

BOTANY

Plant Physiology Metabolism & Biochemistry

for

B.Sc. Sem. V
(Paper 1)

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CONTENTS

UNIT 1. Plant water relation, Mineral Nutrition, Transpiration and translocation in phloem 1-25

Importance of water, water potential and its components; Transpiration and its significance; Factors affecting transpiration; Root pressure and guttation.

Criteria of essentiality of elements; Role of essential elements; Symptoms of mineral deficiency in major crops,

Transport of ions across cell membrane, active and passive transport, Composition of phloem sap, girdling experiment; Pressure flow model.

UNIT 2. Carbon Oxidation 26-48

Krebs cycle, Glycolysis, fate of pyruvate- aerobic and anaerobic respiration and fermentation, regulation of glycolysis, oxidative pentose phosphate pathway, oxidative decarboxylation of pyruvate, regulation of Krebs cycle, mitochondrial electron transport, oxidative phosphorylation, ATP-Synthetase, Chemiosmotic mechanism, P/O ratio, cyanide-resistant respiration, factors affecting respiration.

UNIT 3. Nitrogen Metabolism 49-64

Nitrate assimilation, biological nitrogen fixation (examples of legumes and non-legumes), Physiology and biochemistry of nitrogen fixation, Ammonia assimilation (GS-GOGAT), reductive amination and transamination, amino acid synthesis

UNIT 4. Lipid Metabolism and Photosynthesis 65-89

Lipid Metabolism: Synthesis and breakdown of triglycerides, -oxidation, glyoxylate cycle, gluconeogenesis and its role in mobilization of lipids during seed germination, -oxidation. ;

Photosynthesis: Pigments, Action spectra and Enhancement effect, Electron transport system and Photophosphorylation, C3 & C4 photosynthesis, CAM- Reaction and Significance

UNIT 5. Plant Development, Movements, Dormancy & Responses 90-119

Developmental roles of Phytohormones (auxins, gibberellins, cytokinins, ABA, ethylene.) autonomic & paratonic movements, Photoperiodism (SDP, LDP, Day neutral plants); Phytochrome (discovery and structure), red and far red-light responses on photomorphogenesis, Seed physiology & Dormancy, Vernalization & Senescence

UNIT 6. Biomolecules 120-138

Carbohydrates: Nomenclature and classification; Role of monosaccharides (glucose, fructose, sugar alcohols – mannitol and sorbitol); Disaccharides (sucrose, maltose, lactose), Oligosaccharides and polysaccharides (structural-cellulose, hemicelluloses, pectin, chitin, mucilage; storage – starch, inulin).

Lipids: Storage lipids: Fatty acids structure and functions, Structural lipids: Phosphoglycerides; Lipid functions: cell signals, cofactors, prostaglandins, Introduction of lipid micelles, monolayers, bilayers

UNIT 7. Proteins and Nucleic Acids 139-156

Proteins: Structure of amino acids; Peptide bonds; Levels of protein structure-primary, secondary, Ramchandran plot, tertiary and quaternary; Isoelectric point; Protein denaturation and biological roles of proteins

Nucleic acids: Structure of nitrogenous bases; Structure and function of nucleic acids, Nucleic acid denaturation & Re-naturation, MiRNA

UNIT 8. Enzymes 157-168

Enzymes: Structure of enzyme: holoenzyme, apoenzyme, cofactors, coenzymes and prosthetic group; mechanism of action (activation energy, lock and key hypothesis, induced-fit theory), enzyme inhibition and factors affecting enzyme activity, Allosteric enzymes & Abzymes.

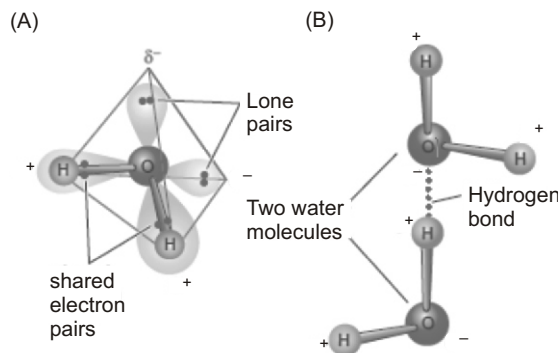
Elementary knowledge of Phytonutrients, Nutraceuticals, dietary supplements and antioxidants.

UNIT 1

Plant Water Relation, Mineral Nutrition, Transpiration and Translocation in Phloem

PLANT WATER RELATION

Water is essential for all living organisms and plays a crucial role in various biological, chemical, and physical processes. Understanding water potential () and its components helps explain how water moves within plants, soils, and cells.



Structure of the water molecule. (A) The strong electronegativity of the oxygen atom means that the two electrons that form the covalent bond with hydrogen are unequally shared, such that each hydrogen atom has a partial positive charge. Each of the two lone pairs of electrons of the oxygen atom produces a partial negative charge. (B) The opposite partial charges (δ^+ and δ^-) on the water molecule lead to the formation of intermolecular hydrogen bonds with other water molecules. Oxygen has six electrons in the outer orbitals; each hydrogen has one.

Importance of Water

Water is vital for life due to its unique properties:

- **Universal Solvent:** Dissolves nutrients and minerals for transport in organisms.
- **Medium for Biochemical Reactions:** Essential for photosynthesis, respiration, and hydrolysis.
- **Temperature Regulation:** High specific heat capacity helps maintain stable temperatures.
- **Structural Support:** Provides turgor pressure in plant cells.
- **Transport Medium:** Facilitates the movement of substances in blood (animals) and xylem/phloem (plants).
- **Habitat:** Supports aquatic ecosystems.

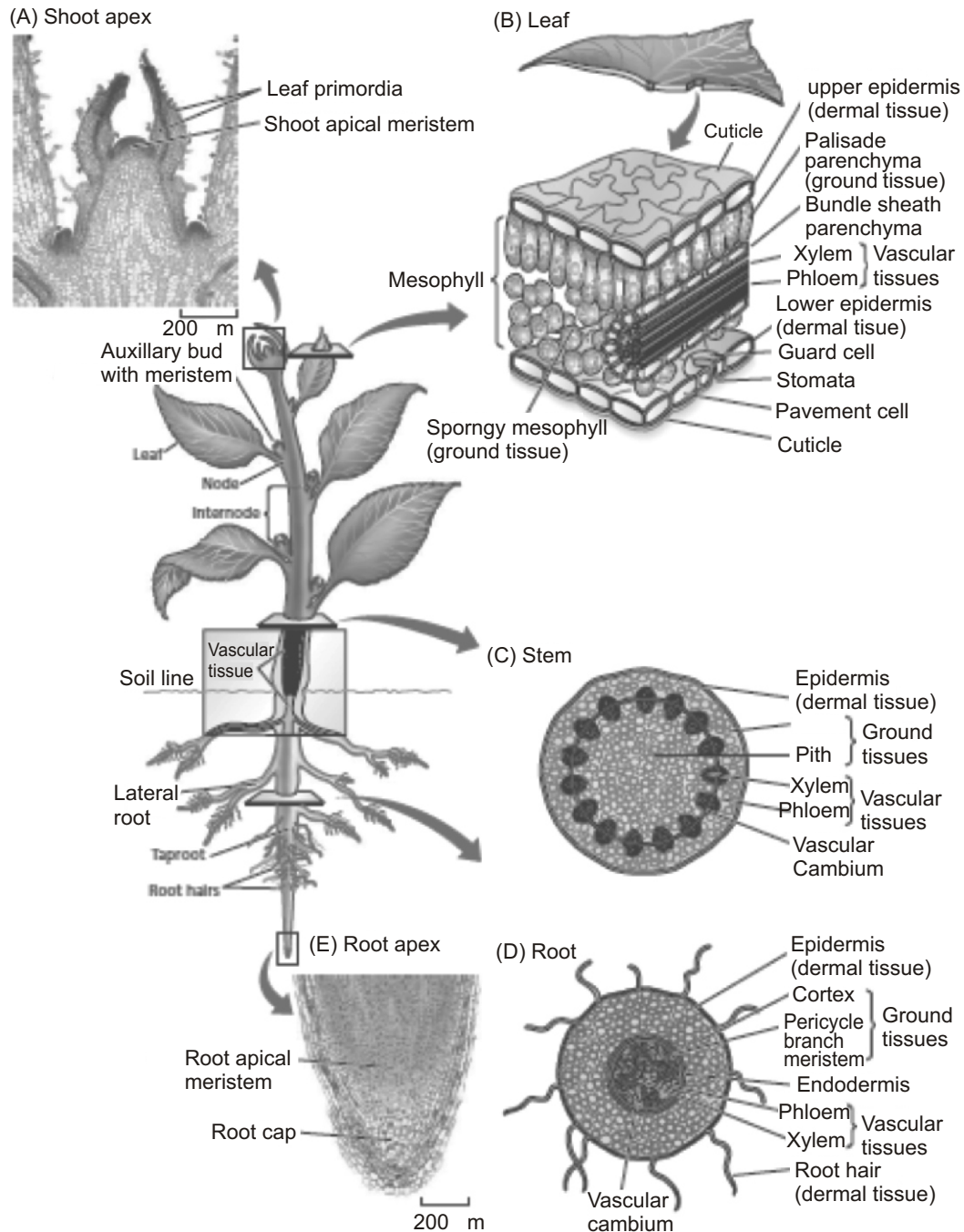
Water Potential ()

Water potential () is a measure of the potential energy of water per unit volume, determining the direction and rate of water movement. Water moves from high to low . It is measured in megapascals (MPa) and is the sum of its components:

$$\psi = \psi_s + \psi_p + \psi_g + \psi_m$$

Where:

- ψ_s Solute potential (Osmotic potential)
- ψ_p Pressure potential
- ψ_g Gravitational potential
- ψ_m Matric potential (in soils)



Cross sections of the (A) shoot apex, (B) leaf, (C) stem, (D) root, and (E) root apex are also shown. The longitudinal sections of the shoot apex and the root apex.

