Chemical Composition of Plants

熊栋梁

Contents

PERIODIC TABLE OF THE ELEMENTS

- Non-metal
- Alkali metal
- Alkaline earth metal
- Transition metal
- Metal
- Metalloid
- Halogen
- Noble gas
- Lanthanide
- Actinide

1 H HYDROGEN 1.0079																	2 He HELIUM 4.0026
3 Li LITHIUM 6.941	4 Be BERYLLIUM 9.0122											5 B BORON 10.811	6 C CARBON 12.011	7 N NITROGEN 14.007	8 O OXYGEN 15.999	9 F FLUORINE 18.998	10 Ne NEON 20.1797
11 Na SODIUM 22.989	12 Mg MAGNESIUM 24.305											13 Al ALUMINIUM 26.981	14 Si SILICON 28.085	15 P PHOSPHORUS 30.974	16 S SULFUR 32.066	17 Cl CHLORINE 35.453	18 Ar ARGON 39.948
19 K POTASSIUM 39.098	20 Ca CALCIUM 40.078	21 Sc SCANDIUM 44.955	22 Ti TITANIUM 47.867	23 V VANADIUM 50.9415	24 Cr CHROMIUM 51.9961	25 Mn MANGANESE 54.938	26 Fe IRON 55.845	27 Co COBALT 58.933	28 Ni NICKEL 58.6934	29 Cu COPPER 63.546	30 Zn ZINC 65.38	31 Ga GALLIUM 69.723	32 Ge GERMANIUM 72.63	33 As ARSENIC 74.921	34 Se SELENIUM 78.971	35 Br BROMINE 79.904	36 Kr KRYPTON 83.798
37 Rb RUBIDIUM 85.467	38 Sr STRONTIUM 87.62	39 Y YTTRIUM 88.9058	40 Zr ZICRONIUM 91.224	41 Nb NIOBIUM 92.9063	42 Mo MOLYBDENUM 95.95	43 Tc TECHNETIUM (98)	44 Ru RUTHENIUM 101.07	45 Rh RHODIUM 102.90	46 Pd PALLADIUM 106.42	47 Ag SILVER 107.8682	48 Cd CADMIUM 112.414	49 In INDIUM 114.818	50 Sn TIN 118.710	51 Sb ANTIMONY 121.760	52 Te TELLURIUM 127.60	53 I IODINE 126.90	54 Xe XENON 131.293
55 Cs CAESIUM 132.905	56 Ba BARIUM 137.327	57-71*	72 Hf HAFNIUM 178.49	73 Ta TANTALUM 180.94	74 W TUNGSTEN 183.84	75 Re RHENIUM 186.207	76 Os OSMIUM 190.23	77 Ir IRIDIUM 192.217	78 Pt PLATINUM 195.084	79 Au GOLD 196.96	80 Hg MERCURY 200.59	81 Tl THALLIUM 204.38	82 Pb LEAD 207.2	83 Bi BISMUTH 208.98	84 Po POLONIUM (209)	85 At ASTATINE (210)	86 Rn RADON (222)
87 Fr FRANCIUM (223)	88 Ra RADIUM (226)	89-103**	104 Rf RUTHERFORDIUM (267)	105 Db DUBNIUM (268)	106 Sg SEABORGIUM (271)	107 Bh BOHRIUM (272)	108 Hs HASSIUM (270)	109 Mt MEITNERIUM (276)	110 Ds DARMSTADTIUM (281)	111 Rg ROENTGENIUM (280)	112 Cn COPERNICIUM (285)	113 Uut UNUNTRIUM (284)	114 Fl FLEROVIUM (289)	115 Uup UNUNPENTIUM (288)	116 Lv LIVERMORIUM (293)	117 Uus UNUNSEPTIUM (294)	118 Uuo UNUNOCTIUM (294)

*	57 La LANTHANUM 138.90	58 Ce CERIUM 140.116	59 Pr PRASEODYMIUM 140.90	60 Nd NEODYMIUM 144.242	61 Pm PROMETHIUM (145)	62 Sm SAMARIUM 150.36	63 Eu EUROPIUM 151.964	64 Gd GADOLINIUM 157.25	65 Tb TERIBIUM 158.92	66 Dy DYSPROSIUM 162.500	67 Ho HOLMIUM 164.93	68 Er ERBIUM 167.259	69 Tm THULIUM 168.93	70 Yb YTTERBIUM 173.054	71 Lu LUTETIUM 174.9668
**	89 Ac ACTINIUM (227)	90 Th THORIUM 232.0377	90 Pa PROTACTINIUM 231.03	92 U URANIUM 238.02	93 Np NEPTUNIUM (237)	94 Pu PLUTONIUM (244)	95 Am AMERICIUM (243)	96 Cm CURIUM (247)	97 Bk BERKELIUM (247)	98 Cf CALIFORNIUM (251)	99 Es EINSTEINIUM (252)	100 Fm FERMIUM (257)	101 Md MENDELEVIUM (258)	102 No NOBELIUM (259)	103 Lr LAWRENCIUM (262)

Elemental Composition of Plants 植物体的组成元素

Methods for Studying Plant Elemental Composition:

To determine the elemental profile of a plant, the **Gravimetric Method(重量分析)** is first employed to differentiate between water content and dry matter. The organic constituents are then removed through **Dry Ashing** (high-temperature combustion) or **Wet Digestion** (acid-based decomposition), leaving behind the inorganic **Mineral Elements** (Ash).

Modern analytical techniques are then applied for precise quantification:

- **ICP-OES/MS:** For simultaneous detection of multiple macro and microelements.
- **AAS (Atomic Absorption Spectroscopy):** Specifically for metallic elements like Ca, Mg, and Fe.
- **Kjeldahl Method:** Historically used for total Nitrogen determination.

Elemental Composition of Plants 植物体的组成元素

Fresh plant tissues

Dry at high temperature
75 -105 ºC

75 ~ 95 % lost as water

H & O

5 ~ 25 % Dry matter (干物质)

Calcination
~ 525 ºC

94% Volatilized as Gas
(CO_2, H_2O, N_2, etc)

C, N, H, S & O

6% Crude Ash 灰分
(Complex composition consisting of mineral elements)

Elemental Composition of Plants 植物体的组成元素

Mineral elements 矿质元素

Element	Perentage
K	42
O	24
Cl	7
Si	7
P	5
Ca	5
Mg	4
S	4
Na	1
Fe, Zn, Mn, Cu, B, Mo	1

Elemental Composition of Plants 植物体的组成元素

Mineral vs. Non-mineral Elements 矿质元素与非矿质元素

Mineral/ash Elements： The non-volatile residues remaining after a plant has been dried and fully combusted. They exist in the **ash** primarily in the form of **oxides**, carbonates, or phosphates.

Non-mineral Elements： Elements that are lost to the atmosphere in **gaseous form** during combustion. **i.e. C, H, O**

Elemental Composition of Plants 植物体的组成元素

Essential Nutrients 必需营养元素

I. Criteria (Arnon & Stout, 1943)

1. **Necessity** (必要性): The element is indispensable for the entire life cycle of all higher plants. Without it, the plant cannot complete its life cycle.
2. **Specificity** (专一性): The function of the element cannot be replaced by any other element. Deficiency results in specific symptoms that can only be alleviated or eliminated by supplying that specific element.
3. **Directness** (直接性): The element must be directly involved in plant metabolism, performing a direct nutritional role rather than merely improving the indirect growth environment.

II. Categories and Content

There are currently **17 confirmed essential elements** for plants.

Elemental Composition of Plants 植物体的组成元素

17 confirmed essential elements

Year	元素	Symbol	μmol/g（dw ）	mg/kg	%
1939	钼	Mo	0.001	0.1	-
1931	铜	Cu	0.1	0.6	-
1926	锌	Zn	0.30	20	-
1922	锰	Mn	1.0	50	-
1844	铁	Fe	2.0	100	-
1923	硼	B	2.0	20	-
1954	氯	Cl	3.0	100	-
1839	硫	S	3.0	-	0.1
1839	磷	P	60	-	0.2
1839	镁	Mg	80	-	0.2
1839	钙	Ca	125	-	0.5
1839	钾	K	250	-	1.0
1804	氮	N	1000	-	1.5
-	氧	O	30000	-	45
1800	碳	C	40000	-	45
-	氢	H	60000	-	6
1987	镍	Ni		1.1	

Elemental Composition of Plants 植物体的组成元素

17 confirmed essential elements

C、H、O ——Non-mineral element

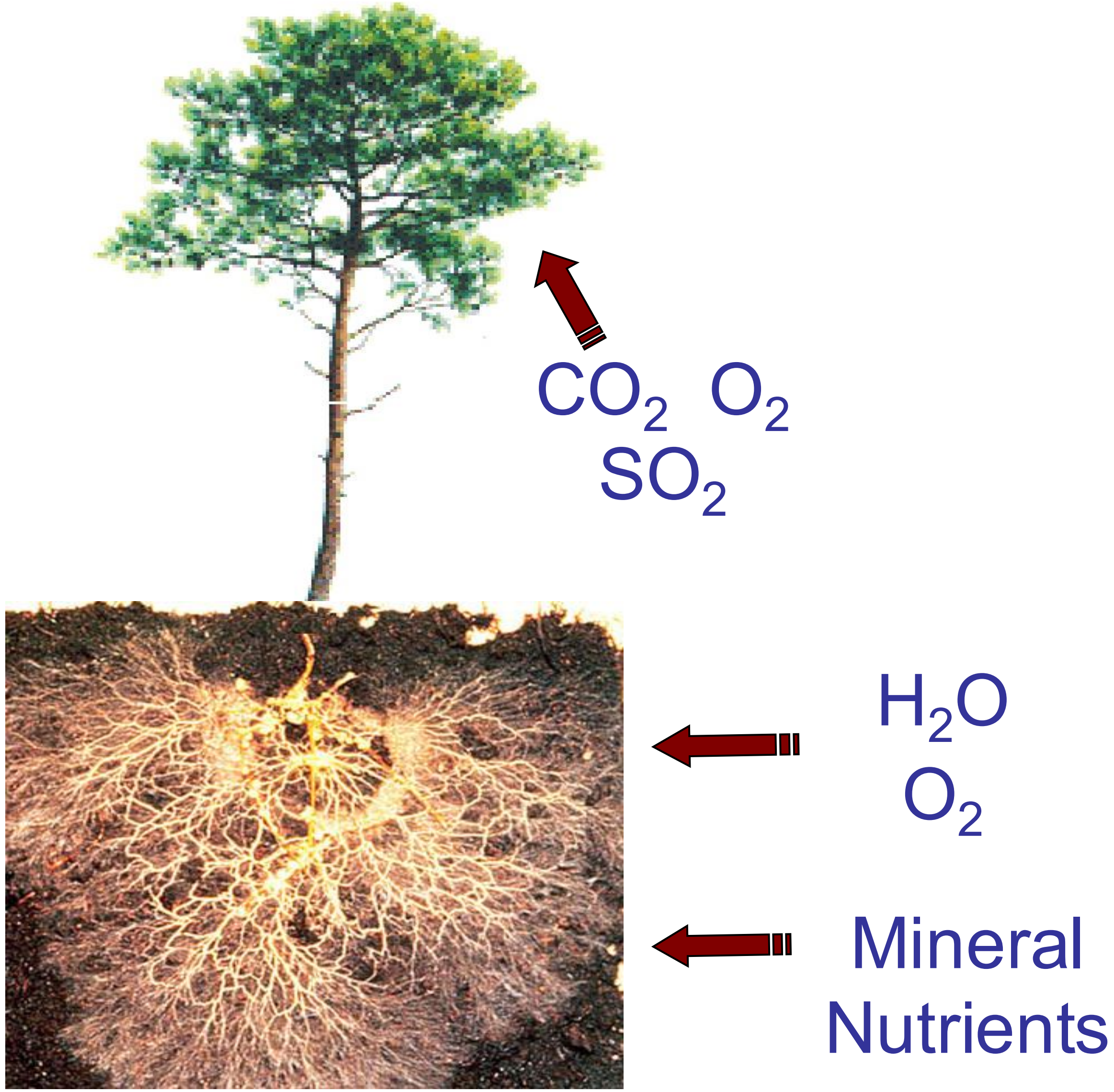
Macronutrients. (0.1% <)	**N、P、K**
	Ca、Mg、S
Micronutrients (0.1% >)	Fe、Mn、Zn、Cu、B、Mo、Cl、（Ni）

Nitrogen (N) is a Mineral Nutrient!

While Nitrogen is lost as gas during combustion (not in ash), it is classified as a **Mineral Element** because:

- Like P and K, plants must absorb N from the **soil** via roots
- Roots taken up as inorganic ions (NO_3^- or NH_4^+) rather than from the air.

Elemental Composition of Plants 植物体的组成元素



Contents

Physiological Functions of Essential Elements

Group 1: C, H, O, N, S

- Structural and Functional Components: Primary building blocks of organic matter (proteins, lipids, carbohydrates).
- Enzymatic Groups: Constituents of atomic groups involved in enzyme-catalyzed reactions.

Group 2: P, B, (Si)

- Macromolecular Linkage: Essential for forming ester bonds that connect large biological molecules.
- Energy Metabolism: Critical for energy storage and transduction (e.g., ATP).

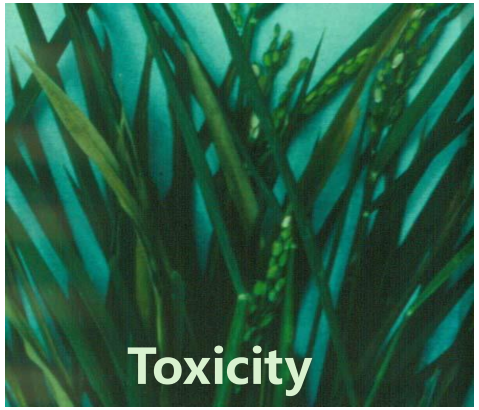
Group 3: K, Mg, Ca, Mn, Cl

- Cellular Homeostasis: Maintenance of cellular order, including osmotic adjustment and electrochemical balance.
- Enzyme Activation: Act as cofactors or activators for various enzymes.
- Structural Stability: Stabilize cell walls and the architecture of biological membranes.

Physiological Functions of Essential Elements

Group 4: Fe, Cu, Zn, Mo, Ni

- Enzyme Prosthetic Groups: Integral components of specific enzyme complexes.
- Electron Transfer: Key components of electron transport systems (e.g., in photosynthesis and respiration).



