NCERT Exemplar Solutions of Class 11 Biology – Chapter 12: Mineral Nutrition

LONG ANSWER TYPE QUESTIONS

1. It is observed that deficiency of a particular element showed its symptoms initially in older leaves and then in younger leaves.

a. Does it indicate that the element is actively mobilized or relatively immobile? b. Name two highly mobile elements and two which are relatively immobile. c. How is the aspect of the mobility of elements important to horticulture and agriculture?

Solution:

a) Element mobility: The element is ACTIVELY MOBILIZED

Explanation:

- **Symptoms in older leaves first** indicates the element can be **translocated**
- **Plant redistributes** the element from older tissues to support new growth
- **Younger leaves remain healthy** initially because they receive the mobilized nutrients
- **Mobile elements** show this pattern of deficiency symptoms

b) Classification of elements:

Highly Mobile Elements:

1. **Nitrogen (N)**
    - Component of amino acids, proteins, nucleic acids
    - Easily remobilized as amino acids
2. **Magnesium (Mg)**
    - Central atom in chlorophyll
    - Can be transported in phloem

Relatively Immobile Elements:

1. **Calcium (Ca)**
    - Structural component of cell walls (calcium pectate)
    - Forms stable complexes, difficult to remobilize
2. **Boron (B)**
    - Involved in cell wall formation
    - Forms stable complexes with cell wall components

Additional examples:

- **Mobile:** Phosphorus, Potassium, Sulfur
- **Immobile:** Iron, Manganese, Zinc

c) Importance to horticulture and agriculture:

Diagnostic significance:

1. Early detection:

- **Mobile element deficiency** - check older leaves first
- **Immobile element deficiency** - check younger leaves first
- **Faster diagnosis** leads to quicker treatment

2. Fertilizer application strategies:

For mobile elements:

- **Foliar sprays** can be applied to older leaves
- **Soil application** works well as elements redistribute
- **Regular applications** needed as elements move to new growth

For immobile elements:

- **Foliar application** to young leaves more effective
- **Soil treatment** must ensure continuous supply
- **Chelated forms** improve availability

3. Crop management:

Pruning strategies:

- Understanding mobility helps decide which leaves to remove
- **Older leaves** with mobile elements can be removed after nutrient recovery

Timing of fertilization:

- **Mobile elements** - can be applied when symptoms appear
- **Immobile elements** - preventive application more important

4. Breeding programs:

- **Select varieties** with better nutrient use efficiency
- **Develop plants** with improved nutrient mobility

5. Economic benefits:

- **Targeted fertilization** reduces costs
- **Prevents crop losses** through early detection
- **Optimizes yield** and quality

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2. We find that Rhizobium forms nodules on the roots of leguminous plants. Also Frankia another microbe forms nitrogen-fixing nodules on the roots of non-leguminous plant Alnus.

a. Can we artificially induce the property of nitrogen fixation in a plant – leguminous or non-leguminous? b. What kind of relationship is observed between mycorrhiza and pine trees? c. Is it necessary for a microbe to be in close association with a plant to provide mineral nutrition? Explain with the help of one example.

Solution:

a) Artificial induction of nitrogen fixation:

YES, it is theoretically and practically possible through:

1. Genetic Engineering approaches:

Transfer of nif genes:

- **Isolate nif genes** from nitrogen-fixing bacteria
- **Insert into plant genome** using transformation techniques
- **Challenges:** Multiple genes involved, oxygen sensitivity, energy requirement

Bacterial transfer:

- **Introduce nitrogen-fixing bacteria** into non-leguminous plants

- **Create artificial nodulation** through genetic modification
- **Examples:** Research on cereals like rice and wheat

2. Current research:

- **Transgenic approaches** with nitrogenase genes
- **Synthetic biology** to create new nitrogen-fixing systems
- **CRISPR technology** for gene editing

3. Practical applications:

- **Azospirillum inoculation** in cereals (partial success)
- **Rhizobium strains** engineered for broader host range
- **Bio-fertilizer development** with improved efficiency

b) Mycorrhiza-Pine tree relationship:

Type: SYMBIOTIC RELATIONSHIP (Mutualism)

Detailed explanation:

Ectomycorrhiza in pines:

- **Fungal hyphae** form sheath around root tips
- **Hartig net** - fungal network between root cells
- **No penetration** into plant cells (unlike endomycorrhiza)

Benefits to Pine trees:

- **Enhanced phosphorus absorption** - fungi more efficient
- **Water uptake** improvement, especially in dry conditions
- **Protection** against root pathogens
- **Expanded root surface area** through hyphal network
- **Nitrogen uptake** from decomposing organic matter