Components of Water Potential

(A) Solute Potential (ψ_s) (Osmotic Potential)

- **Definition:** The effect of dissolved solutes on water potential.
- **Value:** Always negative (since solutes reduce free water molecules).

The term ψ_s , called the solute potential or the osmotic potential, represents the effect of dissolved solutes on water potential. Solutes reduce the free energy of water by diluting the water. This is primarily an entropy effect; that is, the mixing of solutes and water increases the disorder or entropy of the system and thereby lowers the free energy. This means that the osmotic potential is independent of the specific nature of the solute. For dilute solutions of nondissociating substances such as sucrose, the osmotic potential may be approximated by:

$$\psi_s = -RTC_s$$

where R is the gas constant ($8.32 \text{ J mol}^{-1} \text{ K}^{-1}$), T is the absolute

temperature (in degrees Kelvin, or K), and c_s is the solute concentration of the solution, expressed as osmolarity

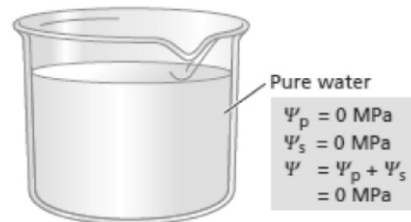
(moles of total dissolved solutes per volume of water [mol L^{-1}]). The minus sign indicates that dissolved solutes reduce the water potential of a solution relative to the reference state of pure water.

- **Role:** Determines osmotic movement of water (e.g., water uptake by roots).

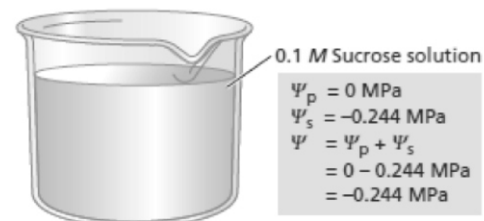
(B) Pressure Potential (ψ_p)

- **Definition:** Physical pressure exerted on water (positive or negative).
- **Positive Pressure:**
 - Turgor pressure in plant cells (keeps them rigid).
 - Root pressure pushes water upward.
- **Negative Pressure (Tension):**
 - Transpiration pull in xylem creates tension.

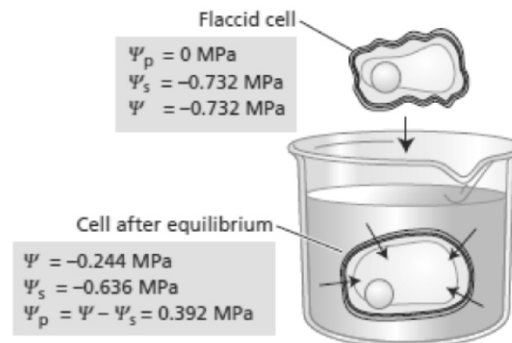
(A) Pure water



(B) Solution containing 0.1 M sucrose



(C) Flaccid cell dropped into sucrose solution



Water potential gradients can cause water to enter a cell. (A) Pure water. (B) A solution containing 0.1 M sucrose. (C) A flaccid cell (in air) is dropped in a 0.1 M sucrose solution. Because the starting water potential of the cell is less than the water potential of the solution, the cell takes up water. After equilibration, the water potential of the cell equals the water potential of the solution, and the result is a cell with a positive turgor pressure.

The term ψ_p , called the pressure potential, represents the effect of hydrostatic pressure on the free energy of water. Positive

pressures raise the water potential; negative pressures reduce it. Both positive and negative pressures occur within plants. The positive hydrostatic pressure within cells is referred to as turgor pressure. Negative hydrostatic pressures, which frequently develop in xylem conduits, are referred to as tension.

(C) Gravitational Potential (ψ_g)

- **Definition:** Effect of gravity on water potential (important in tall trees).
- **Value:** Positive if water is above reference point, negative if below.

Gravity causes water to move downward unless the force of gravity is opposed by an equal and opposite force. The gravitational potential (ψ_g) depends on the height (h) of the water above the reference-state water, the density of water (ρ_w), and the acceleration due to gravity (g). In symbols, we write the following:

$$\psi_g = \rho_w gh$$

where $\rho_w g$ has a value of 0.01 MPa m^{-1} . Thus, raising water a distance of 10 m translates into a 0.1 MPa increase in water potential.

The gravitational component (ψ_g) is generally omitted in considerations of water transport at the cell level, because differences in this component among neighboring cells are negligible compared with differences in the osmotic potential and the pressure potential.

Thus, in these cases equation can be simplified as follows:

(D) Matric Potential (ψ_m)

Definition: Adhesive forces between water and surfaces (e.g., soil particles, cell walls).

- **Value:** Always negative (reduces free energy of water).
- **Role:** Important in soil water retention and capillary action in plants.

Applications of Water Potential

1. **Plant Water Uptake:** Roots absorb water from soil ($\psi_{\text{soil}} > \psi_{\text{root}}$).
2. **Transpiration:** Water moves from high (ψ_{roots}) to low (ψ_{leaves}).
3. **Osmoregulation:** Cells adjust ψ to maintain turgor.
4. **Soil-Plant-Atmosphere Continuum (SPAC):** Describes water movement from soil roots leaves air.

Conclusion

Water potential (ψ) and its components explain how water moves in biological systems. By understanding solute potential (ψ_s), pressure potential (ψ_p), gravitational potential (ψ_g), and matric potential (ψ_m), we can analyze processes like osmosis, transpiration, and plant hydration. This concept is crucial in agriculture, ecology, and plant physiology.

TRANSPIRATION

What is Transpiration?

Transpiration is the loss of water vapor from the aerial parts of plants, primarily through stomata in leaves, but also through lenticels (in stems) and cuticles (waxy layer). It is a crucial part of the water cycle and the Soil-Plant-Atmosphere Continuum (SPAC).

Significance of Transpiration

(A) Positive Effects

1. Creates Transpiration Pull (Cohesion-Tension Theory)

- Water moves upward from roots to leaves due to negative pressure (tension) generated by evaporation.
- Helps in xylem transport of water and minerals.

2. Cooling Effect (Thermoregulation)

- Evaporation of water cools leaves (similar to sweating in animals).

3. Maintains Turgor Pressure

- Ensures cell rigidity and supports plant structure.

4. Facilitates Mineral Absorption & Transport

- Water movement carries dissolved nutrients from roots to shoots.

5. Maintains Hydration for Photosynthesis

- Supplies water needed for CO_2 uptake through stomata.

(B) Negative Effects (Disadvantages)

1. Water Stress

- Excessive transpiration can lead to wilting in drought conditions.

2. Energy Cost

- Plants must balance CO_2 intake (for photosynthesis) with water loss.

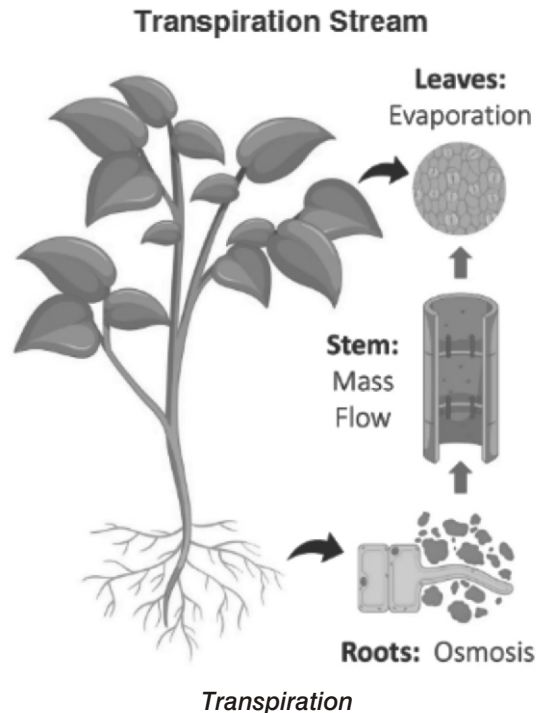
Factors Affecting Transpiration

Transpiration is influenced by environmental (external) factors and plant (internal) factors. These factors determine the rate at which water is lost from leaves through stomata, cuticles, and lenticels.