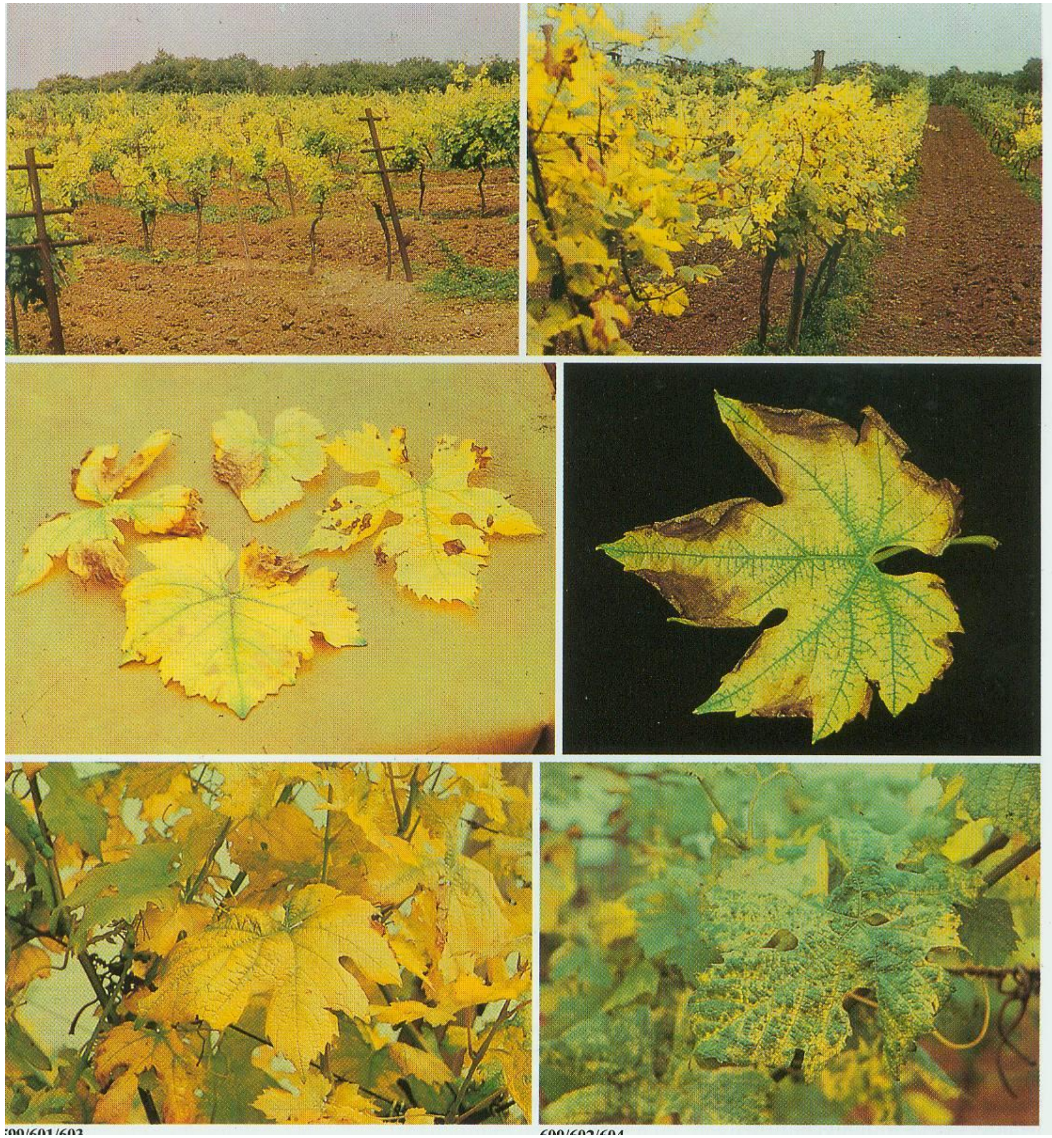
Nutritional Imbalance (植物营养失调症)

Elemental Toxicity(元素毒害症): Symptoms caused by excessive accumulation of an element (e.g., bronzing in iron-toxic rice).

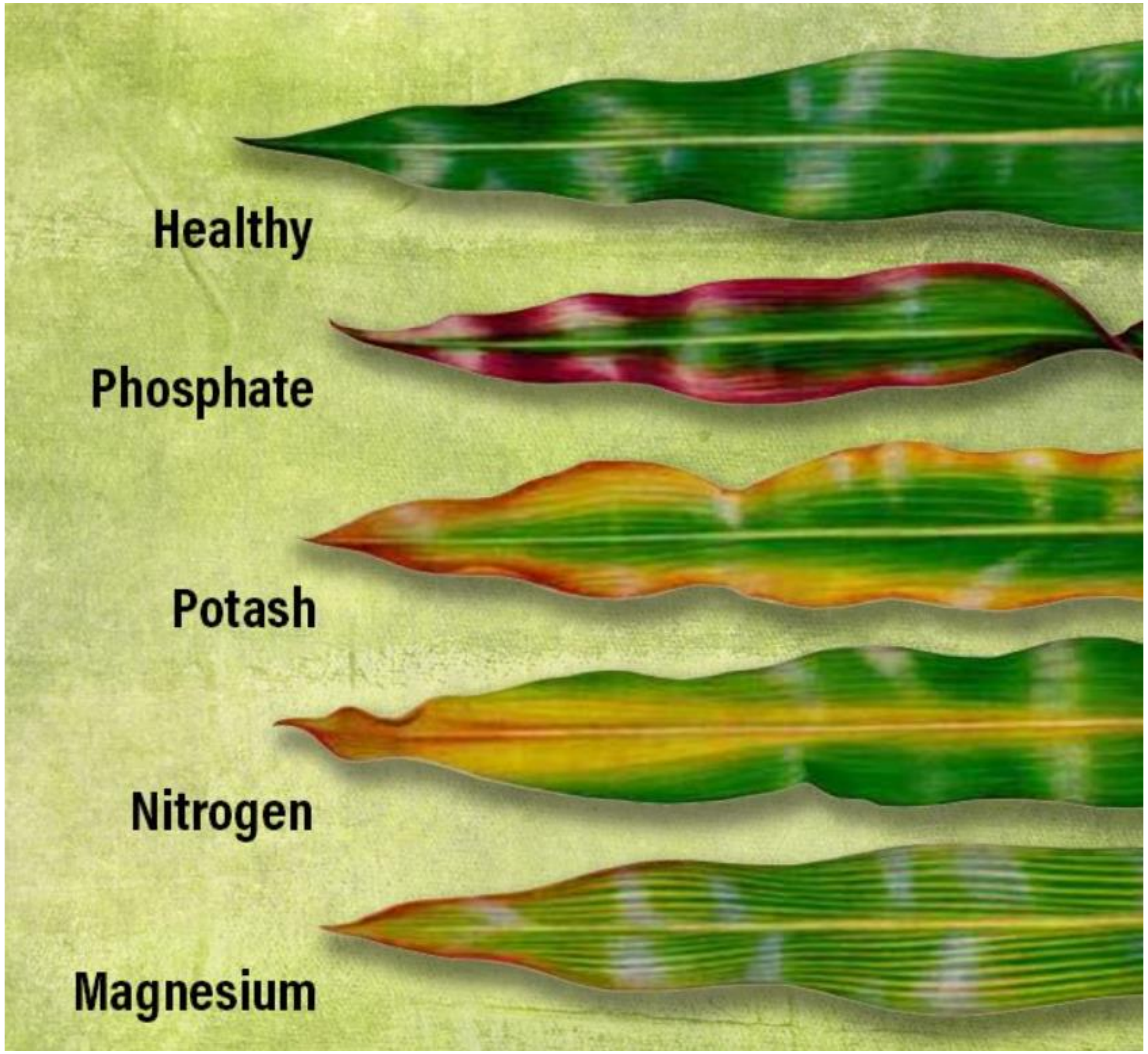
Nutrient Deficiency (营养元素缺乏症): Symptoms caused by an insufficient supply of an essential element (e.g., chlorosis in iron-deficient rice).

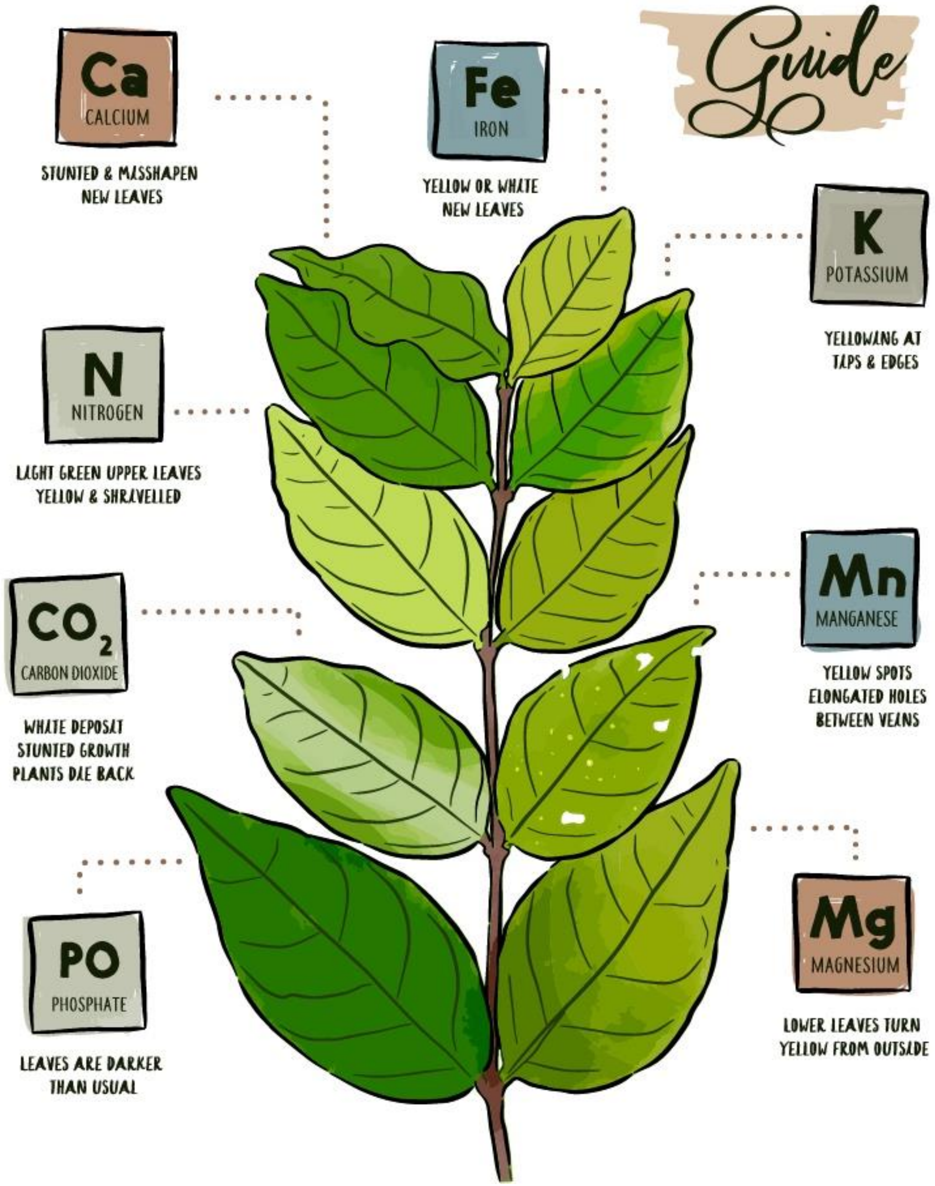
Physiological Functions of Essential Elements

Fe

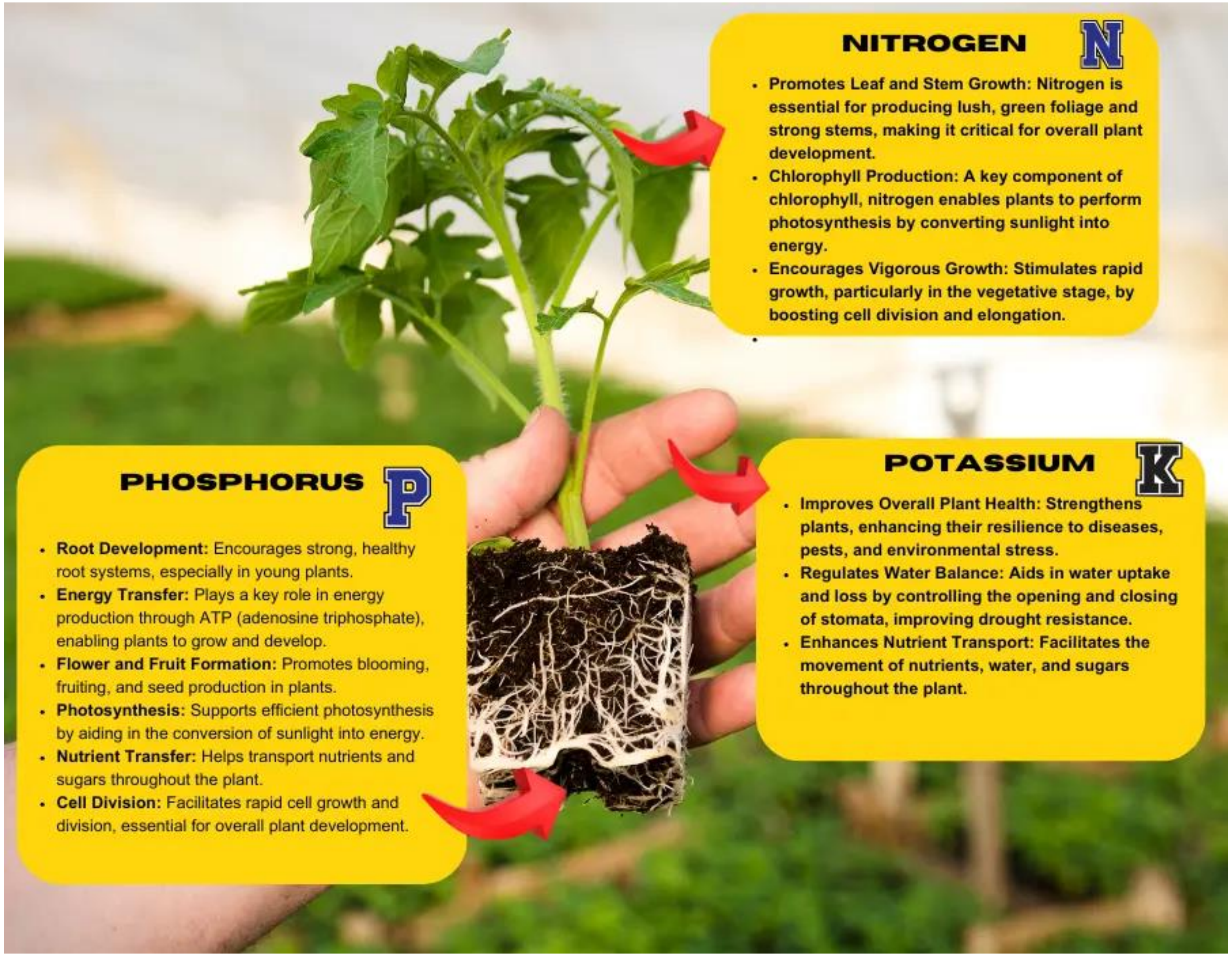


Physiological Functions of Essential Elements





Physiological Functions of Essential Elements



NPK roles

黄瓜缺氮下叶黄

Physiological Functions of Essential Elements

Nitrogen (N) is recognized as the "Element of Life" (生命元素)

A. Structural Roles

- **Genetic Material**: DNA and RNA.
- **Functional Proteins**: All enzymes and structural proteins.
- **Photosynthetic Apparatus**: Chlorophyll and various pigments.
- **Regulatory Substances**: hormones (e.g., IAA, CTK), vitamins (B-complex), and alkaloids.