Benefits to Mycorrhizal fungi:

- **Carbohydrates** from pine photosynthesis
- **Amino acids** and other organic compounds
- **Protected environment** for growth and reproduction
- **Stable carbon source** from host plant

Ecological importance:

- **Essential for pine survival** in nutrient-poor soils
- **Forest ecosystem health**
- **Nutrient cycling** in forest ecosystems

c) Close association necessity:

YES, close association is often necessary for effective mineral nutrition

Example: Rhizobium-Legume Association

Why close association is essential:

1. Biochemical integration:

- **Shared metabolic pathways** - plant provides carbon, bacteria fix nitrogen
- **Coordinated gene expression** - nod genes in bacteria, nodulin genes in plants
- **Biochemical signals** required for communication

2. Oxygen regulation:

- **Leghemoglobin production** requires both partners
- **Microaerobic environment** needs tight regulation
- **Spatial organization** in nodules essential

3. Nutrient exchange:

- **Direct transfer** of fixed nitrogen to plant
- **Efficient transport** through specialized cells
- **Metabolic coordination** between partners

4. Protection and support:

- **Physical protection** of nitrogen-fixing bacteria
- **Stable environment** for enzyme function
- **Energy supply** guaranteed from host

Counter-examples (looser associations):

- **Azotobacter in rhizosphere** - beneficial but not essential
- **Mycorrhiza** - some plants can survive without them
- **PGPR bacteria** - plant growth promotion without intimate contact

Conclusion: While some beneficial effects can occur without close association, **maximum efficiency** in mineral nutrition typically requires intimate symbiotic relationships where both partners have evolved complementary adaptations.

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3. What are the essential elements for plants? Give the criteria of essentiality? How are minerals classified depending upon the amount in which they are needed by the plants?

Solution:

Essential Elements for Plants:

Complete list (17 elements):

Macronutrients (9 elements):

- **Primary macronutrients:** N, P, K
- **Secondary macronutrients:** Ca, Mg, S
- **Structural macronutrients:** C, H, O

Micronutrients (8 elements): Fe, Mn, Zn, Cu, B, Mo, Cl, Ni

Criteria of Essentiality (Arnon and Stout's criteria):

1. Absolute necessity:

- **Without the element** - plant cannot complete its life cycle
- **Growth and reproduction** impossible in absence
- **No substitute** element can perform the same function

2. Direct involvement:

- **Element must be directly involved** in plant metabolism
- **Not just beneficial** but metabolically essential
- **Specific biochemical role** that cannot be replaced

3. Specificity:

- **Deficiency effects** must be prevented only by supplying that specific element
- **No other element** can substitute its function
- **Unique role** in plant physiology

Mineral Classification by Quantity Required:

A. MACRONUTRIENTS (>1000 ppm in dry tissue):

1. Primary Macronutrients:

- **Nitrogen (N): 2-4%**
  - Proteins, nucleic acids, chlorophyll
  - Most commonly limiting nutrient
- **Phosphorus (P): 0.3-0.5%**
  - ATP, DNA, RNA, phospholipids
  - Energy metabolism
- **Potassium (K): 2-4%**
  - Enzyme activation, osmoregulation
  - Stomatal movement

2. Secondary Macronutrients:

- **Calcium (Ca): 0.2-3%**
  - Cell wall structure, membrane stability
  - Second messenger system
- **Magnesium (Mg): 0.1-0.4%**
  - Chlorophyll center, enzyme activation
  - Protein synthesis
- **Sulfur (S): 0.2-0.5%**
  - Amino acids (cysteine, methionine)
  - Coenzymes, proteins

B. MICRONUTRIENTS (1-100 ppm in dry tissue):

Essential micronutrients:

- **Iron (Fe): 20-300 ppm**
  - Cytochromes, ferredoxin, catalase
  - Chlorophyll synthesis
- **Manganese (Mn): 10-500 ppm**
  - Photosystem II, enzyme activation
  - Chloroplast development
- **Zinc (Zn): 3-150 ppm**
  - Enzyme cofactor, auxin synthesis
  - Protein synthesis
- **Copper (Cu): 2-75 ppm**
  - Cytochrome oxidase, plastocyanin
  - Lignin synthesis