👉 Environmental (External) Factors

(A) Light

- **Effect:** Increase Transpiration
- **Reason:**



Stomata open in light for photosynthesis, increasing water loss.

In darkness, stomata close (except in CAM plants, which open stomata at night).

(B) Temperature

- **Effect:** Increase Transpiration (up to a point)
- **Reason:**
Higher temperature increases evaporation from leaf surfaces. Very high temperatures ($>35-40^\circ\text{C}$) may cause stomatal closure to prevent excessive water loss.

(C) Humidity (Atmospheric Moisture)

- **Effect:** Decrease Transpiration
- **Reason:**
High humidity reduces the water vapor gradient between leaf and air, slowing transpiration.

Low humidity increases transpiration because dry air pulls more water out.

(D) Wind Speed / Air Movement

- **Effect:** Initially Increase Transpiration, but very high wind may decrease it
- **Reason:**
Gentle wind removes water vapor near stomata, increasing evaporation.
Strong wind may cause stomatal closure (to prevent dehydration) or cool the leaf, reducing transpiration.

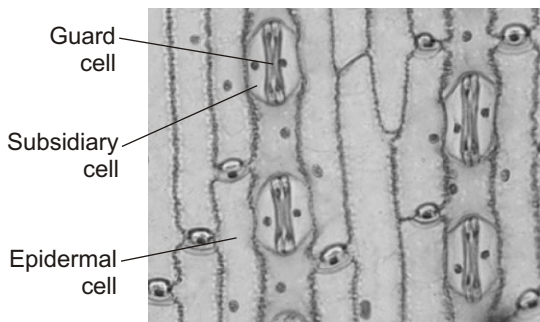
(E) Soil Water Availability

- **Effect:** Increase Transpiration (if water is scarce)
- **Reason:**
Drought leads to root water deficit, triggering ABA hormone release, which closes stomata.
Well-watered plants transpire more.

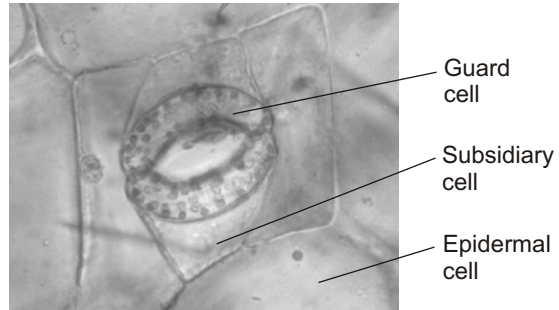
🔍 Plant (Internal) Factors

(A) Stomatal Number & Distribution

- More stomata = Increase Transpiration
E.g., Sun leaves have more stomata than shade leaves.
- Stomatal position matters:
Sunken stomata (e.g., in pine needles) reduce transpiration.



Stomata of corn (Zea mays), showing the dumbbell-shaped guard cells typical of grasses.



Most plants have kidney-shaped guard cells, as seen in this open stoma of Tradescantia zebrina.

(B) Leaf Structure & Cuticle Thickness

- Thick waxy cuticle (e.g., in cacti) Decrease Transpiration.
- Hairy leaves (e.g., in olive plants) trap moisture, reducing water loss.
- Needle-like leaves (e.g., in conifers) reduce surface area for evaporation.

(C) Root-Shoot Ratio

- Deep/extensive roots = Increase Water uptake = Sustained transpiration.
- Shallow roots = Limited water supply = Reduced transpiration under drought.

(D) Hormonal Control (Abscissic Acid - ABA)

- ABA is released during water stress, causing stomatal closure Decrease Transpiration.

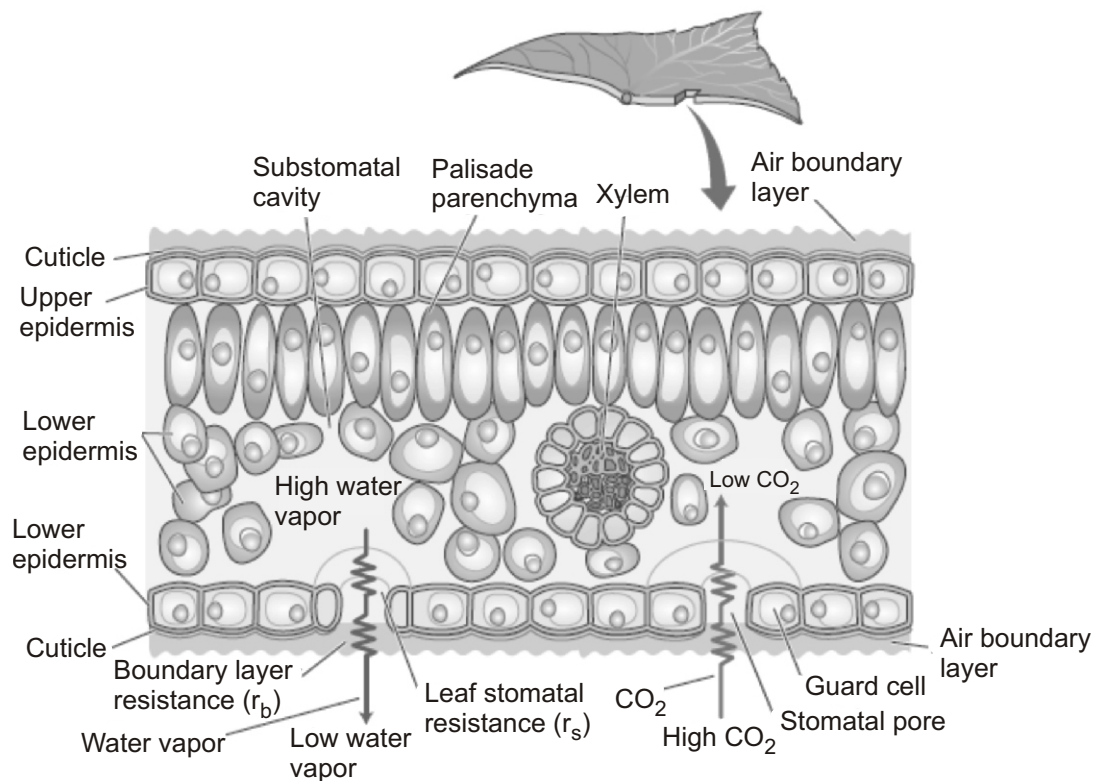
🔍 Adaptations to Control Transpiration

(A) Xerophytes (Desert Plants)

- Reduced leaves (e.g., cactus spines).
- CAM photosynthesis (open stomata at night).
- Sunken stomata (reduce air exposure).

(B) Hydrophytes (Aquatic Plants)

- No stomata on upper leaf surface (only on lower side).
- Thin/no cuticle (since water loss is not a problem).



Water pathway through the leaf. Water is pulled from the xylem into the cell walls of the mesophyll, where it evaporates into the air spaces within the leaf. Water vapor then diffuses through the leaf air space, through the stomatal pore, and across the boundary layer of still air found next to the leaf surface. CO₂ diffuses in the opposite direction along its concentration gradient (low inside, higher outside).

ROOT PRESSURE AND GUTTATION

Root Pressure

Definition: A positive hydrostatic pressure developed in the roots due to active water absorption, which helps push water upward in the xylem.

Mechanism:

- Active transport of ions (e.g., K⁺, Na⁺) into root xylem lowers solute potential (ψ_s).
- Water enters by osmosis, increasing pressure potential (ψ_p).

- This creates root pressure (typically 1-2 atm), forcing water upward.

Evidence of Root Pressure:

- **Bleeding:** Sap exudation from cut stems (e.g., in tomato, grapevines).
- Guttation (discussed below).

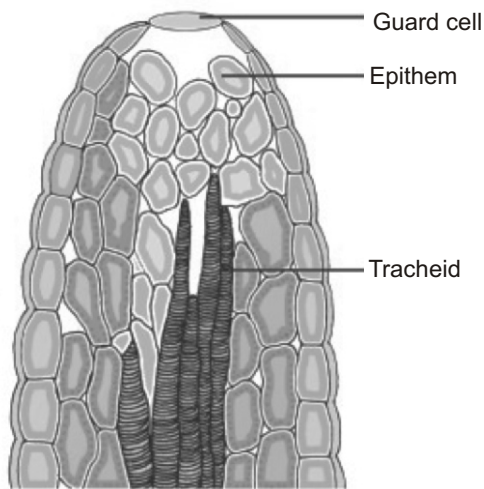
Limitations:

- Only significant in small plants (not tall trees).
- Works best at night/early morning (low transpiration).