B. Metabolic Essentiality

Nitrogen is indispensable for energy and substance metabolism. It is a key constituent of coenzymes and energy carriers, including:

- **Energy Carriers: ADP and ATP.**
- **Metabolic Cofactors: CoA, CoQ, FAD, FMN, NAD^+, and $NADP^+$.**

Physiological Functions of Essential Elements

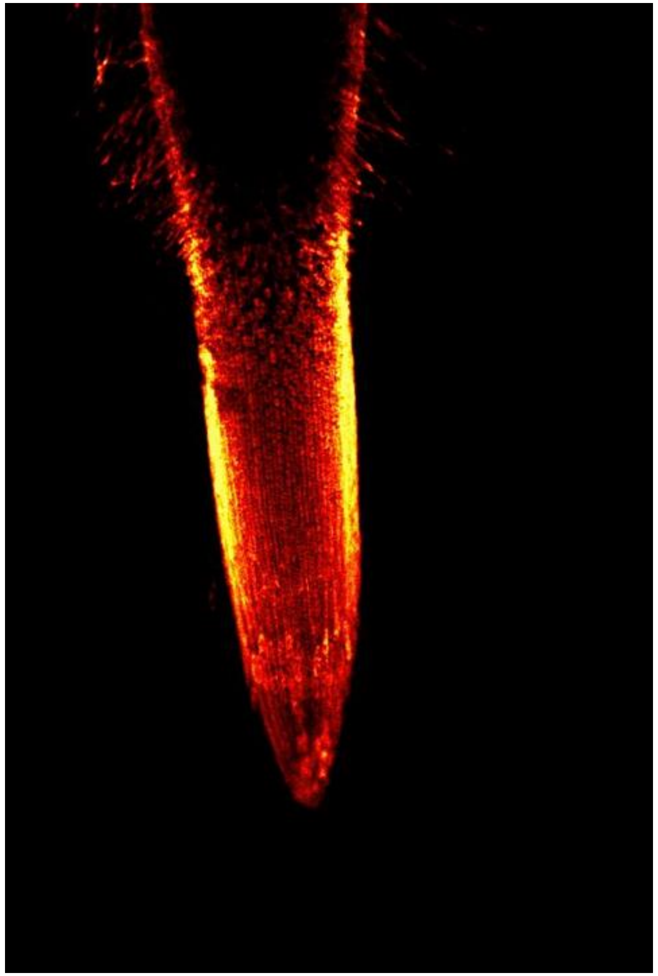
- **Law of Equal Importance:** Every essential element is equally important to the plant 's life. ***In practice, balanced nutrient supply*** *(平衡供给养分)*

- **Law of Irreplaceability:** Each essential element has a unique function that cannot be substituted by any other element. ***In practice, comprehensive nutrient supply****(全面供给养分)*.

Contents

Nutrient Uptake

Roots are the main structures for nutrient uptake



Nutrient Uptake

❑ Forms of Nutrients Absorbed by Plants

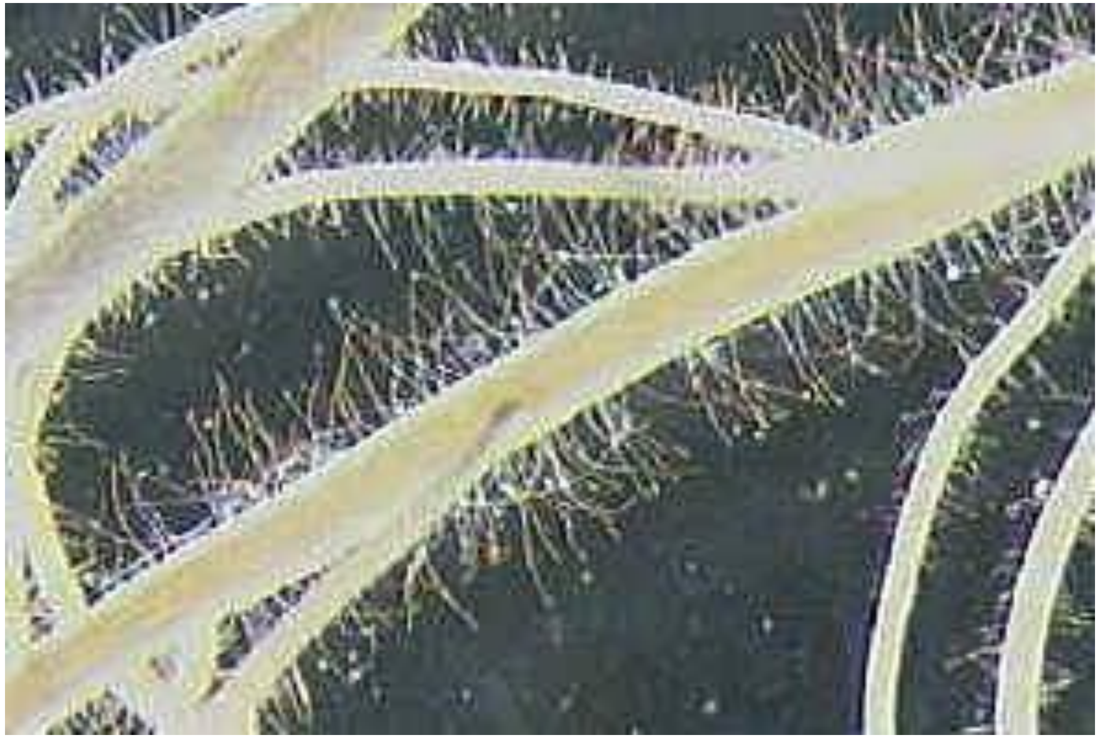
- ❖ **Primary Forms:** Ions or inorganic molecules (离子或无机分子).
- ❖ **Secondary Forms:** Organic substances (有机形态).

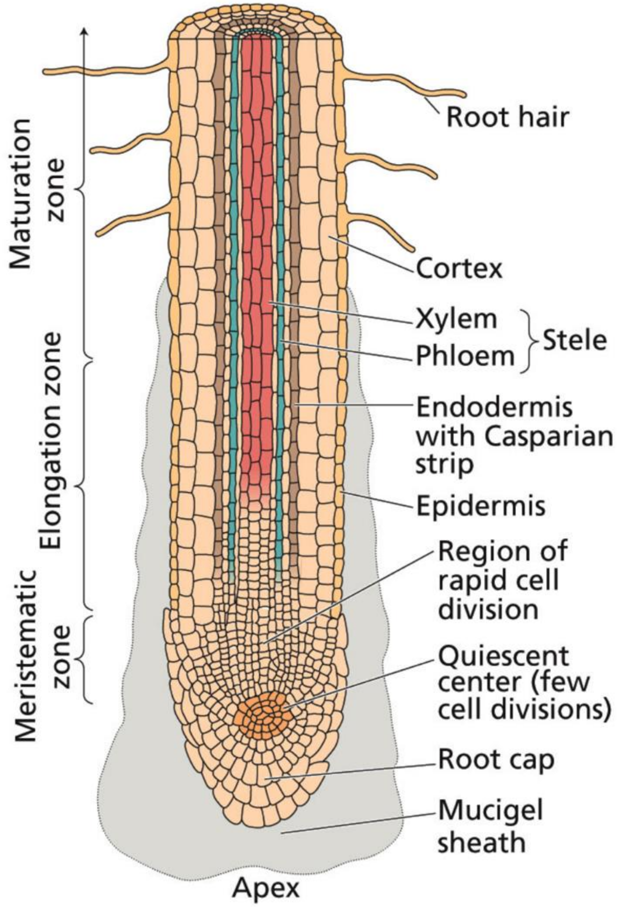
❑ Organs Involved in Nutrient Uptake

- ❖ **Mineral Nutrients:** Primarily absorbed by the **roots**, though the **leaves** are also capable of absorption.
- ❖ **Gaseous Nutrients:** Primarily absorbed by the **leaves**, though the **roots** are also capable of absorption.

Nutrient Uptake

Root Hair Zone (Also known as the *Maturation Zone*)**:** Absorbs a higher quantity of nutrients than any other section. As root hairs increases the external surface area of the root system by 2 to 10 times, enhancing the plant's absorption of nutrients and water.





Nutrient Uptake

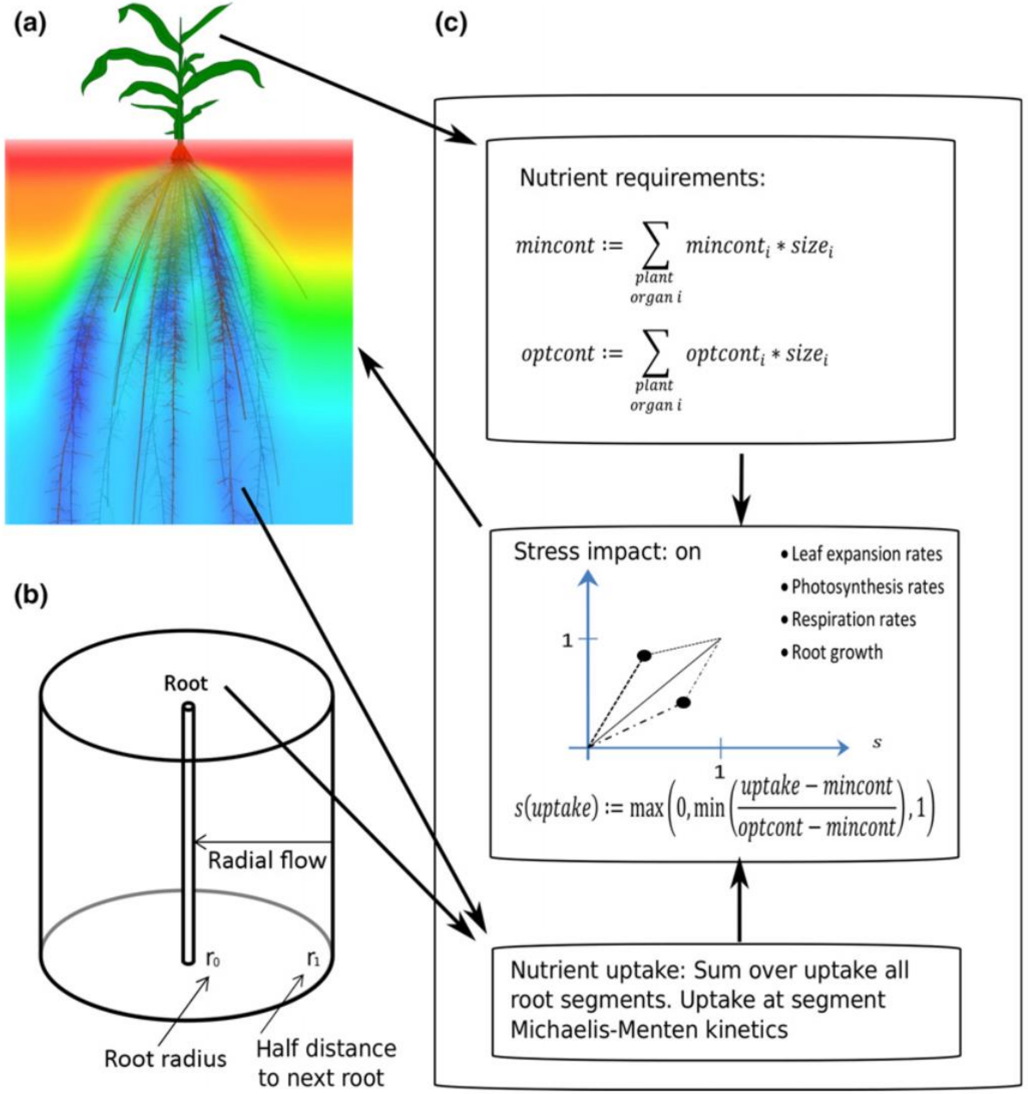
The process of nutrient absorption by the root system includes:

1. **Migration of nutrients to the root surface**
2. **Entry of nutrients into the Apoplast**
3. **Entry of nutrients into the Symplast**

Apoplast (质外体): The network of cell walls and intercellular spaces through which water and solutes can move freely without entering the living cells.

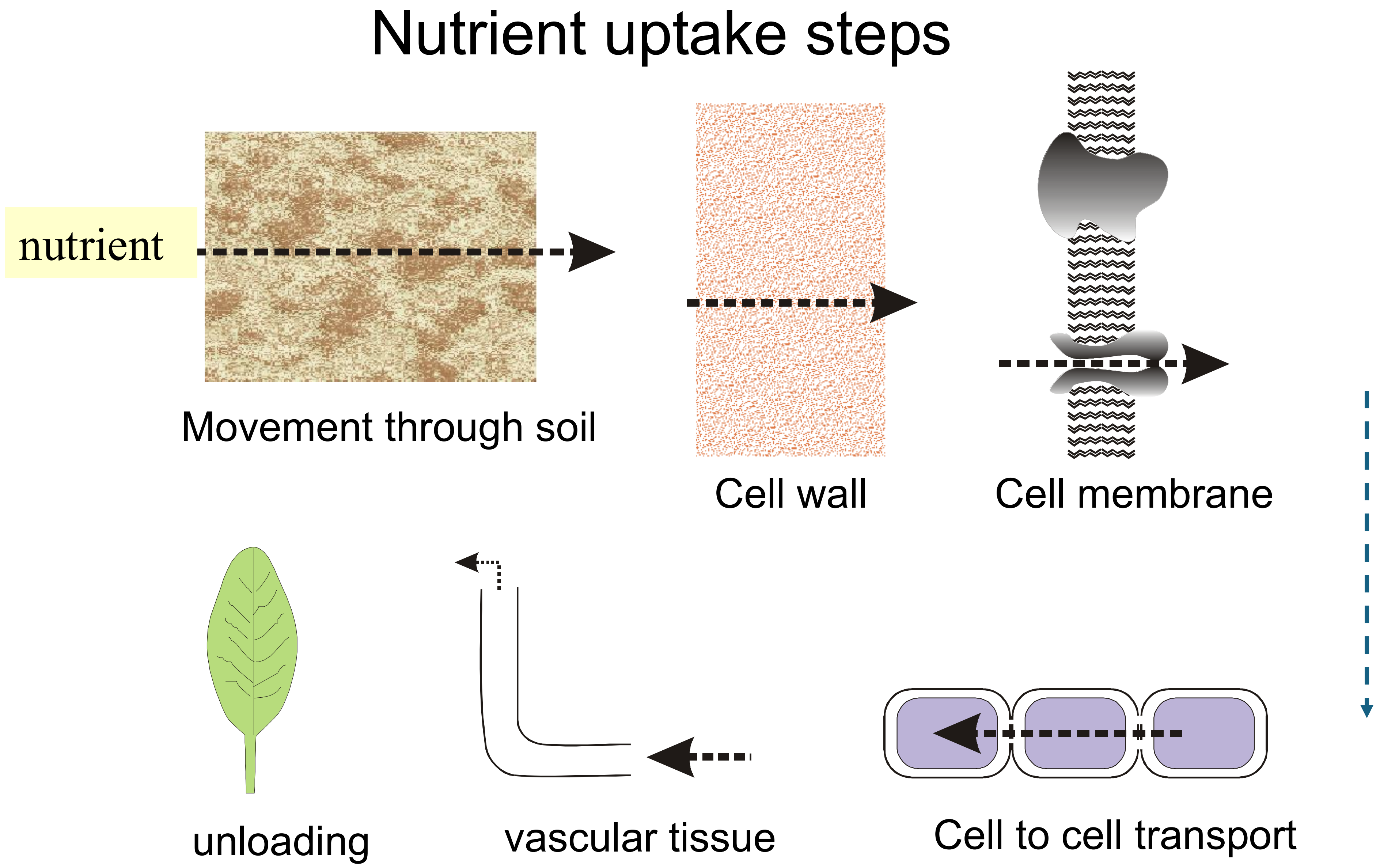
Symplast (共质体): The inner part of the plant, consisting of the cytoplasm of cells connected by plasmodesmata, requiring the nutrients to cross a cell membrane.

