis are fundamental processes that sustain plant life and form the basis of all terrestrial ecosystems. Understanding these processes is essential for pharmacy students as many pharmaceutical compounds are derived from plants, and plant metabolism affects the biosynthesis of bioactive compounds.

Key Points to Remember:

- Plants require 17 essential mineral elements for normal growth and development
- Macronutrients are needed in large quantities while micronutrients are required in trace amounts
- Nitrogen metabolism involves uptake, assimilation, and transport of nitrogen compounds
- The nitrogen cycle maintains nitrogen balance in ecosystems through biological and chemical processes
- Biological nitrogen fixation by bacteria provides a sustainable source of nitrogen for plants
- Photosynthesis converts light energy into chemical energy and produces oxygen
- Different photosynthetic pigments allow plants to utilize various wavelengths of light
- Environmental factors like light, temperature, CO_2, and water significantly affect photosynthetic efficiency

Understanding these concepts provides a foundation for comprehending how plants produce the secondary metabolites that serve as sources for many pharmaceutical drugs and how environmental conditions affect the quality and quantity of these bioactive compounds.