- Cannot explain water ascent beyond ~20 meters (transpiration pull is dominant).

Guttation

Definition: The exudation of water droplets from leaf margins (hydathodes) due to root pressure.



Structure of Hydathode

Process:

1. At night, low transpiration + high root pressure push water up.
2. Water accumulates in hydathodes (special pores at leaf edges).
3. Drops are forced out due to positive pressure.

Conditions Favouring Guttation:

- High soil moisture (e.g., after irrigation/ rain).
- High humidity (reduces transpiration).
- Cool nights (slows evaporation).

Examples:

Grasses, strawberries, colocasia (hydathodes visible as "water pores").

Guttation vs. Dew:

Feature	Guttation	Dew
Source	Pushed out by root pressure	Condensation from atmosphere
Location	Leaf edges (hydathodes)	Entire leaf surface
Time	Early morning	Cold nights/ early morning

Significance of Root Pressure & Guttation

(A) Root Pressure

- Helps refill xylem vessels after cavitation (air bubble formation).
- Supports water uptake in small/ herbaceous plants.

(B) Guttation

- Removes excess water/minerals (e.g., salts).
- Indicates active root function (used in agriculture to monitor plant health).

Limitations

- Not energy-efficient for tall plants (relies on passive transpiration pull).
- Guttation can spread pathogens (e.g., bacteria through hydathodes).

Root Pressure vs. Transpiration Pull

Feature	Root Pressure	Transpiration Pull
Force	Push (positive pressure)	Pull (negative pressure/ tension)
Energy	Active (ATP-dependent)	Passive (solar energy)
Time	Night/early morning	Daytime (high light)
Height Limit	~20 meters	>100 meters (in tall trees)

Factors Affecting Transpiration**(A) Environmental (External) Factors**

Factor	Effect on Transpiration	Explanation
Light	Transpiration	Stomata open in light for photosynthesis, increasing water loss.
Temperature	Transpiration	Higher temps increase evaporation rate from leaf surfaces.
Humidity	Transpiration	High humidity reduces the water vapor gradient, slowing transpiration.
Wind Speed	Transpiration (initially)	Removes water vapor near stomata, increasing evaporation. (Very high wind can close stomata).
Soil Water Availability	Transpiration (if low)	Drought reduces water uptake, leading to stomatal closure.

(B) Plant (Internal) Factors

Factor	Effect on Transpiration	Explanation
Stomatal Number & Distribution	More stomata = More Transpiration	Plants in dry areas may have fewer stomata to conserve water.
Cuticle Thickness	Decrease Transpiration	Thick waxy cuticles reduce water loss (e.g., xerophytes).
Root-Shoot Ratio	Deep roots = Water uptake	More roots help maintain transpiration under dry conditions.
Hormonal Control (ABA - Absciscic Acid)	Decrease Transpiration (under stress)	ABA triggers stomatal closure during drought.

🔍 Adaptations to Reduce Transpiration (Xerophytes)

Plants in dry environments (xerophytes) have adaptations to minimize water loss:

- Sunken stomata (reduce air flow near pores).
- Reduced leaf size (e.g., cactus spines).
- Thick cuticle (limits evaporation).
- CAM Photosynthesis (stomata open at night).

🔍 Measurement of Transpiration

- **Potometer:** Measures water uptake (indirectly estimates transpiration).
- **Cobalt Chloride Paper:** Changes color with humidity near stomata.
- **Weighing Method:** Measures water loss over time.

MINERAL NUTRITION

Criteria of Essentiality of Elements

For an element to be considered essential for plant growth, it must meet specific criteria established by Arnon & Stout (1939). These criteria help distinguish between elements that are vital for plant survival and those that are merely beneficial or non-essential.

Arnon & Stout's Criteria of Essentiality

An element is considered essential if:

1. **Necessity for Growth & Reproduction**
 - The plant cannot complete its life cycle (seed → mature plant → seed) without the element.
2. **Specificity of Function**
 - The element has a specific physiological role (e.g., Mg in chlorophyll, N in proteins).
 - Its deficiency causes specific symptoms that can only be reversed by supplying that element.
3. **Direct Involvement in Metabolism**
 - The element must be directly involved in plant biochemistry (not just indirectly influencing other elements).

Classification of Essential Elements

Based on the criteria, essential elements are divided into:

(A) Macronutrients (Required in Large Amounts)

Element	Role in Plants
Carbon (C)	Main component of organic molecules (carbohydrates, lipids, proteins).
Hydrogen (H)	Part of water and organic compounds.
Oxygen (O)	Essential for respiration and organic molecules.

Nitrogen (N)	Component of amino acids, proteins, chlorophyll, and nucleic acids.
Phosphorus (P)	ATP, nucleic acids, phospholipids.
Potassium (K)	Osmotic regulation, enzyme activation, stomatal function.
Calcium (Ca)	Cell wall structure (middle lamella), membrane stability.
Magnesium (Mg)	Central atom in chlorophyll, enzyme cofactor.
Sulfur (S)	Amino acids (cysteine, methionine), vitamins, coenzymes.

(B) Micronutrients (Required in Trace Amounts)

Element	Role in Plants
Iron (Fe)	Chlorophyll synthesis, electron transport (cytochromes).
Manganese (Mn)	Photosystem II, enzyme activation.
Zinc (Zn)	Auxin synthesis, enzyme cofactor.
Copper (Cu)	Electron transport (plastocyanin), lignin formation.
Boron (B)	Cell wall formation, sugar transport.
Molybdenum (Mo)	Nitrogen fixation (nitrate reductase).
Chlorine (Cl)	Osmotic balance, photosynthesis (water-splitting complex).
Nickel (Ni)	Urease enzyme (urea metabolism).

Beneficial vs. Non-Essential Elements

Category	Examples	Role
Beneficial Elements	Silicon (Si), Sodium (Na), Cobalt (Co)	Enhance growth but not strictly essential.
Non-Essential Elements	Aluminum (Al), Lead (Pb), Cadmium (Cd)	No known biological function; may be toxic.

🔑 Importance of Essentiality Criteria

- Helps in fertilizer formulation (NPK fertilizers).
- Guides diagnosis of nutrient deficiencies (e.g., yellowing leaves = N deficiency).
- Differentiates between essential and toxic elements (e.g., excess Na harms plants).

🔑 Conclusion

An element is essential only if it meets all three criteria (necessary for life cycle, has a specific role, and is directly involved in metabolism). Macronutrients and micronutrients are classified based on their quantity required, but all are equally vital for plant survival.

Role of Essential Elements in Plants

Essential elements play critical roles in plant growth, development, and metabolism. They are classified into macronutrients (required in larger amounts) and micronutrients (required in trace amounts). Below is a detailed breakdown of their functions:

🔑 Macronutrients**(A) Primary Macronutrients (NPK - Most Critical)**

Element	Major Roles	Deficiency Symptoms
Nitrogen (N)	- Component of amino acids, proteins, chlorophyll, nucleic acids (DNA/RNA). - Promotes leaf growth (vegetative phase).	- Yellowing (chlorosis) of older leaves. - Stunted growth.
Phosphorus (P)	- Key in ATP, nucleic acids, phospholipids (cell membranes). - Important for root development, flowering, seed formation.	- Dark green/purple leaves. - Poor root growth.
Potassium (K)	- Regulates stomatal opening, enzyme activation, osmotic balance. - Improves disease resistance & fruit quality.	- Leaf edge scorching (necrosis). - Weak stems.

(B) Secondary Macronutrients

Element	Major Roles	Deficiency Symptoms
Calcium (Ca)	- Strengthens cell walls (middle lamella). - Involved in cell division & membrane stability.	- Young leaves distorted (tip burn). - Blossom end rot (tomatoes).
Magnesium (Mg)	- Central atom in chlorophyll. - Activates enzymes in photosynthesis & respiration.	- Interveinal chlorosis (yellowing between veins).
Sulfur (S)	- Component of cysteine, methionine (amino acids), vitamins, coenzymes.	- Yellowing of young leaves (similar to N deficiency but in new growth).