- **Boron (B): 5-100 ppm**
  - Cell wall formation, pollen germination
  - Carbohydrate metabolism
- **Molybdenum (Mo): 0.1-5 ppm**
  - Nitrogenase, nitrate reductase
  - Nitrogen metabolism
- **Chlorine (Cl): 2-20,000 ppm**
  - Photosystem II, osmoregulation
  - Disease resistance
- **Nickel (Ni): 0.01-10 ppm**
  - Urease enzyme
  - Nitrogen metabolism

Functional Classification:

1. Structural elements:

- **C, H, O** - basic building blocks
- **Ca** - cell wall structure
- **Mg** - chlorophyll structure

2. Energy-related:

- **P** - ATP, energy transfer
- **Mg** - photosynthesis
- **Fe** - electron transport

3. Enzyme activation:

- **Mg, Mn, Zn, Cu, Mo** - cofactors
- **K** - enzyme activation
- **Cl** - enzyme cofactor

4. Metabolic regulation:

- **N** - proteins, enzymes
- **S** - enzyme structure
- **B** - membrane function

Deficiency symptoms pattern:

- **Mobile elements** - older leaves affected first
- **Immobile elements** - younger leaves affected first

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4. With the help of examples describe the classification of essential elements based on the function they perform.

Solution:

Functional Classification of Essential Elements:

I. ESSENTIAL ELEMENTS AS COMPONENTS OF ENERGY-RELATED COMPOUNDS:

Examples:

Magnesium (Mg) in Chlorophyll:

- **Central atom** in chlorophyll molecule
- **Light absorption** and energy conversion
- **Photosystem I and II** function
- **Energy capture** in photosynthesis
- **Formula:** $C_{55}H_{72}MgN_4O_5$ (Chlorophyll a)

Phosphorus (P) in ATP:

- **High-energy phosphate bonds** in ATP
- **Energy currency** of the cell
- **Phosphorylation reactions**
- **Energy storage and release**
- **Structure:** Adenine-Ribose-PPP

Iron (Fe) in Cytochromes:

- **Electron transport chain** components
- **Redox reactions** ($Fe^{3+} \leftrightarrow Fe^{2+}$)
- **Cellular respiration** and photosynthesis
- **Energy generation** through electron flow

II. COMPONENTS OF STRUCTURAL ELEMENTS OF CELLS:

Examples:

Carbon (C), Hydrogen (H), Oxygen (O):

- **Basic building blocks** of all organic molecules
- **Carbohydrates:** $(CH_2O)_n$
- **Proteins:** CHON compounds
- **Lipids:** Long chain hydrocarbons
- **Nucleic acids:** DNA, RNA structure

Calcium (Ca) in Cell Walls:

- **Calcium pectate** in middle lamella
- **Cell wall stability** and structure
- **Intercellular cement**
- **Mechanical support** to plant body

Sulfur (S) in Proteins:

- **Disulfide bridges** in cysteine
- **Protein tertiary structure**
- **Enzyme active sites**
- **Structural stability** of proteins

III. ESSENTIAL ELEMENTS AS ACTIVATORS AND INHIBITORS OF ENZYMES:

Examples:

Magnesium (Mg^{2+}) as Enzyme Activator:

- **RuBisCO activation** in Calvin cycle
  - Ribulose 1,5-bisphosphate carboxylase
  - CO_2 fixation in photosynthesis

- **Phosphoenolpyruvate carboxylase**
  - C_4 photosynthesis pathway
  - Primary CO_2 fixation

Zinc (Zn^{2+}) in Enzyme Function:

- **Carbonic anhydrase** - CO_2 hydration
- **RNA polymerase** - transcription
- **Alcohol dehydrogenase** - metabolism
- **Over 300 enzymes** require zinc

Molybdenum (Mo) in Nitrogenase:

- **Component of nitrogenase** enzyme
- **N_2 → NH_3** conversion
- **Nitrogen fixation** in root nodules
- **Nitrate reductase** activation

Manganese (Mn) in Water Splitting:

- **Oxygen-evolving complex** in PSII
- **Water photolysis:** $2H_2O \rightarrow 4H^+ + 4e^- + O_2$
- **Superoxide dismutase** activation
- **Antioxidant enzyme** function

IV. ESSENTIAL ELEMENTS ALTERING OSMOTIC PRESSURE:

Examples:

Potassium (K^+) in Stomatal Regulation:

- **Guard cell function**
- **Stomatal opening:** K^+ influx → water influx → turgor increase
- **Stomatal closing:** K^+ efflux → water efflux → turgor decrease
- **Mechanism:**

Light → H^+-ATPase activation → K^+ channels open →
K^+ influx → Water follows → Stomata open