Nutrient Uptake

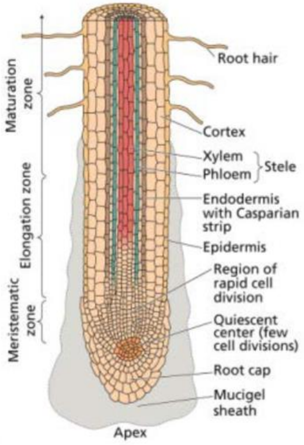


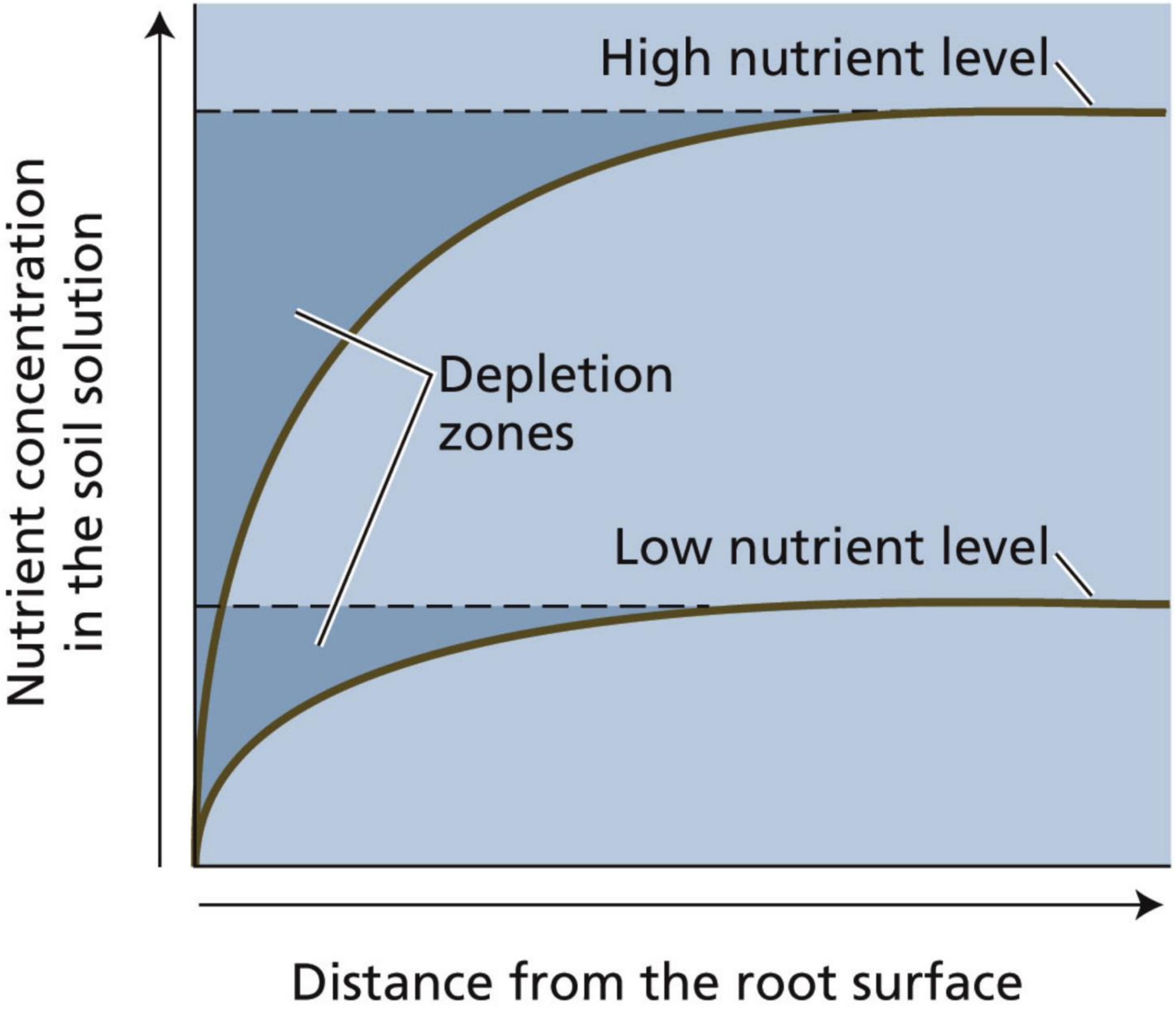
Postma et al., 2017

Nutrient Uptake



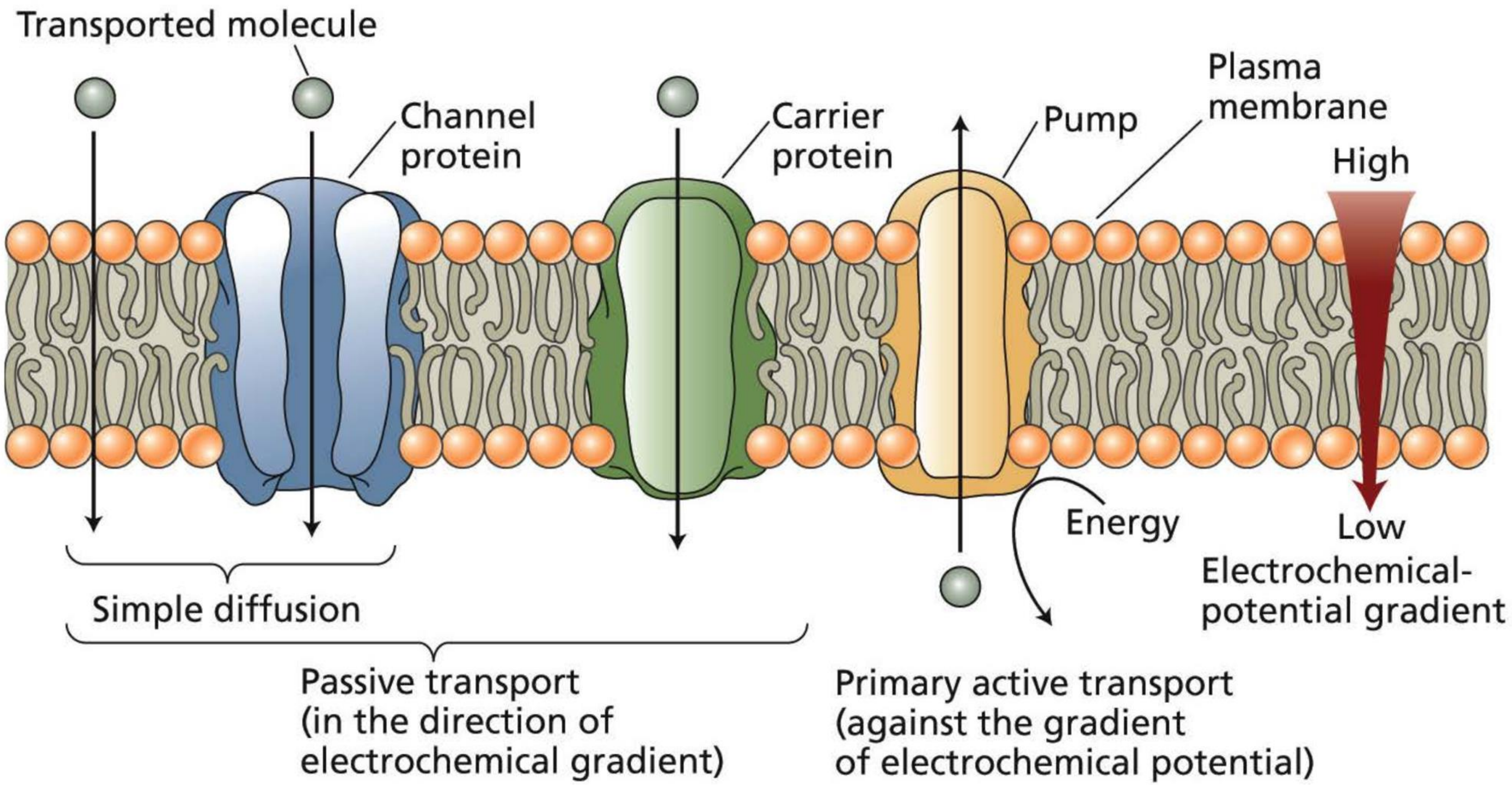
Nutrient Uptake





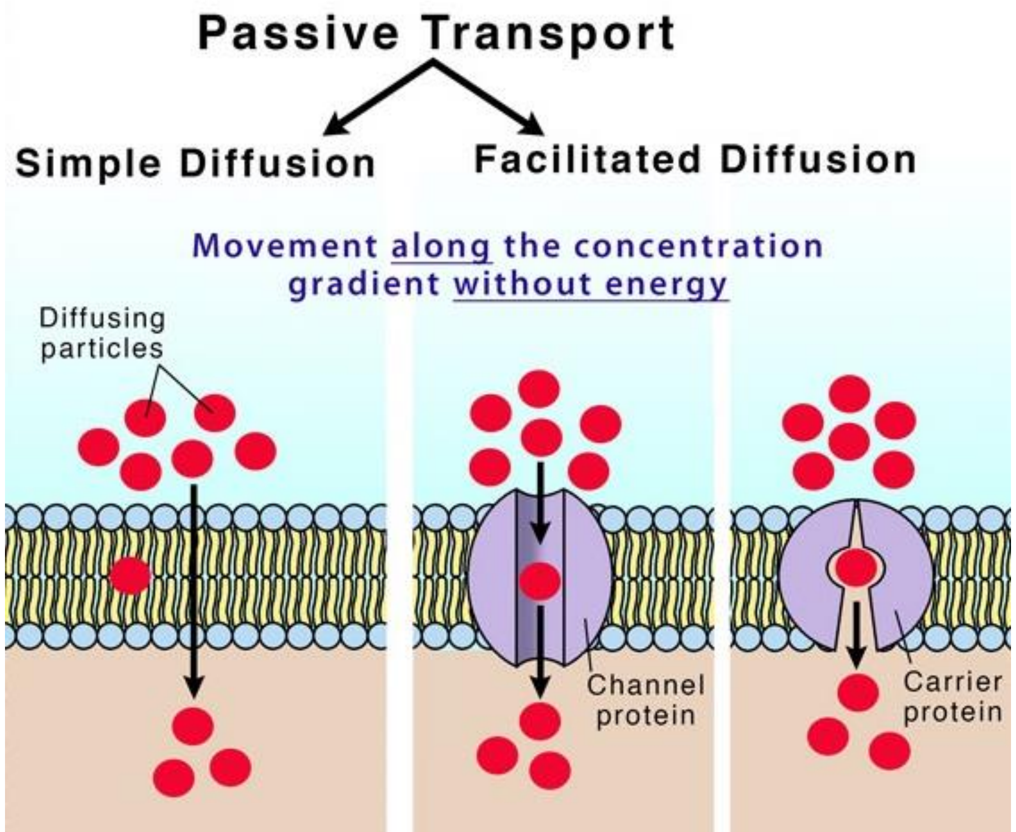
Nutrient Uptake

- Movement across membranes is facilitated by
- Channels (passive, can be gated)
- Carriers (passive or active)
- Pumps (active – it requires energy)



Nutrient Uptake

Passive Absorption(被动吸收): The process by which nutrients outside the membrane enter the plasma membrane **spontaneously** (non-selectively) along a **concentration gradient** (for molecules) or an **electrochemical potential gradient** (for ions), without consuming metabolic energy.