Micronutrients (Trace Elements)

Element	Major Roles	Deficiency Symptoms
Iron (Fe)	- Essential for chlorophyll synthesis, electron transport (cytochromes).	- Interveinal chlorosis in young leaves.
Manganese (Mn)	- Activates enzymes in photosynthesis (PS-II), nitrogen metabolism.	- Interveinal chlorosis with necrotic spots.
Zinc (Zn)	- Needed for auxin (IAA) synthesis, enzyme activation (alcohol dehydrogenase).	- Stunted growth, small leaves (rosette formation).
Copper (Cu)	- Involved in electron transport (plastocyanin), lignin synthesis.	- Wilting, twisted young leaves.
Boron (B)	- Important for cell wall formation, pollen tube growth, sugar transport.	- Brittle leaves, hollow stems, poor fruiting.
Molybdenum (Mo)	- Required for nitrogen fixation (nitrate reductase enzyme).	- Yellowing & curling of leaves (similar to N deficiency).
Chlorine (Cl)	- Maintains osmotic balance, photosynthesis (water-splitting complex).	- Wilting, bronzed leaves (rare deficiency).
Nickel (Ni)	- Activates urease enzyme (urea breakdown).	- Leaf tip necrosis (rare deficiency).

** Key Functions of Essential Elements****(A) Structural Roles**

- C, H, O: Building blocks of carbohydrates, lipids, proteins.
- Ca, B: Strengthen cell walls.
- Mg, Fe: Central to chlorophyll.

(B) Enzymatic & Metabolic Roles

- **K, Mn, Zn, Cu:** Act as enzyme activators/cofactors.
- **N, S:** Required for amino acid & protein synthesis.
- **P:** Part of ATP, DNA, RNA.

(C) Osmotic & Ionic Balance

- **K, Cl:** Maintain turgor pressure & stomatal function.
- **Ca:** Stabilizes cell membranes.

(D) Energy Transfer & Redox Reactions

- **Fe, Cu, Mn:** Involved in electron transport (photosynthesis & respiration).

☞ Deficiency vs. Toxicity

- **Deficiency:** Leads to stunted growth, chlorosis, necrosis.
- **Toxicity (Excess):** Can cause leaf burn, nutrient imbalances (e.g., excess K inhibits Mg uptake).

☞ Conclusion

Each essential element has specific biochemical roles crucial for plant survival. Macronutrients are needed in large quantities for structural and metabolic functions, while micronutrients act as enzyme cofactors. Balanced nutrition is vital for optimal plant growth, and deficiencies can be diagnosed through leaf symptoms.

Mineral Deficiency Symptoms in Major Crops

Mineral deficiencies can severely impact crop yield and quality. Below are the key deficiency symptoms observed in major crops (rice, wheat, maize, potato, tomato, and legumes), categorized by essential elements.

☞ Macronutrient Deficiencies**(A) Nitrogen (N) Deficiency**

- **Crops Affected:** Rice, Wheat, Maize, Tomato, Potato.
- **Symptoms:**
 - Yellowing (chlorosis) of older leaves (N is mobile).
 - Stunted growth, thin stems.
 - Delayed maturity (e.g., late flowering in wheat).

(B) Phosphorus (P) Deficiency

- **Crops Affected:** Maize, Potato, Legumes (Soybean, Peas).
- **Symptoms:**
 - Dark green/purple leaves (anthocyanin accumulation).
 - Poor root development (short, stubby roots in potatoes).
 - Reduced flowering & fruiting (tomatoes, legumes).

(C) Potassium (K) Deficiency

- **Crops Affected:** Banana, Potato, Tomato, Wheat.
- **Symptoms:**
 - Scorching/browning of leaf edges (necrosis).
 - Weak stems & lodging (falling over in wheat).
 - Poor fruit quality (uneven ripening in tomatoes).

(D) Calcium (Ca) Deficiency

- **Crops Affected:** Tomato, Apple, Potato, Legumes.
- **Symptoms:**
 - Blossom-end rot (dark, sunken spots on tomato fruits).
 - Young leaves distorted/cupped (tip burn in cabbage).
 - Weak cell walls (cracked potatoes).

(E) Magnesium (Mg) Deficiency

- **Crops Affected:** Potato, Tomato, Citrus, Wheat.
- **Symptoms:**
 - Interveinal chlorosis (yellowing between veins) in older leaves.
 - Leaf curling & premature drop (tomatoes).

(F) Sulfur (S) Deficiency

- **Crops Affected:** Canola, Wheat, Legumes.
- **Symptoms:**
 - Yellowing of young leaves (similar to N but affects new growth first).

Stunted growth (smaller leaves in wheat).

🔧 Micronutrient Deficiencies

(A) Iron (Fe) Deficiency

- **Crops Affected:** Rice, Soybean, Citrus.
- **Symptoms:**
Interveinal chlorosis in young leaves (veins remain green).
Severe in high-pH soils (e.g., calcareous soils).

(B) Zinc (Zn) Deficiency

- **Crops Affected:** Maize, Rice, Wheat.
- **Symptoms:**
Stunted growth (rosette formation) in maize.
White streaks (midrib chlorosis) in rice ("Khaira disease").

(C) Boron (B) Deficiency

- **Crops Affected:** Sugar beet, Potato, Apple.
- **Symptoms:**
Brittle leaves & cracked stems.
Hollow heart in potatoes & malformed fruits (apple).

(D) Manganese (Mn) Deficiency

- **Crops Affected:** Oats, Wheat, Soybean.
- **Symptoms:**
Gray speck disease in oats (necrotic spots).
Interveinal chlorosis (similar to Mg but in young leaves).

(E) Copper (Cu) Deficiency

- **Crops Affected:** Wheat, Barley.
- **Symptoms:**
Wilting & twisted young leaves.
"White tip" disease in wheat.

(F) Molybdenum (Mo) Deficiency

Crops Affected: Legumes (Peas, Beans), Cauliflower.

Symptoms:

Yellowing & cupping of leaves (whiptail in cauliflower).

Poor nitrogen fixation in legumes.

Crop-Specific Deficiency Symptoms

Crop	Most Common Deficiencies	Key Symptoms
Rice	N, Zn, Fe	Yellowing (N), Khaira disease (Zn), Interveinal chlorosis (Fe).
Wheat	N, P, K, Cu	Lodging (K), Purple leaves (P), White tip (Cu).
Maize	N, Zn, Mg	Stunted growth (Zn), Yellow stripes (Mg).
Tomato	Ca, Mg, K	Blossom-end rot (Ca), Leaf curl (Mg), Scorched edges (K).
Potato	K, B, Mg	Cracked tubers (B), Purple leaves (P).
Soybean	Fe, Mn, Mo	Interveinal chlorosis (Fe), Poor nodules (Mo).

🔧 Diagnosis & Correction

- **Visual Symptoms:** Compare leaf patterns (old vs. new leaves).
- **Soil Testing:** Identifies pH-related deficiencies (e.g., Fe in alkaline soils).
- **Fertilizer Solutions:**
Foliar sprays (for quick correction of micronutrients).
Soil amendments (lime for Ca, gypsum for S).

🔧 Conclusion

Mineral deficiencies vary by crop and soil type, but key symptoms (chlorosis, necrosis, stunting) help diagnose issues. Balanced fertilization is crucial for optimal yield.

TRANSPORT OF IONS ACROSS CELL MEMBRANES: ACTIVE AND PASSIVE TRANSPORT

Biological membranes regulate the movement of ions (e.g., K^+ , Na^+ , Ca^{2+} , Cl^-) and molecules to maintain cellular homeostasis. Transport mechanisms are classified into passive (no energy required) and active (energy-dependent) processes.

👉 Passive Transport

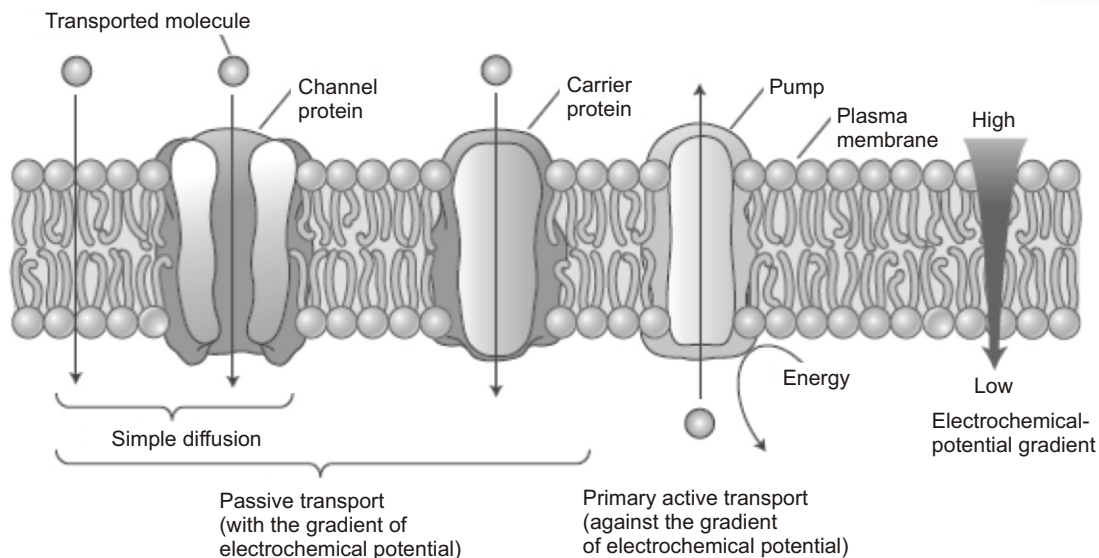
Movement along a concentration/electrochemical gradient (high → low), no ATP needed.