Sodium (Na^+) in Halophytes:

- **Salt accumulation** in vacuoles
- **Osmotic adjustment** in saline conditions
- **Turgor maintenance** under salt stress
- **Example:** Salicornia (glasswort)

Chlorine (Cl^-) in Osmoregulation:

- **Counterion** for K^+ transport
- **Charge balance** maintenance
- **Turgor regulation**
- **Guard cell movement**

V. ESSENTIAL ELEMENTS IN METABOLIC PROCESSES:

Examples:

Iron (Fe) in Electron Transport:

- **Ferredoxin** - electron carrier
- **Cytochrome c** - respiratory chain
- **Catalase** - H_2O_2 decomposition
- **Peroxidase** - oxidative reactions

Copper (Cu) in Oxidases:

- **Cytochrome oxidase** - terminal electron acceptor
- **Plastocyanin** - photosynthetic electron transport
- **Ascorbate oxidase** - ascorbic acid metabolism
- **Laccase** - lignin synthesis

Boron (B) in Cell Wall Synthesis:

- **Pectin cross-linking**
- **Cell wall expansion**
- **Pollen tube growth**
- **Sugar transport** across membranes

VI. REGULATORY FUNCTIONS:

Examples:

Calcium (Ca^{2+}) as Second Messenger:

- **Signal transduction** pathways
- **Calmodulin activation**
- **Enzyme regulation**
- **Response to stimuli**

Nitrogen (N) in Growth Regulation:

- **Amino acid synthesis**
- **Protein formation**
- **Growth hormone** components
- **Chlorophyll synthesis**

Integration of Functions: Many elements perform **multiple functions** simultaneously, demonstrating the **interconnected nature** of plant metabolism and the **essential role** each element plays in maintaining plant health and productivity.

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5. We know that plants require nutrients. If we supply these in excess, will it be beneficial to the plants? If yes, how/ If no, why?

Solution:

Answer: NO, excess nutrients are NOT beneficial to plants

Detailed Explanation:

I. TOXICITY EFFECTS:

General toxicity symptoms:

- **Dry weight reduction** by 10% or more
- **Growth inhibition** beyond optimal levels
- **Physiological disorders**

- **Reduced crop quality**

Specific toxicity examples:

1. Nitrogen (N) toxicity:

- **Excessive vegetative growth**
- **Delayed flowering and fruiting**
- **Increased susceptibility** to diseases
- **Poor root development**
- **Lodging in cereals**

2. Phosphorus (P) toxicity:

- **Induced zinc deficiency** (P-Zn antagonism)
- **Iron chlorosis** in alkaline soils
- **Reduced mycorrhizal colonization**

3. Potassium (K) toxicity:

- **Magnesium deficiency** induced
- **Calcium uptake** reduced
- **Salt stress** symptoms

4. Micronutrient toxicity:

- **Iron:** Bronze speckling, necrosis
- **Manganese:** Brown spots, Ca and Fe deficiency
- **Boron:** Marginal leaf burn, reduced growth
- **Copper:** Chlorosis, stunted roots

II. NUTRIENT ANTAGONISM:

Competitive inhibition mechanisms:

1. Ion competition at uptake sites:

- **Similar ionic radii** compete for same carriers
- **Example:** Mg^{2+} vs Mn^{2+}, Ca^{2+} vs Mg^{2+}
- **Transport protein saturation**

2. Metabolic interference:

- **Enzyme binding site** competition
- **Example:** Excess Mn inhibits Fe-containing enzymes
- **Protein synthesis** disruption

Specific antagonistic relationships:

Manganese excess effects:

- **Inhibits calcium translocation** to shoot apex
- **Competes with iron** for enzyme binding
- **Reduces magnesium** availability
- **Mechanism:** Similar ionic properties cause competitive inhibition

Phosphorus-Zinc antagonism:

- **High P levels** precipitate Zn
- **Zn-P compounds** become unavailable

- **Reduced Zn uptake** and translocation

III. PHYSIOLOGICAL DISRUPTIONS:

1. Osmotic stress:

- **High salt concentration** in soil solution
- **Water uptake** difficulties
- **Plasmolysis** of root cells
- **Growth cessation**

2. pH changes:

- **Excessive fertilization** alters soil pH
- **Nutrient availability** affected
- **Microbial activity** disrupted
- **Root function** impaired

3. Hormonal imbalances:

- **Excess nitrogen** affects auxin levels
- **Zinc deficiency** (from P excess) reduces auxin synthesis
- **Growth regulator** disruption