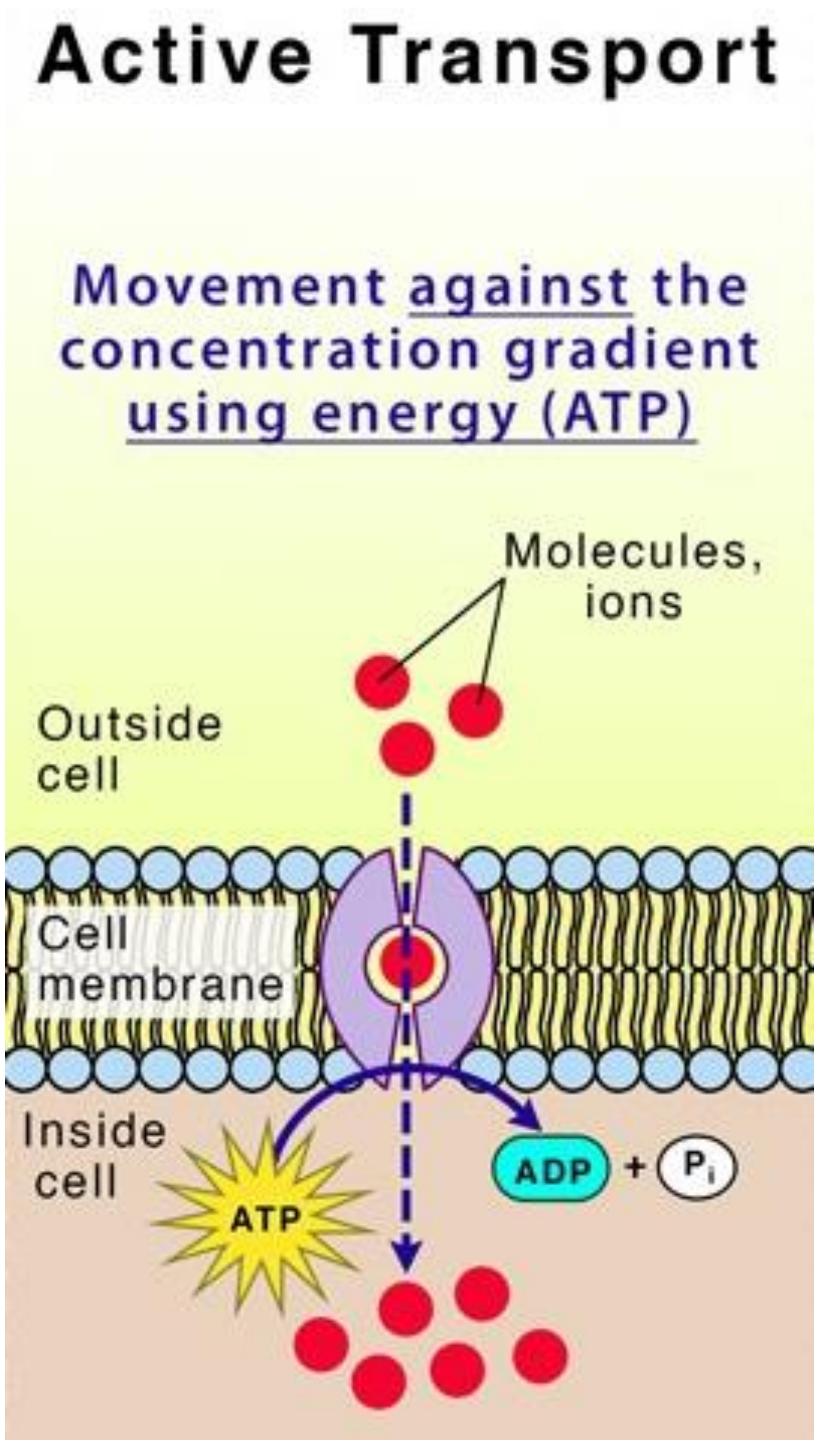
Simple Diffusion

VS

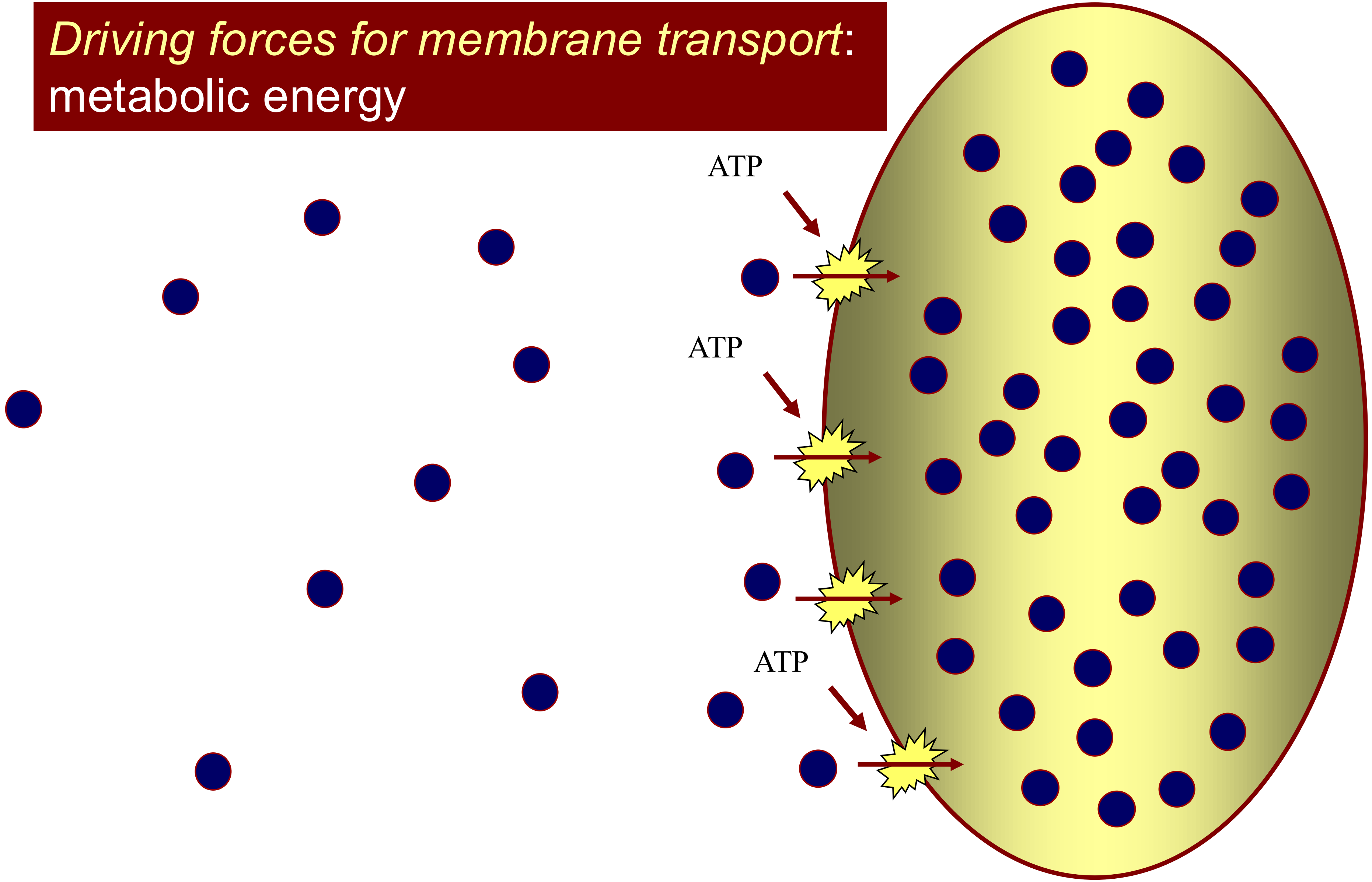
Facilitated Diffusion

Nutrient Uptake

Active Absorption (主动吸收) **:** The process cells absorb nutrient ions **against** a concentration gradient or an electrochemical potential gradient, requiring the **consumption of metabolic energy** and the participation of specific **carrier proteins**.



Driving forces for membrane transport: metabolic energy

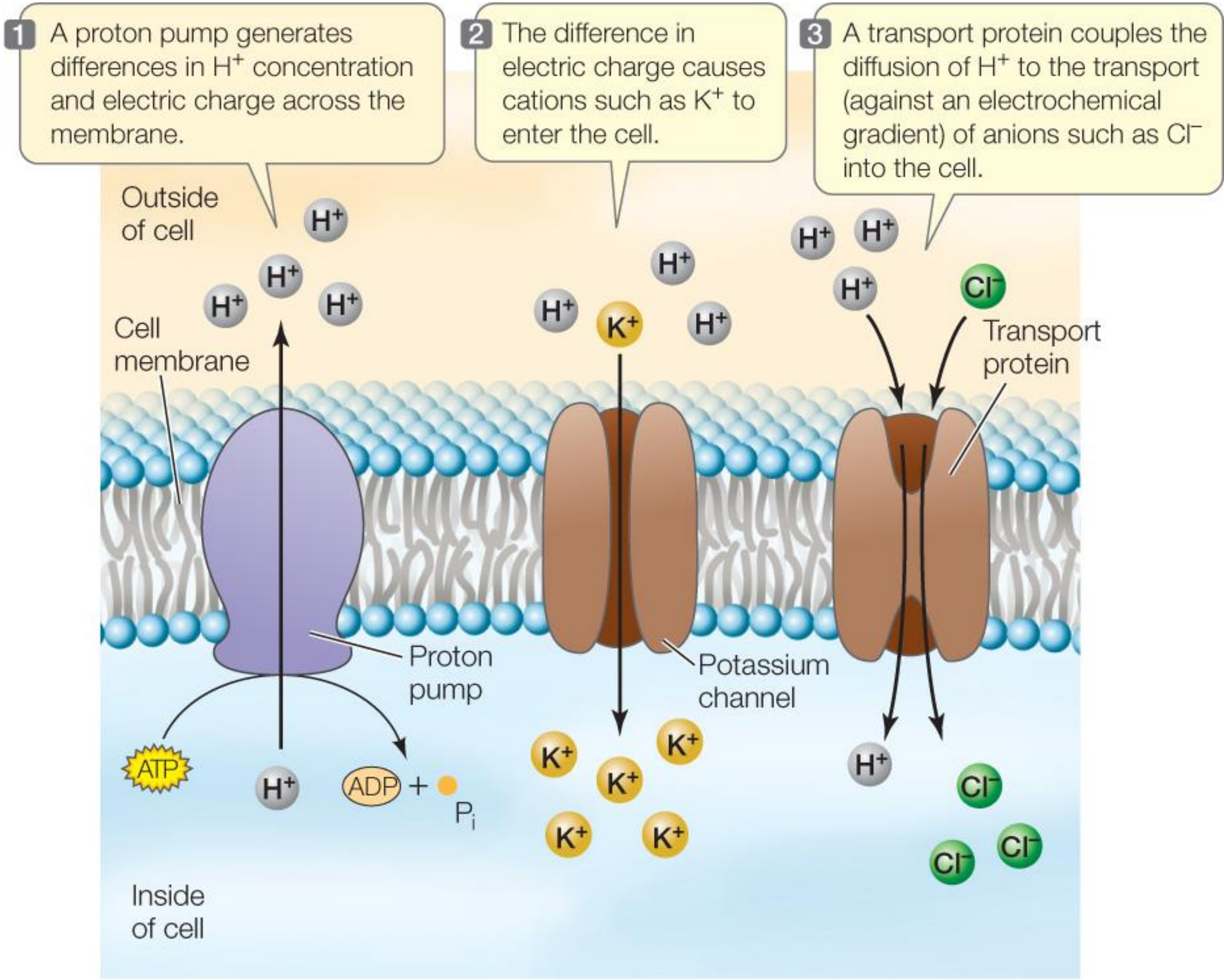


Rob Reid, 2004

Nutrient Uptake

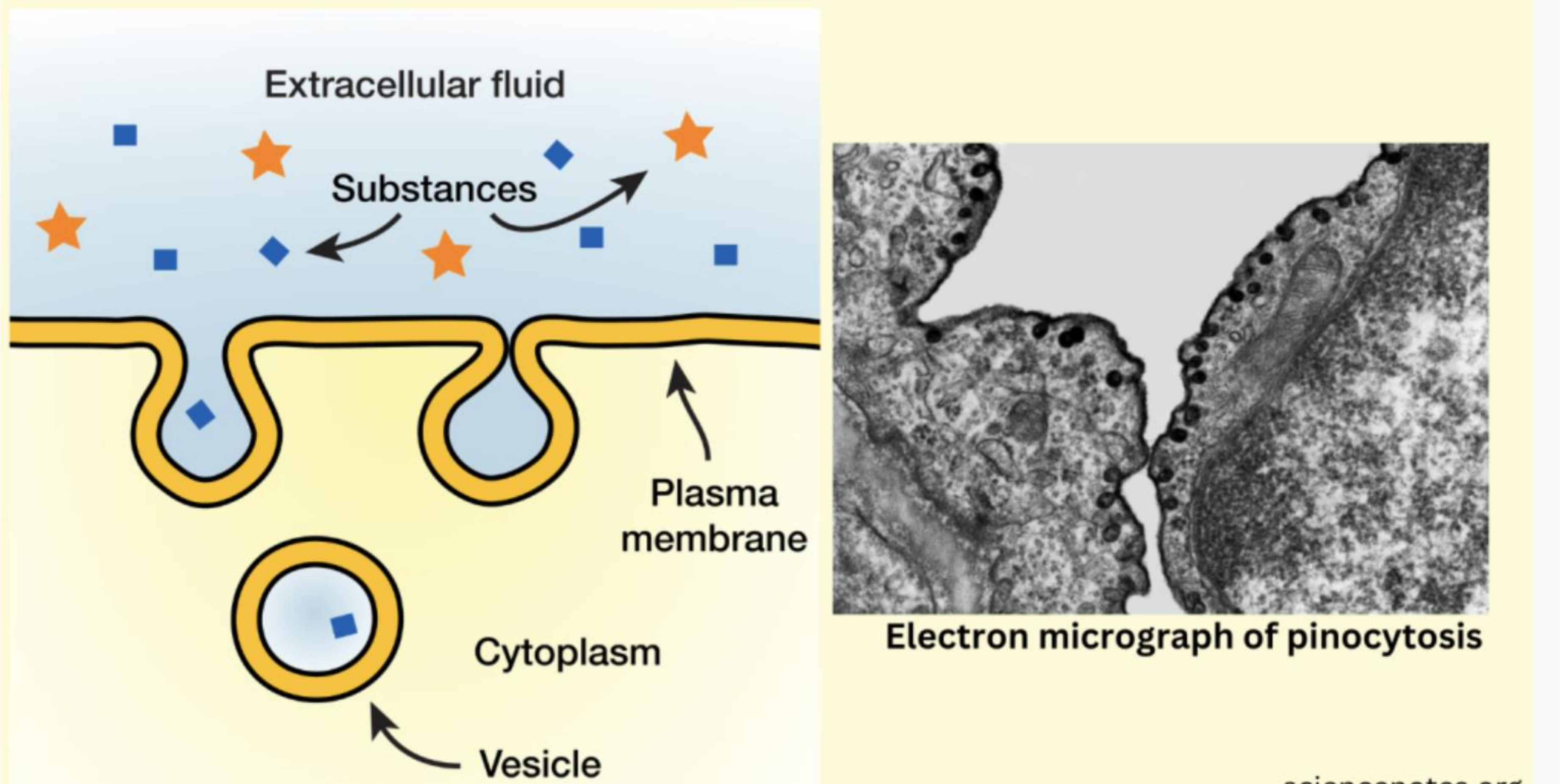
Pumps

Active transporters that utilize energy, usually derived from ATP, to transport minerals against their concentration gradient.



Nutrient Uptake

Pinocytosis or “cell drinking” is a crucial cellular process that involves ingesting liquid and dissolved solutes.



Electron micrograph of pinocytosis

Nutrient Uptake

Key factors influencing mineral uptake

1. Temperature Effects

- Both high or low extremes inhibit uptake
- **Low-Temperature Mechanisms:**
  - **Metabolic Depression:** Reduced respiration leads to **ATP deficiency**, hindering **active transport**.
  - **Biophysical Resistance:** Increased **protoplasmic viscosity**(细胞质粘性) raises the physical barrier to ionic influx.
- **Ion Specificity:** Uptake of **Potassium (K)** and **Silicon (Si)** is most sensitive to thermal fluctuations.

Nutrient Uptake

Key factors influencing mineral uptake

2. Oxygen Availability

- Directly governs **aerobic respiration** rates, providing the metabolic energy (proton motive force) required for nutrient loading.

3. External Solution Concentration

- Follows a classic dose-response curve;
- both nutrient deficiency (dilution) and **osmotic stress/salinity** (excess) are detrimental.

Nutrient Uptake

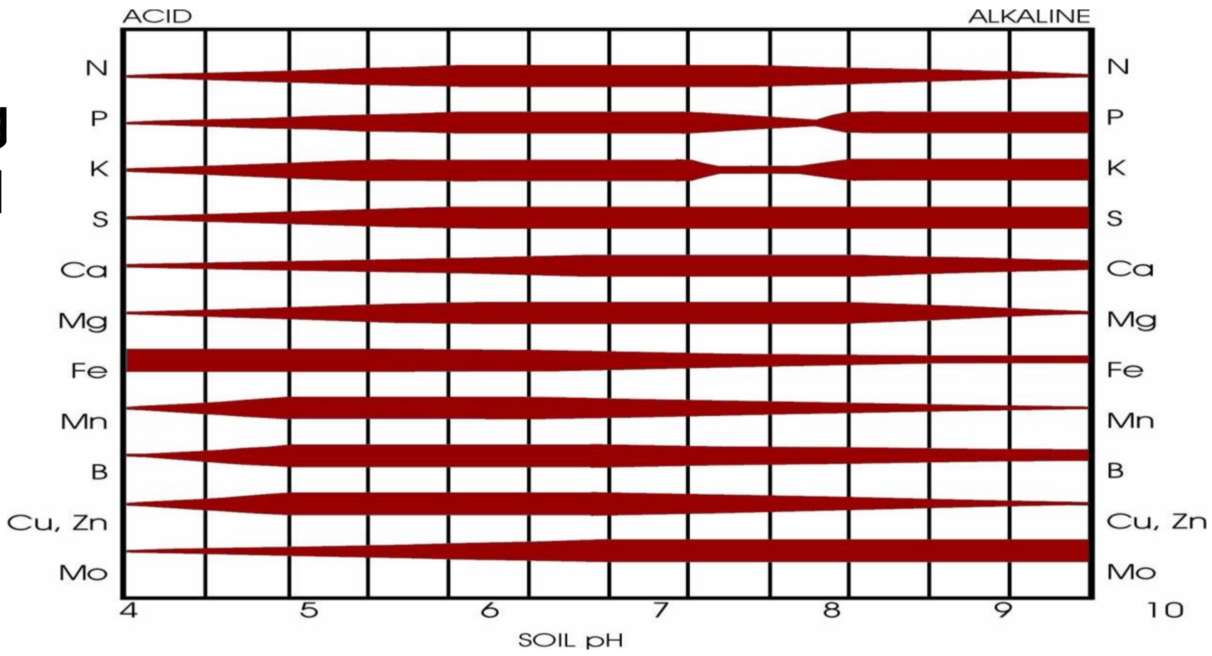
Key factors influencing mineral uptake

- ❖ **Alkaline Stress (pH > 7.0):**
  - Induces precipitation of **Fe, Ca, Mg, and Zn**.
  - Leads to **low bioavailability** and induced deficiency symptoms.
- ❖ **Acidic Stress (pH < 5.5):**
  - **Nutrient Leaching:** While **P, K, Ca, and Mg** dissolve readily, they are highly mobile and prone to leaching by rainfall before uptake occurs.
  - **Metal Toxicity:** Rapid increase in the solubility of **Fe, Al, and Mn**, often reaching **phytotoxic levels** that damage root architecture.