A. Simple Diffusion

- **Mechanism:** Direct movement of small, nonpolar molecules (O_2 , CO_2) or ions through the lipid bilayer.
- **Example:** O_2 entering cells, CO_2 exiting.

B. Facilitated Diffusion

- **Mechanism:** Carrier proteins or channels assist polar/charged molecules.
 - Channel Proteins:** Allow rapid ion flow (e.g., K^+ leak channels).
 - Carrier Proteins:** Bind and transport molecules (e.g., GLUT transporters for glucose).
- **Example:** Cl^- movement via ion channels.



Three classes of membrane transport proteins: channels, carriers, and pumps. Channels and carriers can mediate the passive transport of a solute across a membrane (by simple diffusion or facilitated diffusion) down the solute's gradient of electrochemical potential. Channel proteins act as membrane pores, and their specificity is determined primarily by the biophysical properties of the channel. Carrier proteins bind the transported molecule on one side of the membrane and release it on the other side.

C. Osmosis

- **Mechanism:** Water diffusion across semipermeable membranes (low solute high solute).
- **Example:** Root water uptake in plants.

☞ Active Transport

Movement against a gradient (low → high), requiring ATP or electrochemical energy.

A. Primary Active Transport

- **Mechanism:** Direct ATP use to pump ions.
P-Type ATPases: Na⁺/K⁺ pump (3 Na⁺ out, 2 K⁺ in per ATP).
H⁺-ATPases: In plants/fungi (acidifies extracellular space).
- **Example:** Neuronal action potentials (Na⁺/K⁺ pump).

B. Secondary Active Transport

- **Mechanism:** Uses energy from ion gradients (created by primary transport).
Symport: Same direction (e.g., Na⁺-glucose symport in intestines).
Antiport: Opposite directions (e.g., Na⁺/H⁺ exchanger in kidneys).
- **Example:** Nitrate (NO₃⁻) uptake in plant roots via H⁺ cotransport.

C. Endocytosis/Exocytosis

- **Mechanism:** Bulk transport via vesicle formation (ATP-dependent).
Phagocytosis: Engulfing large particles (e.g., immune cells).
Pinocytosis: Uptake of fluids.
- **Example:** Nutrient absorption in root hairs.

Key Differences: Active vs. Passive Transport

☞ Diagnosis & Correction

- **Visual Symptoms:** Compare leaf patterns (old vs. new leaves).
- **Soil Testing:** Identifies pH-related deficiencies (e.g., Fe in alkaline soils).
- **Fertilizer Solutions:**
 Foliar sprays (for quick correction of micronutrients).
 Soil amendments (lime for Ca, gypsum for S).

☞ Conclusion

Mineral deficiencies vary by crop and soil type, but key symptoms (chlorosis, necrosis, stunting) help diagnose issues. Balanced fertilization is crucial for optimal yield.

Key Differences: Active vs. Passive Transport

Feature	Passive Transport	Active Transport
Energy Requirement	No ATP needed	Requires ATP or gradient
Direction	High → Low concentration	Low → High concentration
Examples	Diffusion, Osmosis	Na ⁺ /K ⁺ pump, Phagocytosis
Saturation	Rate plateaus at high solute	Rate depends on ATP/transporters

TRANSLOCATION IN PHLOEM

Composition of Phloem Sap

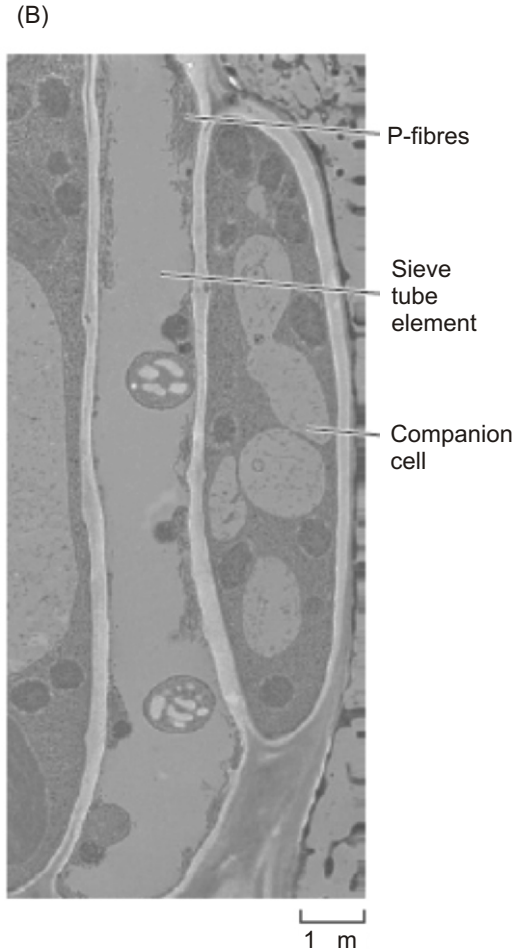
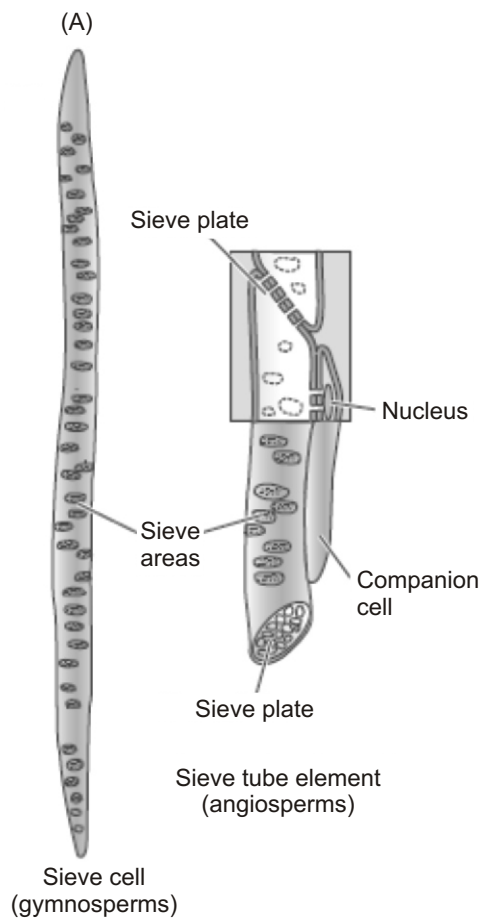
Phloem sap is the nutrient-rich fluid transported in sieve tubes. Its major components include:

- Sugars (Primary solute, 10-30%)
 Sucrose (most common) -
 Non-reactive, energy-efficient for transport.
 Raffinose, Stachyose (in some plants).
- Amino Acids & Proteins (2-5%)

Glutamine, aspartate (nitrogen transport).

P-Proteins (seal sieve plates after injury).

- Hormones
 Auxins, cytokinins (regulate growth).
- Ions (K^+ , Mg^{2+} , Cl^- , PO_4^{3-})
 Maintain osmotic balance & pH.
- Viruses & RNA (occasionally)
 Some plant viruses (e.g., Cucumber Mosaic Virus) spread via phloem.

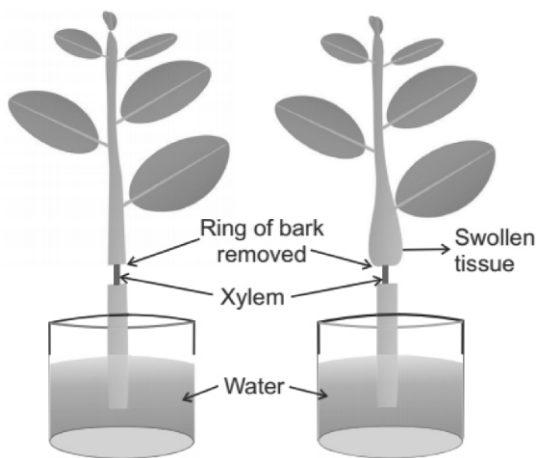


Composition of Phloem

Girdling Experiment (Proof of Phloem Transport)

Procedure:

- A ring of bark (phloem) is removed from a stem, xylem remains intact.
- **Observations after days/weeks:**
Above the girdle: Swelling (accumulation of sugars).
Below the girdle: Roots starve & die (no sugar transport).
Leaves remain green (xylem still supplies water).



Girdling Experiment

Conclusion:

- Phloem transports organic nutrients (sugars) downward.
- Xylem is not blocked (water transport continues).