IV. ENVIRONMENTAL CONSEQUENCES:

1. Eutrophication:

- **Excess N and P** runoff to water bodies
- **Algal blooms** and oxygen depletion
- **Ecosystem disruption**

2. Soil degradation:

- **Salt accumulation** from over-fertilization
- **Soil structure** deterioration
- **Beneficial microbe** reduction

3. Groundwater contamination:

- **Nitrate leaching** beyond root zone
- **Human health** risks
- **Environmental pollution**

V. ECONOMIC LOSSES:

Direct costs:

- **Reduced yield** and quality
- **Increased disease** susceptibility
- **Remediation costs**

Indirect costs:

- **Environmental cleanup**
- **Health care costs**
- **Ecosystem service** losses

VI. OPTIMAL NUTRIENT MANAGEMENT:

Liebig's Law of Minimum:

- **Growth limited** by most deficient nutrient
- **Excess of others** doesn't compensate
- **Balanced nutrition** essential

Principles of efficient fertilization:

1. Soil testing:

- **Determine existing** nutrient levels
- **Calculate requirement** based on crop needs
- **Avoid unnecessary** applications

2. Timing:

- **Split applications** match plant uptake
- **Critical growth stages** prioritized
- **Reduced losses** through leaching

3. Methods:

- **Slow-release fertilizers**
- **Precision application**
- **Integrated nutrient management**

4. Monitoring:

- **Plant tissue analysis**
- **Growth monitoring**
- **Yield optimization**

CONCLUSION:

"More is not always better" in plant nutrition. The goal is to provide **adequate amounts** of all essential nutrients in **proper balance** rather than excess quantities. **Optimal nutrition** occurs within a narrow range where all essential elements are present in sufficient quantities without reaching toxic levels or causing antagonistic effects.

Best practice: Follow **4R principles** - Right source, Right rate, Right time, Right place for sustainable and efficient nutrient management.

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6. Trace the events starting from the coming in contact with Rhizobium to a leguminous root till nodule formation. Add a note on the importance of leghemoglobin.

Solution:

Sequential Events in Nodule Formation:

STAGE 1: INITIAL CONTACT AND RECOGNITION

Event 1: Chemotaxis and Root Hair Contact

- **Rhizobium bacteria** in soil attracted to **root exudates**
- **Flavonoids** (genistein, daidzein) released by legume roots
- **Chemotactic response** - bacteria move toward root surface
- **Initial contact** with root hair tips

- **Species-specific** recognition between bacteria and host

STAGE 2: ROOT HAIR INFECTION

Event 2: Root Hair Curling

- **Nod factors** (lipochito-oligosaccharides) produced by bacteria
- **Root hair curling** response triggered
- **Shepherd's crook formation** - characteristic curved structure
- **Bacteria trapped** within the curl
- **Host plant** prepares for bacterial entry

Event 3: Infection Thread Formation

- **Plant cell wall** dissolution at infection site
- **Infection thread initiation** - tubular structure formation
- **Cellulose walls** surround growing bacteria
- **Guided growth** through root hair toward base
- **Bacterial multiplication** within infection thread

STAGE 3: CORTICAL CELL INVASION

Event 4: Infection Thread Extension

- **Thread grows through root hair** into cortical cells
- **Branching** of infection threads occurs
- **Bacterial release** into cortical cells
- **Membrane-bound compartments** (symbiosomes) formed
- **Host cell division** stimulated

STAGE 4: NODULE DEVELOPMENT

Event 5: Nodule Initiation

- **Cortical cell division** accelerated
- **Meristematic activity** in inner cortex
- **Nodule primordium** formation
- **Vascular differentiation** begins
- **Nodule shape determination** (spherical vs cylindrical)

Event 6: Nodule Maturation

- **Bacterial differentiation** into bacteroids
- **Nitrogenase synthesis** begins
- **Leghemoglobin production** starts
- **Vascular connections** established with host
- **Functional nitrogen fixation** initiated

STAGE 5: FUNCTIONAL SYMBIOSIS

Event 7: Nitrogen Fixation

- **Mature bacteroids** begin N_2 fixation
- **Nitrogenase activation** in microaerobic environment
- **Ammonia production** and export to host
- **Carbohydrate supply** from host to bacteria

- **Sustained symbiotic relationship**

MOLECULAR SIGNALING PATHWAY:

Root Exudates (Flavonoids) → Nod Gene Activation →
Nod Factor Synthesis → Plant Response →
Infection Thread Formation → Nodule Development

THE IMPORTANCE OF LEGHEMOGLOBIN:

Structure and Properties:

- **Pink-red pigment** giving nodules characteristic color
- **Similar to animal hemoglobin** but plant-produced
- **Globin portion** synthesized by plant
- **Heme portion** contributed by bacteria
- **High oxygen affinity** - 10x higher than animal hemoglobin

Critical Functions:

1. Oxygen Paradox Resolution: The Challenge:

- **Nitrogenase is oxygen-sensitive** - irreversibly inactivated by O_2
- **Bacteroids need oxygen** for respiration and ATP production
- **Plant cells require oxygen** for normal metabolism

The Solution:

- **Leghemoglobin maintains** optimal O_2 concentration
- **Free O_2 levels** kept at 10-50 nanomolar (vs 250,000 nM in air)
- **Sufficient O_2** for respiration but not enough to inhibit nitrogenase

2. Oxygen Transport Function:

- **Facilitated diffusion** of O_2 to bacteroids
- **Controlled release** at site of utilization
- **Prevents O_2 fluctuations** that could damage nitrogenase

3. Nitrogen Fixation Efficiency:

- **Enables maximum nitrogenase activity**
- **Optimal ATP generation** for N_2 fixation
- **Energy balance** between respiration and fixation

4. Structural Organization:

- **Maintains nodule architecture**
- **Spatial separation** of oxygen-requiring and oxygen-sensitive processes
- **Compartmentalization** of metabolic activities

Quantitative Importance:

- **Leghemoglobin comprises** 20-25% of total nodule protein
- **Concentration gradient** from outer cortex to central infected zone
- **Essential for** economically significant nitrogen fixation rates

Regulation:

- **Plant gene expression** (leghemoglobin gene family)
- **Coordinated with** nodule development

- **Responsive to** oxygen and nitrate levels

Evolutionary Significance:

- **Unique adaptation** allowing nitrogen fixation in aerobic conditions
- **Key innovation** enabling legume-Rhizobium symbiosis success
- **Convergent evolution** with animal oxygen-carrying proteins

Economic Impact:

- **Enables biological nitrogen fixation** worth billions of dollars annually
- **Reduces fertilizer requirement** in legume crops
- **Sustainable agriculture** through natural nitrogen input

Research Applications:

- **Biomarker** for nodule function assessment
- **Target for** improving nitrogen fixation efficiency
- **Model system** for studying plant-microbe interactions

CONCLUSION: The formation of functional root nodules is a **complex, highly regulated process** involving **precise molecular communication** between legumes and Rhizobium. **Leghemoglobin is absolutely essential** for this symbiosis, solving the fundamental incompatibility between oxygen requirement for energy production and oxygen sensitivity of nitrogen fixation machinery. Without leghemoglobin, the **economically and ecologically vital process** of biological nitrogen fixation would be impossible.

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7. Give the biochemical events occurring in the root nodule of a pulse plant. What is the end product? What is its fate?

Solution:

BIOCHEMICAL EVENTS IN ROOT NODULE:

I. NITROGEN FIXATION REACTION:

Primary Reaction:

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

Overall Process:

$N_2 + 8H^+ + 8e^- \rightarrow 2NH_3 + H_2$

Detailed Mechanism:

Step 1: Nitrogenase Complex Formation

- **Mo-Fe protein** (Component I) - catalytic component
- **Fe protein** (Component II) - electron donor
- **Complex formation** in presence of Mg^{2+} and ATP

Step 2: Electron Transfer Chain

NADH → Ferredoxin → Fe protein → Mo-Fe protein → N_2

Step 3: ATP-Dependent Reduction

- **16 ATP molecules** required per N_2 fixed
- **High energy demand** - most energy-expensive biological process

- **Concurrent H_2 evolution** - unavoidable side reaction

II. SUPPORTING BIOCHEMICAL PROCESSES:

1. Energy Generation:

- **Respiration in bacteroids** provides ATP and NADH
- **TCA cycle** and electron transport chain
- **Oxygen consumption** regulated by leghemoglobin

2. Carbon Metabolism:

- **Carbohydrates from host** (sucrose, glucose)
- **Converted to organic acids** (malate, succinate)
- **Respiratory substrates** for ATP production

3. Oxygen Regulation:

- **Leghemoglobin-mediated** oxygen transport
- **Microaerobic conditions** maintained
- **Respiratory protection** of nitrogenase

END PRODUCT:

Primary End Product: AMMONIA (NH_3)

At physiological pH: NH_4^+ (Ammonium ion)

Secondary Products:

- **Hydrogen gas (H_2)** - released or recycled by uptake hydrogenase
- **ADP + Pi** - from ATP hydrolysis

III. FATE OF AMMONIA:

IMMEDIATE PROCESSING:

1. Assimilation in Bacteroids:

NH_3 + α-ketoglutaric acid + NADPH → Glutamate + $NADP^+$ + H_2O

Enzyme: Glutamate dehydrogenase (GDH)

2. Transamination:

Glutamate + α-keto acid → α-ketoglutarate + Amino acid

EXPORT TO HOST PLANT:

Transport Forms:

- **Ureides** (allantoin, allantoic acid) - in tropical legumes
- **Amino acids** (asparagine, glutamine) - in temperate legumes

1. Ureide Pathway (Soybean, Cowpea):

NH_3 → Glutamine → Purines → Allantoin → Allantoic acid

Advantages:

- **High N:C ratio** - efficient nitrogen transport
- **Stable compounds** - non-toxic at high concentrations

2. Amide Pathway (Pea, Clover):

NH_3 → Glutamine → Asparagine

Transport mechanism:

- **Xylem transport** to shoots

- **Phloem redistribution** to growing tissues

IV. UTILIZATION IN PLANT:

1. Protein Synthesis:

Amino acids → Polypeptides → Proteins

2. Nucleic Acid Synthesis:

- **Purines and pyrimidines** from nitrogen compounds
- **DNA and RNA** synthesis
- **Cell division** and growth

3. Chlorophyll Synthesis:

Glutamate → δ-aminolevulinic acid → Chlorophyll

4. Secondary Metabolites:

- **Alkaloids** (caffeine, nicotine)
- **Hormones** (auxins, cytokinins)
- **Defense compounds**

V. METABOLIC INTEGRATION:

Carbon-Nitrogen Balance:

- **C:N ratio** regulation in plant tissues
- **Feedback control** of nitrogen fixation
- **Optimal resource allocation**

Regulatory Mechanisms:

- **Nitrate inhibition** of nitrogen fixation
- **Amino acid feedback** regulation
- **Energy status** control

VI. QUANTITATIVE ASPECTS:

Efficiency:

- **150-300 kg N/ha/year** fixed by legume crops
- **20-30% of total plant nitrogen** from fixation
- **Energy cost:** 16 ATP per N_2 molecule

Economic Value:

- **Equivalent to $100-300 worth of fertilizer** per hectare
- **Sustainable nitrogen** input for agriculture
- **Reduced environmental impact**

VII. ENVIRONMENTAL FATE:

Soil Enrichment:

- **Root and nodule senescence** releases nitrogen
- **Soil organic matter** enhancement
- **Benefit to subsequent crops**

Ecosystem Impact:

- **Increased soil fertility**
- **Enhanced biodiversity**

- **Reduced fertilizer pollution**

SUMMARY:

The **end product of nitrogen fixation is ammonia**, which is immediately converted to **ammonium** at physiological pH. Its **fate involves** complex biochemical transformations leading to:

1. **Immediate assimilation** into amino acids in bacteroids
2. **Export** as ureides or amides to plant tissues
3. **Utilization** for protein synthesis, nucleic acids, and other nitrogen compounds
4. **Integration** into plant metabolism for growth and development
5. **Long-term contribution** to soil nitrogen pool

This process represents one of the most **economically and ecologically important** biochemical pathways in agriculture, providing sustainable nitrogen input worth billions of dollars globally while reducing environmental pollution from synthetic fertilizers.

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8. Hydroponics has been shown to be a successful technique for growing of plants. Yet most of the crops are still grown on land. Why?

Solution:

REASONS WHY MOST CROPS ARE STILL GROWN ON LAND:

I. ECONOMIC FACTORS:

1. High Initial Investment:

- **Infrastructure costs** - greenhouses, systems, equipment
- **Technology requirements** - pumps, sensors, control systems
- **Setup costs** can be 10-50 times higher than traditional farming
- **Capital-intensive** nature limits adoption

2. Operating Costs:

- **Electricity** for pumps, lighting, climate control
- **Nutrient solutions** must be purchased regularly
- **Maintenance** of complex systems
- **Skilled labor** requirements increase costs

3. Economic Viability:

- **High-value crops** (tomatoes, lettuce, herbs) economically viable
- **Staple crops** (rice, wheat, corn) not cost-effective
- **Market prices** often don't justify hydroponic costs
- **Return on investment** longer compared to field crops