4. Rhizosphere pH Dynamics

The optimal range for most crops is

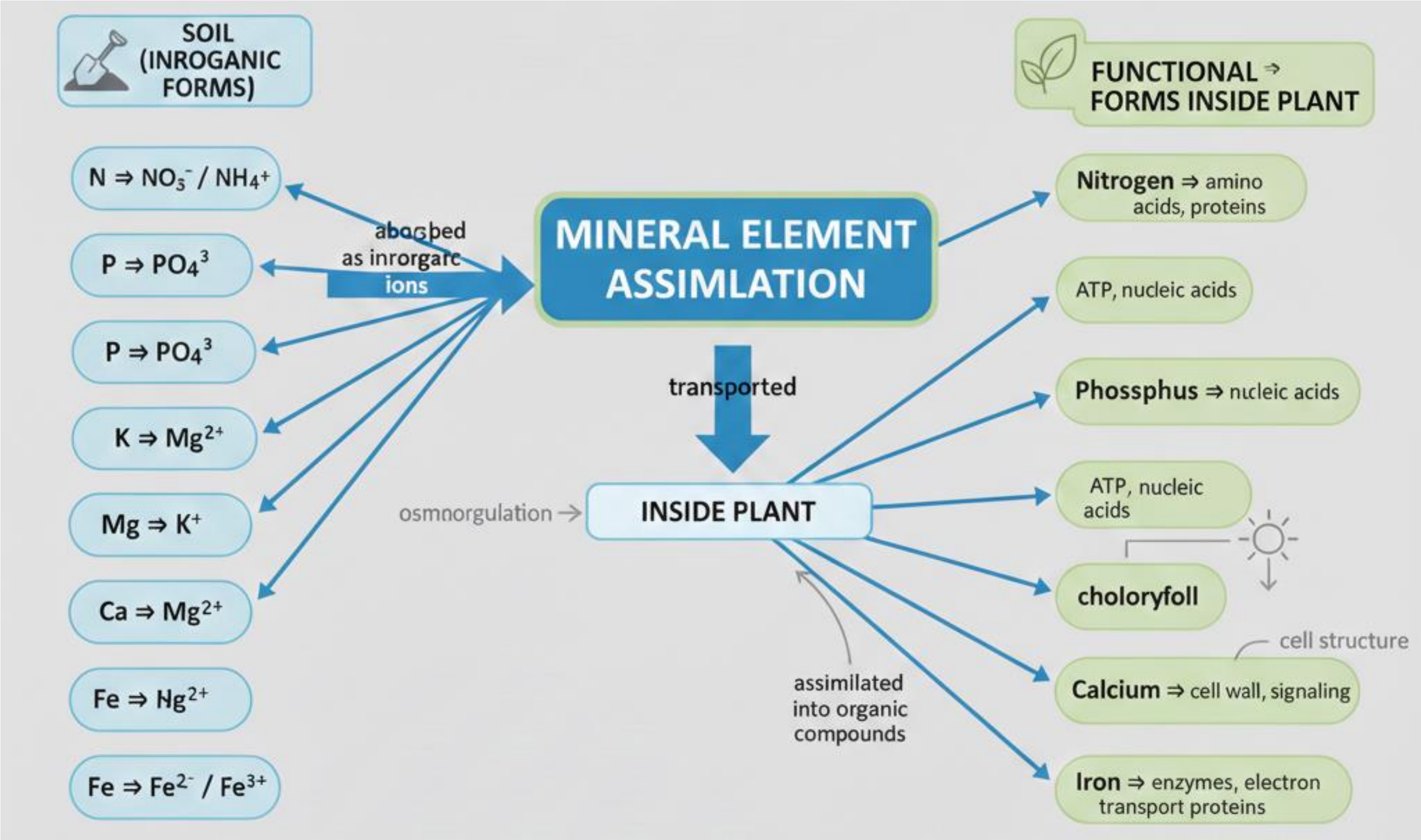
pH 6.0 – 7.0



Contents

Assimilation of Mineral Nutrients

The process of incorporating inorganic nutrients into organic substances (e.g. amino acids, nucleic acids, chlorophyll).



Assimilation of Mineral Nutrients

N assimilation as an example

Plants cannot use atmospheric nitrogen (N_2) directly, they primarily take up nitrogen as **Nitrate** (NO^{3-}) or **Ammonium** (NH^{4+}), and the most common form is $-NH_2$ in amino acids.

Phase I: Nitrate Reduction (The two-step reduction)

Step 1: the NO_3^- is firstly reduced into NO_2^- in **Cytosol**:

Nitrate Reductase (NR)

硝酸还原酶

$$NO_3^- + NAD(P)H + H^+ + 2e^- \longrightarrow NO_2^- + NAD(P)^+ + H_2O$$

NR is a large enzyme containing three prosthetic groups (FAD, Heme, and a Molybdenum cofactor)

Assimilation of Mineral Nutrients

N assimilation as an example

Phase I: Nitrate Reduction (The two-step reduction)

Step 2: the NO_2^- is reduced into NH_4^+ in **Chloroplasts (leaves) or Plastids (roots)**:

Nitrite Reductase (NiR)
亚硝酸还原酶

$$\boldsymbol{NO_2^- + 6Fd_{red} + 8H^+ + 6e^- \longrightarrow NH_4^+ + 6Fd_{ox} + 2H_2O}$$

Fd_{red}: ferredoxin (铁氧还蛋白)

$$6Fd_{red} \rightarrow 6Fd_{ox} + 6e^-$$

NO_2^- is highly reactive and potentially toxic, so it is immediately transported into the plastid(质体).

Assimilation of Mineral Nutrients

N assimilation as an example

Phase II: Ammonium Assimilation (The GS-GOGAT Cycle)

Step 1: The Glutamine Synthetase (GS) reaction

NH_4^+ is toxic because it can dissipate transmembrane **proton gradients**. Therefore, plants never store it; they "fix" it into organic molecules immediately via the **GS-GOGAT pathway**.

Glutamine Synthetase (GS)
谷氨酰胺合成酶

$$\text{Glutamate} + NH_4^+ + \text{ATP} \longrightarrow \text{Glutamine} + \text{ADP} + \text{Pi}$$

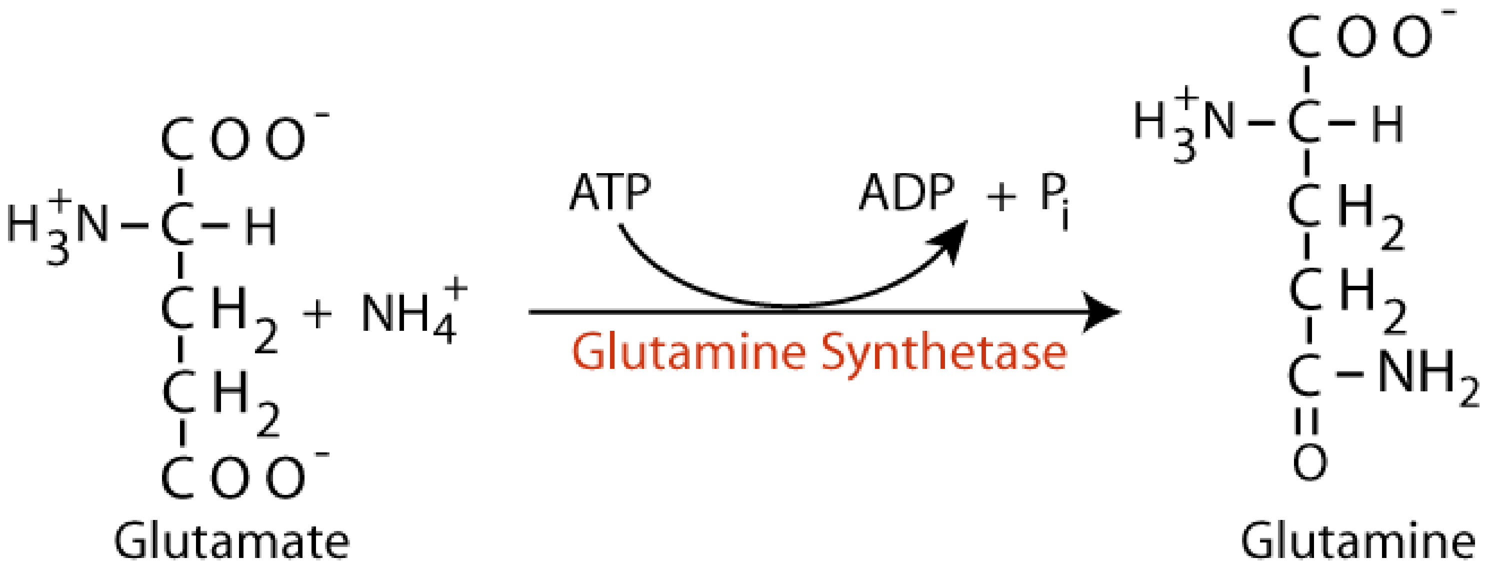
谷氨酸 谷氨酰胺

Assimilation of Mineral Nutrients

N assimulation as an example

Phase II: Ammonium Assimilation (The GS-GOGAT Cycle)

Step 1: The Glutamine Synthetase (GS) reaction



Glutamine contains 2 N, and it is the principal carrier for plant nitrogen transport and storage.

Assimilation of Mineral Nutrients

N assimilation as an example

Phase II: Ammonium Assimilation (The GS-GOGAT Cycle)

Step 2: The Glutamate Synthase (GOGAT, 谷氨酸合酶) reaction

GOGAT stands for **G**lutamine: **O**xo**G**lutarate **A**mino **T**ransferase (谷氨酰胺: α酮戊二酸氨基转移酶)

Plants use two types of GOGAT enzymes depending on the tissue and electron donor available:

A. Fd-GOGAT (Ferredoxin-dependent), primarily in the chloroplasts of leaves

$$\text{Glutamine} + \alpha\text{-ketoglutarate} + 2\ \text{Fd}_{red} \xrightarrow{\text{Fd-GOGAT}} 2\ \text{Glutamate} + 2\ \text{Fd}_{ox}$$

α-酮戊二酸

B. NADH-GOGAT (NADH-dependent), mainly in non-photosynthetic tissues or vascular bundles

$$\text{Glutamine} + \alpha\text{-ketoglutarate} + \text{NADH} + \text{H}^+ \xrightarrow{\text{NADH-GOGAT}} 2\ \text{Glutamate} + \text{NAD}^+$$

Assimilation of Mineral Nutrients

N assimilation as an example

Nitrate Reductase (NR) 硝酸还原酶

$$NO_3^- + NAD(P)H + H^+ + 2e^- \longrightarrow NO_2^- + NAD(P)^+ + H_2O$$

1 NAD(P)H

Nitrite Reductase (NiR) 亚硝酸还原酶

$$NO_2^- + 6Fd_{red} + 8H^+ + 6e^- \longrightarrow NH_4^+ + 6Fd_{ox} + 2H_2O$$

6 Fd_{red}

Glutamine Synthetase (GS) 谷氨酰胺合成酶

$$Glutamate + NH_4^+ + ATP \longrightarrow Glutamine + ADP + Pi$$

1 ATP

Fd-GOGAT

$$Glutamine + \alpha\text{-ketoglutarate} + 2\ Fd_{red} \longrightarrow 2\ Glutamate + 2\ Fd_{ox}$$

2 NADH/ Fd_{red}

1 ATP + 9 e^-

Contents

Transport and Redistribution of Nutrients

Fate of absorbed nutrients

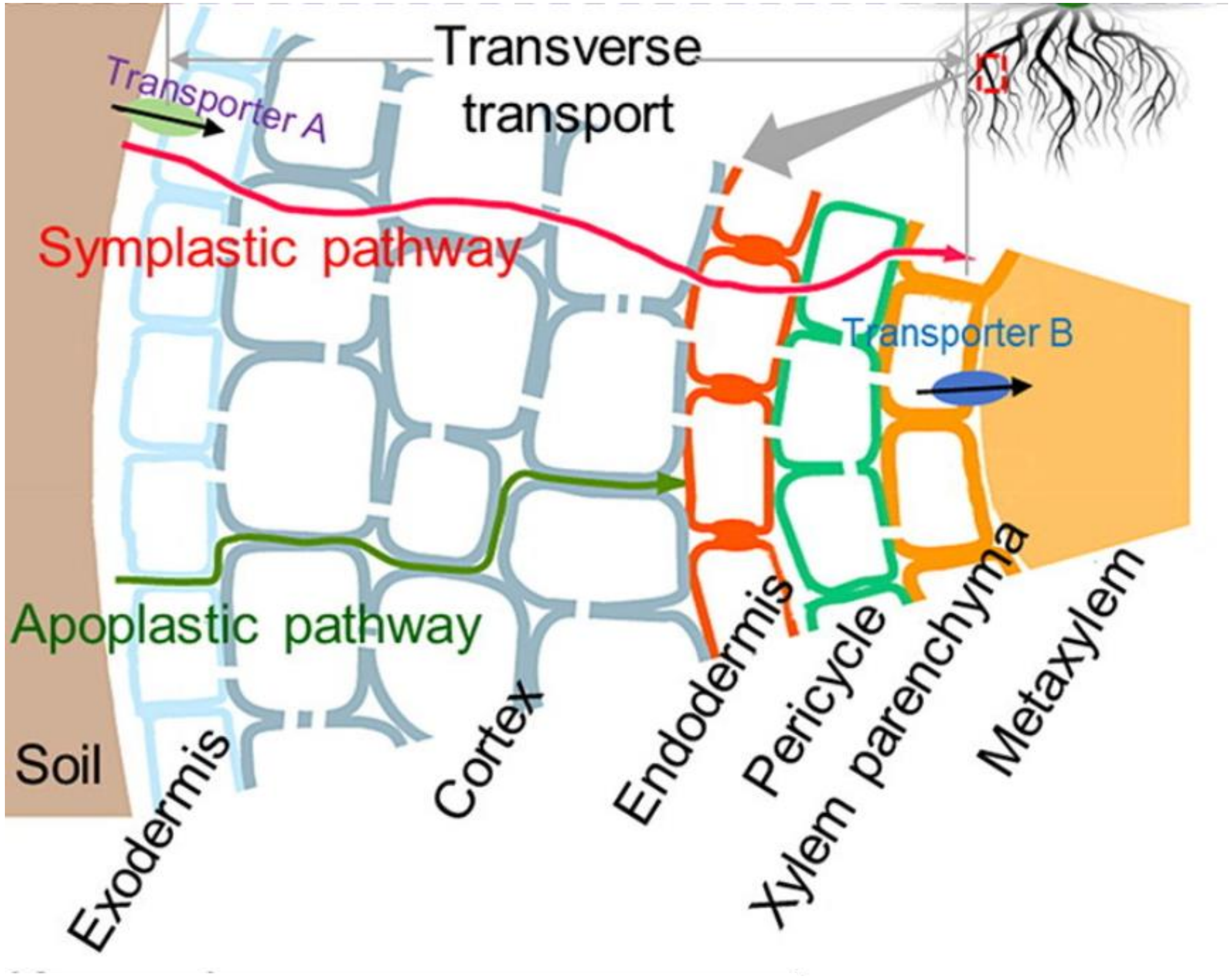
1. Local Assimilation & Vacuolar Storage
2. Short-distance Transport (Lateral)
3. Long-distance Translocation (Xylem/Phloem)
4. Root Exudation/Efflux

Transport and Redistribution of Nutrients

Short-Distance Transport

Definition: Also known as lateral transport, it refers to the migration process of nutrients from the external growth medium through the root epidermis, cortex, and endodermis, finally reaching the stele (xylem vessels).