Pressure Flow Hypothesis (Mass Flow Theory)

Proposed by Ernst Münch (1930), this model explains phloem translocation.

Mechanism:

1. **Loading at Source (Photosynthetic Leaves):**

- Sugars (sucrose) are actively loaded into sieve tubes (via companion cells).
- Uses proton-sucrose symport (H⁺ gradient drives uptake).
- Increases osmotic pressure water enters from xylem (↑ turgor pressure).

2. Flow Through Phloem:

- High pressure at source pushes sap toward sink (roots/fruits).

3. Unloading at Sink (Roots/Fruits):

- Sugars are removed & stored (as starch) or metabolized.
- Osmotic pressure drops water exits phloem, returns to xylem.

Evidence Supporting Pressure Flow:

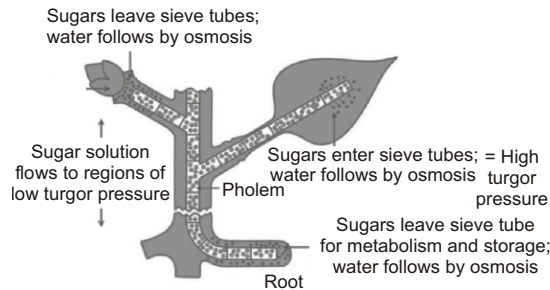
- Sap moves at 1 m/hr (too fast for diffusion).
- Girdling blocks flow (supports phloem's role).
- Radioactive tracer studies show bidirectional flow in different phloem strands.

Differences: Phloem vs. Xylem Transport

Feature	Phloem	Xylem
Direction	Bidirectional (source to sink)	Unidirectional (roots leaves)
Material	Sugars, amino acids, hormones	Water, minerals
Energy	Active (ATP for loading/unloading)	Passive (transpiration pull)
Pressure	High turgor pressure	Negative tension

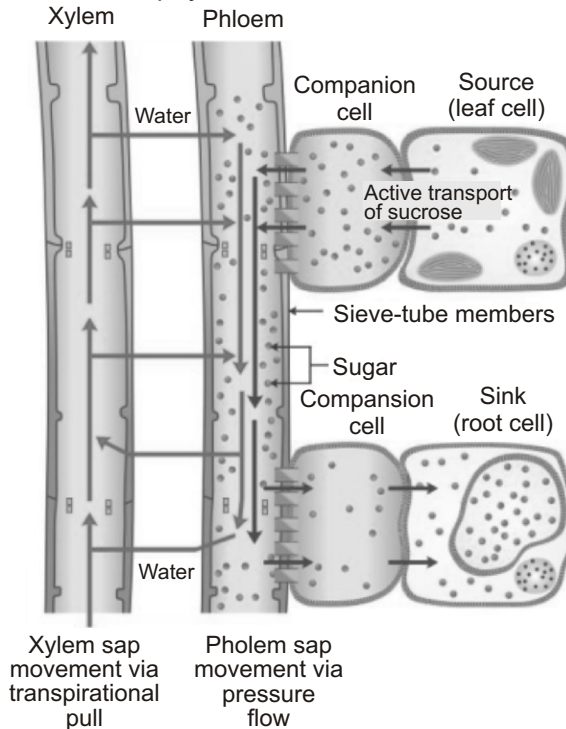
☞ Munch's Mass Flow Hypothesis

- The mass flow or pressure theory was first proposed by Munch (1930) and later elaborated by Crafts (1938).
- According to this theory, organic solutes are translocated en masse through the sieve tubes from the source (leaves) to the storage sites (roots, fruits and tubers).



Mechanism of translocation

- Mesophyll cells synthesise sugars during photosynthesis. As these get dissolved in the cell sap, the osmotic concentration and diffusion pressure deficit (DPD) of the mesophyll cells increase.
- Water enters the mesophyll cells from the xylem, and hence, the turgor pressure or pressure potential of the mesophyll cells increases.



Mass Flow Hypothesis

- Sugars dissolved in water move from the mesophyll cells into the symplast system of the sieve tubes through the companion cells.
- Solutes are carried en masse through the symplast to finally reach the consumption centres.
- At the consumption end, food materials are either used up, as in roots, or are stored in an insoluble form, as in fruits and tubers. As a result, the osmotic concentration, and consequently, the turgor pressure in these cells are low.
- In this way, a continuous turgor pressure gradient is established across the symplast between the cells of the source and the cells of the sink.
- Water returns to the source through the apoplast system.

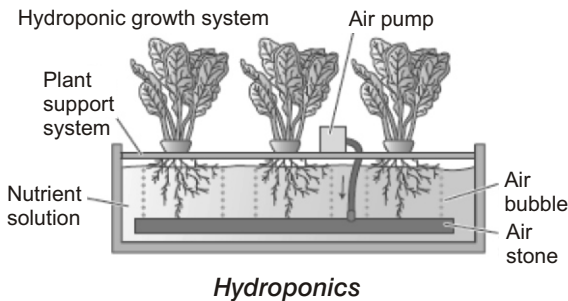
Hydroponics

Hydroponics is the growing of plants in a liquid nutrient solution with or without the use of artificial media. Commonly used mediums include expanded clay, coir, perlite, vermiculite, brick shards, polystyrene packing peanuts and wood fiber.

Hydroponics has been recognized as a viable method of producing vegetables (tomatoes, lettuce, cucumbers and peppers) as well as ornamental crops such as herbs, roses, freesia and foliage plants. Due to the ban on methyl bromide in soil culture, the demand for hydroponically grown produce has rapidly increased in the last few years.

History

The word hydroponics comes from two Greek words - 'hydro' meaning water and 'ponos' meaning labor. This word was first used in 1929 by Dr. Gericke, a California professor who began to develop what previously had been a laboratory technique into a commercial means of growing plants. The U.S. Army used hydroponic culture to grow fresh food for



troops stationed on infertile Pacific islands during World War II. By the 1950s, there were viable commercial farms in America, Europe, Africa and Asia.

Advantages

- It can be used in places where in-ground agriculture or gardening is not possible (for example, dry desert areas or cold climate regions).
- More complete control of nutrient content, pH and growing environment.
- Lower water and nutrient costs associated with water and nutrient recycling.
- Faster growth due to more available oxygen in root area.
- Elimination or reduction of soil related insects, fungi and bacteria.
- Much higher crop yields.
- No weeding or cultivation required.
- Some crops, such as lettuce and strawberries, can be lifted from ground level to a much better height for planting, cultivation and harvesting. This gives much better working conditions and lowers labor costs.

- Crop rotation/fallowing is not necessary.
- Transplant shock is reduced.

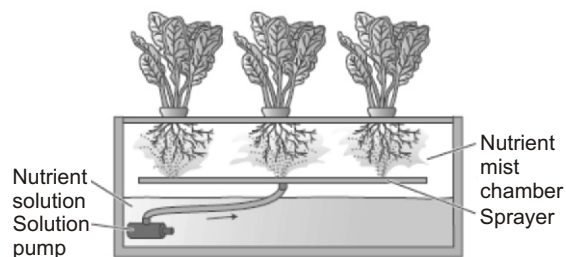
Disadvantages

- Initial and operational costs are higher than soil culture.
- Skill and knowledge are needed to operate properly.
- Some diseases like fusarium and verticillium can spread quickly through the system. However, many varieties resistant to the above diseases have been bred.

Aeroponics

Aeroponics is a soil-free cultivation technique where plant roots are suspended in the air and regularly misted with a nutrient-rich solution. Derived from Greek words for "air" and "labour" (air and work), it's a type of hydroponics that offers advantages such as efficient water use, faster growth, higher yields, and elimination of soil-borne pests and diseases.

Aeroponic growth system



QUESTIONS



Section A: Very Short Answer Type Questions

1. Define water potential (ψ_w).

Ans. Water potential (ψ_w) is the potential energy of water in a system compared to pure water, under standard conditions. It determines the direction of water movement and is measured in pressure units (megapascals, MPa). Pure water has a ψ_w of zero, and the presence of solutes or pressure alters this value, causing water to move from regions of higher to lower water potential.

2. What is guttation?

Ans. Guttation is the exudation of liquid water droplets from the margins or tips of leaves, especially during the early morning. It occurs through specialized structures called hydathodes and is driven by root pressure when transpiration is low or absent.

3. Name two factors affecting transpiration.

Ans. Two key factors affecting transpiration are temperature and humidity. High temperatures increase the rate of evaporation, thereby enhancing transpiration, while high humidity decreases the water vapor gradient between the leaf and atmosphere, reducing transpiration.

4. Which mineral deficiency causes chlorosis in plants?

Ans. Chlorosis, the yellowing of leaves due to reduced chlorophyll, is commonly caused by deficiencies in essential minerals like nitrogen, magnesium, or iron. Among these, iron deficiency is a frequent cause of interveinal chlorosis, especially in young leaves.