II. TECHNICAL CHALLENGES:

1. Nutrient Management Complexity:

- **Precise nutrient solutions** required
- **pH and EC monitoring** continuously
- **Nutrient imbalances** can occur rapidly
- **Technical expertise** needed for management

2. System Maintenance:

- **Equipment failures** can cause crop losses
- **Pump breakdowns** affect nutrient delivery
- **Clogging** of irrigation systems
- **Regular system cleaning** required

3. Disease Management:

- **Rapid disease spread** in hydroponic systems
- **Root diseases** particularly problematic
- **Sterilization** of systems needed
- **Limited pesticide options** in closed systems

III. SCALE AND PRACTICALITY:

1. Production Scale:

- **Limited production area** compared to field agriculture
- **Small-scale operations** don't meet global food demand
- **Scalability challenges** for major crop production
- **Land efficiency** varies by crop type

2. Crop Limitations:

- **Best suited for** leafy vegetables, herbs, tomatoes
- **Cereal crops** (wheat, rice, corn) less suitable
- **Root crops** difficult to grow hydroponically
- **Tree fruits** require extensive support systems

3. Geographic Limitations:

- **Climate-controlled environments** needed in many regions
- **Energy requirements** high in extreme climates
- **Limited to** areas with reliable electricity
- **Transportation costs** for remote areas

IV. RESOURCE REQUIREMENTS:

1. Water Quality:

- **High-quality water** essential
- **Water treatment** may be necessary
- **Salinity issues** in some regions
- **Continuous water supply** required

2. Energy Demands:

- **Electricity** for pumps, lights, climate control
- **High energy costs** in many regions
- **Carbon footprint** from electricity use
- **Renewable energy** integration challenging

3. Skilled Labor:

- **Technical knowledge** required
- **Training programs** limited

- **Higher wages** for skilled workers
- **Continuous monitoring** needed

V. ADVANTAGES OF SOIL-BASED AGRICULTURE:

1. Natural Benefits:

- **Soil already contains** many essential nutrients
- **Natural buffering capacity** of soil
- **Beneficial microorganisms** present
- **Self-regulating ecosystem**

2. Low-Cost Production:

- **Minimal infrastructure** required
- **Natural rainfall** provides water
- **Solar energy** powers photosynthesis
- **Traditional knowledge** available

3. Large-Scale Feasibility:

- **Vast areas available** for cultivation
- **Mechanization possible** for large fields
- **Bulk production** economically viable
- **Global food security** depends on field crops

VI. SPECIFIC APPLICATIONS WHERE HYDROPONICS SUCCEEDS:

1. High-Value Crops:

- **Greenhouse tomatoes** - premium prices
- **Leafy greens** - year-round production
- **Herbs** - high value per unit area
- **Strawberries** - extended season

2. Challenging Environments:

- **Desert regions** - water conservation
- **Urban areas** - space limitations
- **Contaminated soils** - avoidance of soil problems
- **Controlled environments** - research applications

3. Special Situations:

- **Space research** - NASA studies
- **Vertical farming** - urban agriculture
- **Teaching tools** - educational demonstrations
- **Pharmaceutical plants** - controlled conditions

VII. FUTURE PROSPECTS:

1. Technological Improvements:

- **Automation** reducing labor costs
- **LED technology** improving energy efficiency
- **Sensor technology** simplifying management
- **AI and IoT** integration

2. Economic Trends:

- **Rising land costs** making hydroponics competitive
- **Water scarcity** increasing hydroponic adoption
- **Urban agriculture** growth
- **Consumer preferences** for local, pesticide-free produce

3. Research Developments:

- **Nutrient film technique** improvements
- **Deep water culture** optimization
- **Aeroponics** advancement
- **Integrated pest management** in hydroponic systems

CONCLUSION:

While **hydroponics is successful** for specific applications, **traditional soil-based agriculture remains dominant** because:

1. **Economic reality** - most crops cannot justify hydroponic costs
2. **Scale requirements** - global food security depends on large-scale field production
3. **Natural advantages** - soil provides many benefits at low cost
4. **Technical complexity** - requires expertise not widely available
5. **Resource limitations** - energy and water requirements significant

Hydroponics will likely expand in:

- **High-value crop production**
- **Urban and peri-urban agriculture**
- **Regions with poor soil or climate**
- **Controlled environment research**

However, **field agriculture will continue** to provide the bulk of global food production due to its **economic efficiency** and **ability to operate at the scale required** for feeding the world's population.

The **future likely involves** both systems coexisting, with **hydroponics filling specialized niches** while **traditional agriculture** continues as the backbone of global food production