Apoplast Pathway (质外体途径)
vs
Symplast Pathway (共质体途径)



Transport and Redistribution of Nutrients

Early Theory: The Leakage Hypothesis

Proposed that ions within the symplast passively cross the cortex tissue and, after passing through endodermal cells, leak into xylem vessels.

1. **Absorption at Root Surface**
   Ions from soil solution enter root epidermal cells (root hairs) across the plasma membrane.

2. **Symplastic Movement**
   Ions travel through the symplast — cytoplasm connected by plasmodesmata — across the cortex.

3. **Crossing the Endodermis**
   The Casparian strip blocks apoplastic flow; ions must pass through endodermal cells via the symplast.

4. **Passive Leakage into Xylem**
   Ions were thought to passively leak from pericycle parenchyma into the xylem vessel lumen.

Transport and Redistribution of Nutrients

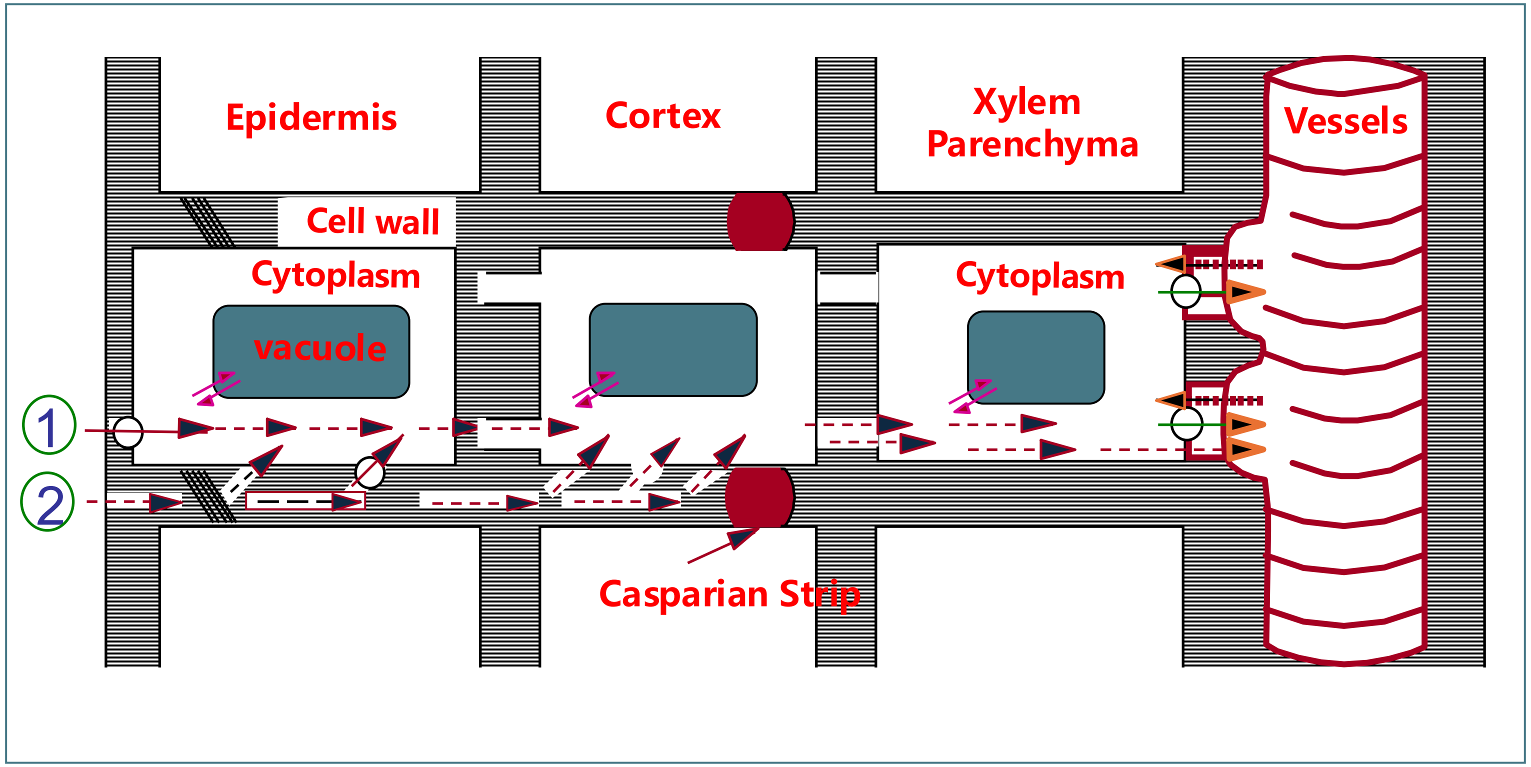
Modern View: The Dual Pump Model

FIRST PUMP — Entry into Symplast

Ions are actively pumped from the soil medium or free apoplastic space across the plasma membrane into the cytoplasm of epidermal or cortex cells.

SECOND PUMP — Entry into Apoplast (Xylem)

Ions are actively pumped from xylem parenchyma (thin-walled) cells across their plasma membrane into the xylem vessel lumen.



Transport and Redistribution of Nutrients

Long-distance Translocation

It refers to the process where nutrients move upward through the **xylem vessels** or upward/downward through the **phloem sieve tubes**.

Two Main Pathways/Conduits

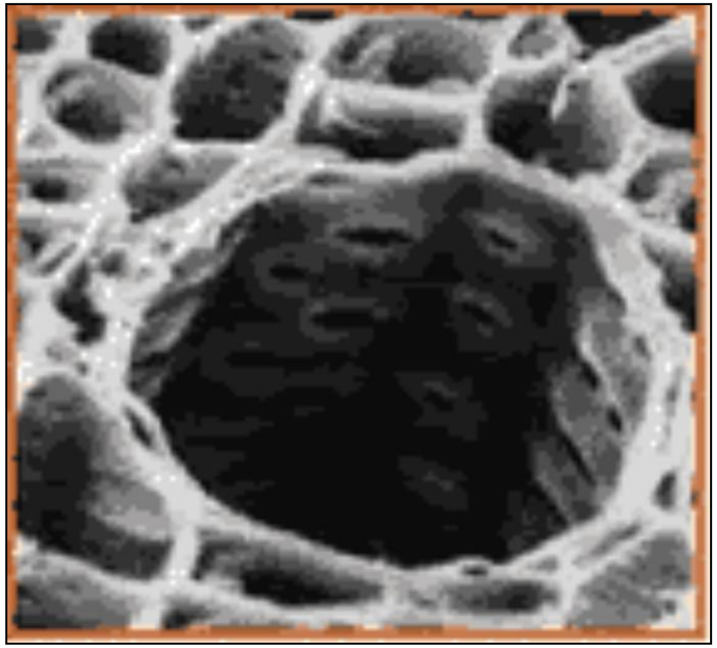
- **Xylem Transport:** Primarily for water and mineral nutrients absorbed by roots.
- **Phloem Transport:** Primarily for organic photohydrates and the redistribution of mobile mineral elements.

Transport and Redistribution of Nutrients

Long-distance Translocation

Driving Forces of Xylem Transport

Primary Driving Force: Transpiration acts as the dominant "pulling" force for the upward movement of xylem sap which mineral dissolved in.



The efficiency of nutrient transport in the xylem is determined by

- **Plant Growth Stage:** Seedling vs. reproductive stages.
- **Diurnal Rhythms:** Day vs. night activity.
- **Ionic Properties:** The specific type and concentration of ions.

Transport and Redistribution of Nutrients

Long-distance Translocation

Direction of Xylem Transport

Predominantly **Unidirectional** (单向), moving from the roots to the above-ground organs (shoot system).

Main Destinations:

- **Leaves:** For photosynthesis and metabolic use.
- **Fruits and Seeds:** Acting as major sinks for nutrient accumulation.

Transport and Redistribution of Nutrients

Chemical Forms of Nutrient Transport

Plants do not simply move "raw" elements; nutrients are transported in specific chemical forms to ensure **metabolic stability**, **solubility**, and **minimal toxicity** during their journey through the xylem or phloem.

Metallic Cations (K^+, Ca^{2+}, Mg^{2+}, etc.) transported predominantly in their **ionic state**.

Phosphorus (P) transported mainly as Inorganic Orthophosphate ($H_2PO_4^-$ or HPO_4^{2-}).

Nitrogen (N) transported as Amides (Glutamine, Asparagine) and Amino Acids; can also transported as NO_3^-) .

Sulfur (S) transported almost exclusively as Sulfate (SO_4^{2-}).

Transport and Redistribution of Nutrients

The Internal Recycling System

Redistribution refers to the physiological process where nutrients, previously accumulated in one organ, are exported and transported to other parts of the plant to meet new growth demands. This acts as a **survival strategy** during localized nutrient deficiency or natural senescence.

The redistribution of nutrients depends on the element's mobility within the **Phloem.**

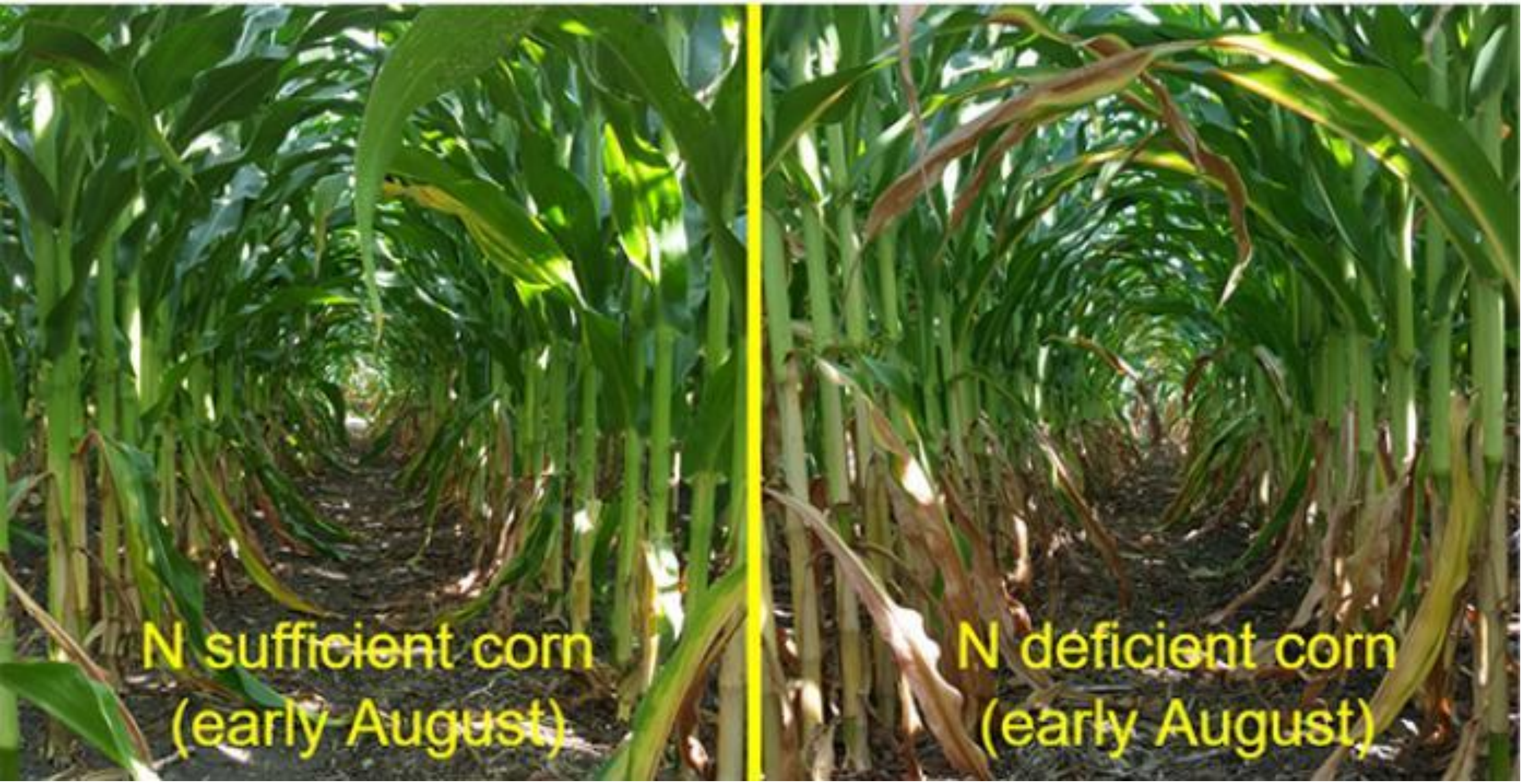
Mobile Elements (可再利用元素)

- **Examples:** N, P, K, Mg, Zn
- **Form:** Exist as free ions or unstable organic compounds.
- **Symptom Pattern:** Deficiencies appear first in **older leaves** because plant "sacrifices" old tissue to support new growth.

Immobile Elements (不可再利用元素)

- **Examples:** **Ca**, B, Cu, Mn, S, Fe
- **Reason:** Often structural (e.g., Calcium in cell walls) or poorly transported in phloem.
- **Symptom Pattern:** Deficiencies appear first in young leaves/buds.

Transport and Redistribution of Nutrients



Contents

Foliar Nutrition

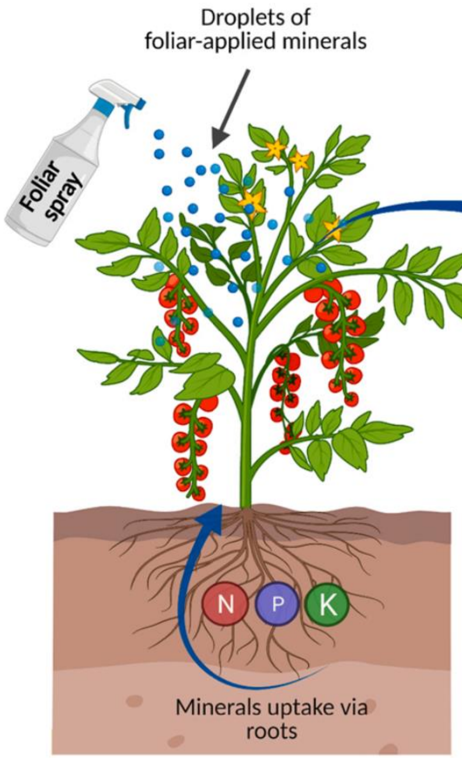
Foliar nutrition is the practice of applying liquid fertilizer directly to the above-ground organs (mainly leaves) to be absorbed and utilized by the plant.