5. What is the composition of phloem sap?

Ans. Phloem sap primarily contains sucrose, along with amino acids, hormones (like auxins and cytokinins), minerals, organic acids, and sometimes messenger RNAs and proteins. It serves as the medium for transporting nutrients from source to sink tissues.

6. Give an example of a macronutrient.

Nitrogen (N) is a classic example of a macronutrient. It is required in large quantities by plants for synthesizing amino acids, nucleic acids, proteins, and chlorophyll.

7. What does root pressure indicate?

Ans. Root pressure is a positive pressure developed in the xylem due to active absorption of minerals and water by roots. It indicates the ability of roots to push water upward through the stem, especially when transpiration is minimal.

8. Differentiate between active and passive transport.

Ans. Active transport requires energy (usually ATP) to move molecules against their concentration gradient through membrane proteins. In contrast, passive transport does not require energy and involves movement along the concentration gradient, such as diffusion or osmosis.

9. Which experiment demonstrates phloem translocation? (2023)

Ans. The girdling (ringing) experiment demonstrates phloem translocation. In this method, removing a ring of bark (including phloem) from a stem causes accumulation of sugars above the ring, confirming that food is transported through the phloem.

10. What is the pressure flow hypothesis? (2022)

The pressure flow hypothesis explains the translocation of sugars in phloem. According to it, sugars move from source (leaf) to sink (e.g., root or fruit) due to a pressure gradient created by osmotic influx of water into sieve tubes at the source, pushing the sap toward the sink.

Section B: Short Answer Type Questions**11. Define water potential (ψ_w). What are its components? (CCSU 2021, 2023)**

Ans. Water potential (ψ_w) is the potential energy of water in a system compared to pure water, indicating the direction of water movement.

Components:

ψ_p (pressure potential) + ψ_s (solute potential) + ψ_g (gravitational potential) + ψ_m (matrix potential)

12. How does transpiration aid in nutrient uptake? (CCSU 2020)

Ans. Transpiration creates a negative pressure (transpiration pull) in xylem vessels, which helps in the upward movement of water along with dissolved minerals from roots to shoots.

13. List three factors affecting transpiration rate. (CCSU 2019, 2022)

Ans. Temperature

- Humidity
- Wind speed

14. What is guttation? How does it differ from transpiration? (CCSU 2018)

Ans. Guttation is the exudation of liquid water from leaf margins through specialized structures called hydathodes, usually at night.

Difference: Guttation involves liquid water loss, while transpiration involves water vapor loss.

15. Explain the criteria for essentiality of mineral elements in plants. (CCSU 2021)

Ans. An element is essential if:

- The plant cannot complete its life cycle without it.
- The element's deficiency causes specific symptoms.
- The element is directly involved in plant metabolism.

16. Name two macro-elements and their deficiency symptoms in wheat. (CCSU 2020, 2023)

Ans. Nitrogen (N): Yellowing of older leaves (chlorosis), stunted growth

- **Potassium (K):** Marginal leaf scorching and weak stems

17. Differentiate between active and passive ion transport across membranes. (CCSU 2019)

Ans.

- **Active transport:** Requires energy (ATP) to move ions against the concentration gradient.
- **Passive transport:** No energy needed; ions move along the concentration gradient.

18. What does phloem sap primarily contain? (CCSU 2022)

Ans. Phloem sap primarily contains sucrose, amino acids, hormones, and other organic nutrients.

Section C: Long Answer Type Questions

19. Discuss the significance of transpiration in plants. How do external factors (light, humidity) influence it? (CCSU 2019, 2022)

Ans. Significance of Transpiration:

- **Cooling Effect:** Transpiration causes evaporative cooling of leaves, protecting plants from overheating.
- **Water Movement:** Generates a negative pressure (transpiration pull) that helps transport water and minerals from roots to leaves through xylem.
- **Nutrient Transport:** Facilitates upward movement of essential nutrients dissolved in water.
- **Maintains Turgor Pressure:** Helps maintain cell turgidity essential for structural support and growth.
- **Gas Exchange:** Opens stomata for CO₂ uptake required in photosynthesis.

Influence of External Factors:

- **Light:** Increases transpiration by stimulating stomatal opening to allow CO₂ entry for photosynthesis, increasing water vapor loss.
- **Humidity:** High humidity reduces the vapor pressure difference between inside and outside the leaf, lowering transpiration rate; low humidity increases transpiration.

20. Explain the pressure-flow hypothesis for phloem translocation. How does the girdling experiment support it? (CCSU 2020, 2023)

Ans. Pressure-Flow Hypothesis:

- Phloem translocation moves sugars (mainly sucrose) from sources (leaves) to sinks (roots, fruits).
- At the source, sugars are actively loaded into sieve tubes, lowering water potential and causing water to enter from xylem by osmosis.
- This creates a high turgor pressure that drives the flow of sap toward sinks.
- At sinks, sugars are actively or passively unloaded, increasing water potential and causing water to exit, reducing pressure.

Girdling Experiment:

- Girdling removes a ring of bark including phloem but leaves xylem intact.

- After girdling, sugars accumulate above the girdle because phloem transport is interrupted, while xylem transport continues.
- This accumulation supports the pressure-flow hypothesis by showing that phloem translocation depends on active loading and pressure differences.

21. Describe the role of essential elements (N, P, K) in plant growth. Add a note on their deficiency symptoms. (CCSU 2018, 2021)

Ans. Role of Essential Elements:

- **Nitrogen (N):** Key component of amino acids, proteins, nucleic acids, and chlorophyll; essential for vegetative growth and photosynthesis.
- **Phosphorus (P):** Vital for energy transfer through ATP, nucleic acids, and phospholipids; important in root development and flowering.
- **Potassium (K):** Regulates osmotic balance, enzyme activation, and stomatal movement; important for drought resistance and overall plant health.

Deficiency Symptoms:

- **Nitrogen Deficiency:** Chlorosis (yellowing) of older leaves, stunted growth, reduced yield.
- **Phosphorus Deficiency:** Dark green coloration, delayed maturity, poor root growth, and purple pigmentation on leaves.
- **Potassium Deficiency:** Marginal leaf scorching, weak stems, poor fruit development, and increased susceptibility to diseases.

22. Compare root pressure and transpiration pull as mechanisms of water movement in plants.

Ans.

(CCSU 2020)

Feature	Root Pressure	Transpiration Pull
Mechanism	Positive pressure developed in roots due to active ion absorption, causing water to move up.	Negative pressure (tension) created by transpiration at leaf surfaces pulls water upward through xylem.
Occurrence	Occurs mainly at night or when transpiration is low.	Occurs during the day when transpiration rate is high.
Driving Force	Osmotic pressure from active solute uptake in roots.	Evaporation of water from stomata creates tension.
Height of Water Ascent	Limited, usually effective only in small plants or short distances.	Can pull water to great heights, supporting tall trees.
Evidence	Guttation and exudation of sap from cut stems.	Cohesion-tension theory supported by experiments like the movement of air bubbles in xylem.
Role in Water Transport	Minor contributor in overall water ascent.	Major and primary mechanism for long-distance water transport.

23. How are ions transported across cell membranes? Discuss the role of ATPase pumps.
(CCSU 2021, 2023)

Ans. Ion Transport Across Membranes:

- Ions move via passive transport (facilitated diffusion) along the electrochemical gradient using ion channels or carriers.
- Active transport moves ions against their concentration gradient, requiring energy.

Role of ATPase Pumps:

- ATPase pumps (e.g., H⁺-ATPase) use energy from ATP hydrolysis to pump H⁺ ions out of the cell, creating an electrochemical gradient.
- This gradient drives secondary active transport of other ions and nutrients (like nitrate, phosphate) via symporters or antiporters.
- ATPase pumps maintain ion homeostasis, regulate cell pH, and generate membrane potential critical for nutrient uptake.

24. What is water potential? Derive the relationship between its components (ψ_s , ψ_p , ψ_m).

Ans. Water Potential (ψ_w): (CCSU 2022)

- It is the potential energy of water per unit volume relative to pure water in reference conditions. It predicts the direction of water movement, flowing from regions of higher to lower water potential.

Derivation of Components:

- $\psi_w = \psi_s + \psi_p + \psi_m$

Where:

- ψ_s (**solute potential/osmotic potential**): Negative potential due to solute concentration; more solutes lower ψ_s , reducing free energy of water.
- ψ_p (**pressure potential**): Positive or negative pressure exerted on or by water (e.g., turgor pressure in cells).
- ψ_m (**matric potential**): Effect of adhesion of water molecules to surfaces (like cell walls or soil particles), usually negative, reducing free water.

Hence, total water potential (ψ_w) is the sum of these components, determining net water movement in plants.