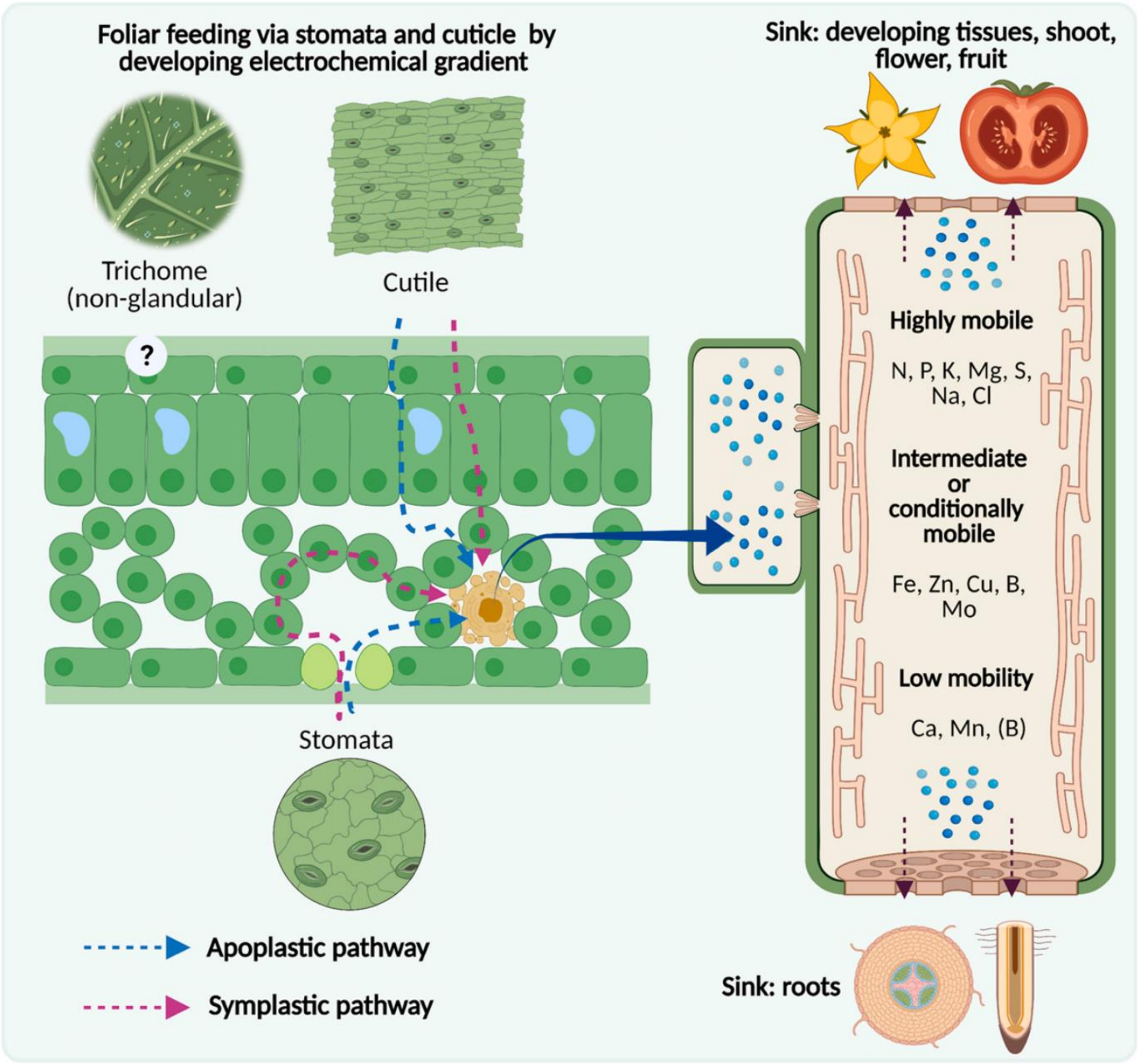
Why use Foliar Application?

- **Rapid Response:** Bypasses soil immobilization and root-to-shoot translocation delays.
- **Overcoming Root Limitations:** Effective when root activity is restricted by low soil temperature, waterlogging, or salinity.
- **Targeted Supplementation:** Ideal for addressing micronutrient deficiencies (e.g., Fe, Zn) during critical growth stages like flowering or fruit development.

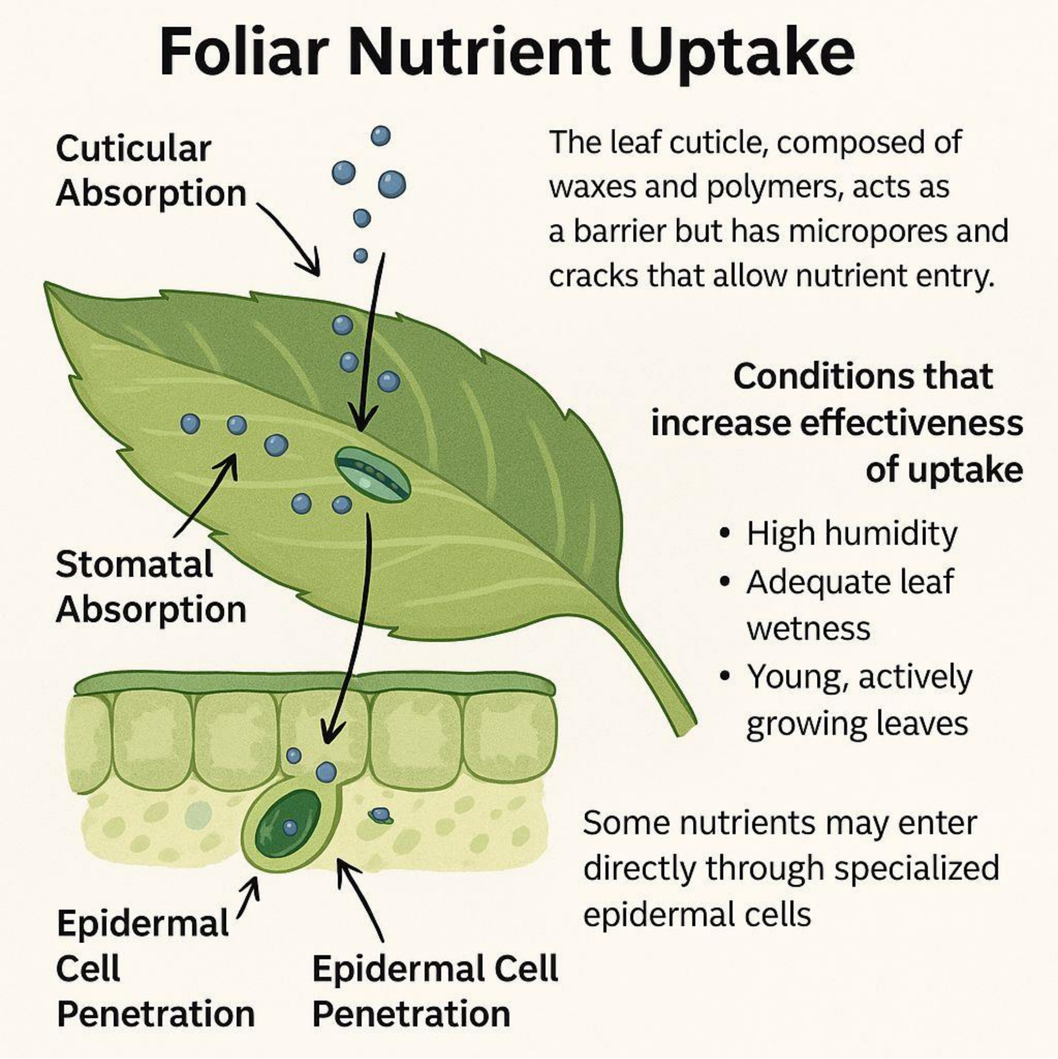
Foliar Nutrition

Pathways of Foliar Absorption





Foliar Nutrition



Pathways of Foliar Absorption

- **The Cuticle** (角质层): The primary hydrophobic barrier. Nutrients enter through microscopic "aqueous pores" within the wax matrix.
- **Stomatal Pathway** (气孔路径): While primarily for gas exchange, liquid nutrients can enter through the stomatal chambers, especially when surfactants are used to lower surface tension.
- **Ectodesmata** (外连丝): Specialized channels in the epidermal cell walls that facilitate the inward movement of solutes.

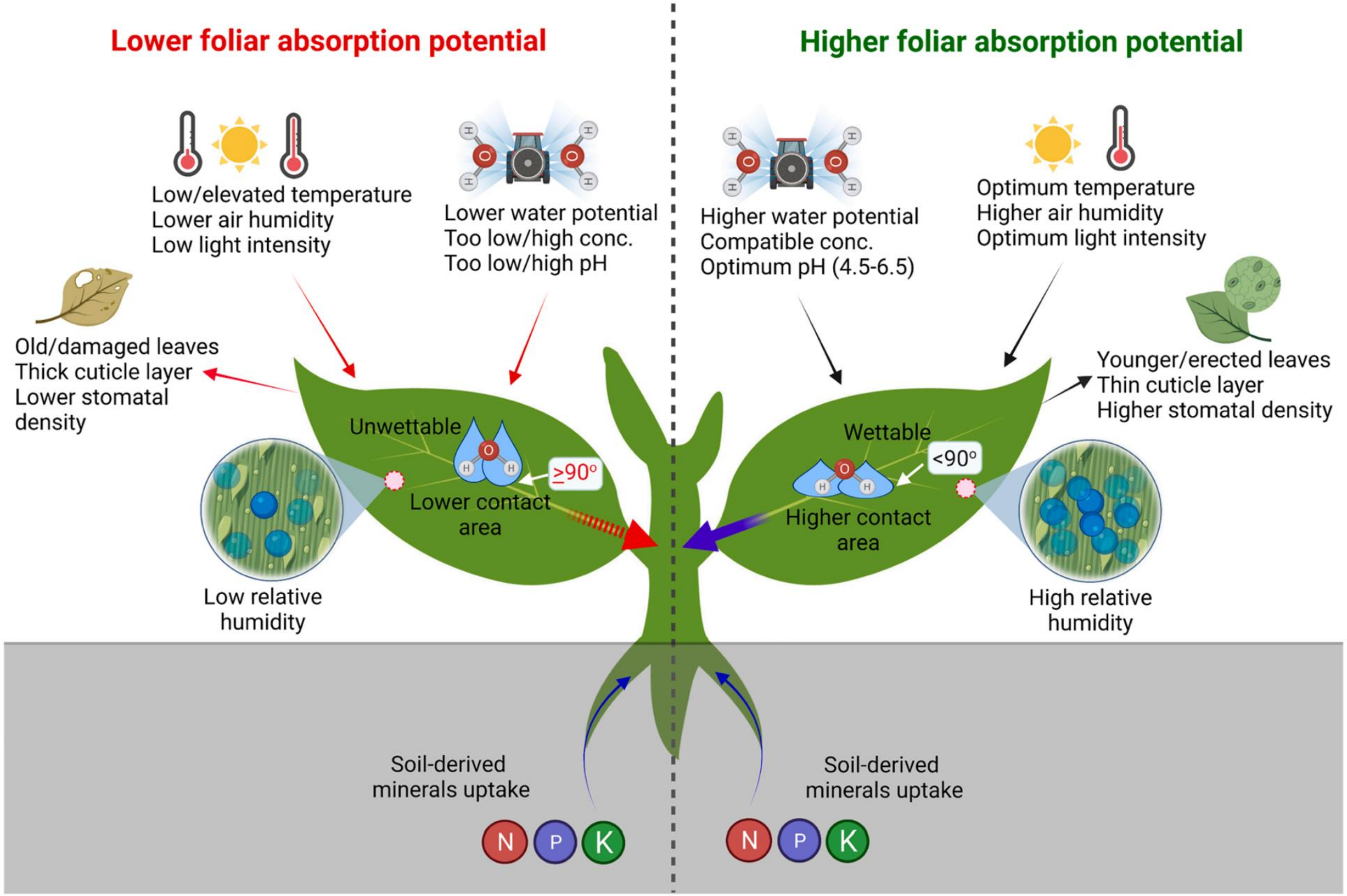
Foliar Nutrition

Factors Affecting Foliar Absorption

- **Plant Factors**
  - **Leaf Age:** Younger leaves generally have thinner cuticles and higher metabolic activity, leading to better absorption.
  - **Leaf Morphology:** Waxy or hairy (trichome-rich) leaves may repel liquid droplets, requiring higher concentrations of wetting agents.
- **Environmental Factors**
  - **Humidity:** High humidity keeps the fertilizer in a liquid state longer, extending the absorption window.
  - **Temperature**: Best applied in early morning or late evening to avoid rapid evaporation and leaf "burn" (phytotoxicity).

Foliar Nutrition

Factors Affecting Foliar Absorption



Foliar Nutrition

Root vs. Foliar Nutrient Uptake

Feature	Root Uptake (Main Channel)	Foliar Nutrition
Primary Barrier	**Endodermis / Casparian Strip** (selective filtration)	**Cuticle / Stomata** (hydrophobic barrier)
Transport Pathway	**Apoplast & Symplast** (Short-distance lateral transport)	**Cuticular/pores/Ectodesmata** (Direct symplastic entry)
Driving Force	**Transpiration Pull**	**Diffusion Gradient** & Surfactant-enhanced wetting
Speed of Action	Slower (requires translocation through the xylem)	**Very Rapid** (immediate absorption into leaf metabolism)
Target Nutrients	All essential elements (Macro + Micro)	Primarily **Micronutrients** and supplemental N/P/K

Root vs. Foliar Nutrient Uptake

The role of Root Uptake is the "Supply" system:

- Designed for bulk nutrient acquisition from the growth medium (rhizosphere).
- Nutrients are "loaded" into the xylem to be distributed to all above-ground organs.

The role of Foliar Uptake is the "Correction" system:

- Directly addresses the needs of a specific **"Sink"** (e.g., developing fruits or young leaves).
- Crucial for elements with low soil mobility or when the **transpiration stream** is insufficient.

The functional role of Root Uptake can not be replaced by the Foliar Uptake

Contents

Physiological Basis of Rational Fertilization

The Concept of Rational Fertilization

Rational fertilization is the practice of applying the right type of fertilizer, in the right amount, at the right time, and using the right method.

Physiological Objectives

- **Optimizing Source-Sink Relationships:** Ensuring that the "Source" (photosynthetic leaves) can adequately supply the "Sink" (developing grains, fruits, or tubers).
- **Maximizing Nutrient Use Efficiency (NUE):** Reducing losses to the environment (leaching, volatilization) by synchronizing application with the plant's maximum demand.
- **Carbon-Nitrogen (C-N) Balance:** Balancing vegetative growth (leaves/stems) with reproductive development (seeds/fruits).

Physiological Basis of Rational Fertilization

Critical Periods of Nutrient Demand

1. The Critical Period of Nutrition (营养临界期)

- **Definition:** A specific stage in early development when the plant is extremely sensitive to the *deficiency* of a particular element.
- **Physiological Impact:** Even if the nutrient is supplied later, the damage to yield potential caused during this period often cannot be reversed.

2. The Period of Maximum Efficiency (营养最大效率期)

- **Definition:** The stage when the plant absorbs nutrients most rapidly and shows the greatest growth response to fertilization.
- **Timing:** Usually coincides with the period of most vigorous vegetative growth or early reproductive transition (e.g., the jointing stage in cereals).

Physiological Basis of Rational Fertilization

Indicators of Plant Nutritional Status

Morphological Indicators

外相形态指标

Leaf Color: Using SPAD meters or leaf color charts to assess chlorophyll levels (linked to N status).

Growth Rate: Monitoring plant height, leaf area index (LAI), or tiller number.

Deficiency Symptoms: Identifying visual cues like chlorosis (yellowing) or necrosis (browning).

Physiological and Biochemical Indicators

生理生化指标

Analysis of Xylem Sap: Measuring the chemical forms and concentrations of nutrients being transported from the roots.

Enzyme Activity: Using enzymes as "bio-sensors" (e.g., Nitrate Reductase activity as an indicator of N status).

Tissue Testing: Measuring the concentration of total elements or specific ions (NO_3^-, PO_4^{3-})

Physiological Basis of Rational Fertilization

Interactions Between Nutrients

Rational fertilization must account for how one element affects another.

- ❖ **Synergism** (协同作用): Where the presence of one element promotes the uptake of another (e.g., NO_3^- can promote the uptake of cations like K^+ and Mg^{2+}).
- ❖ **Antagonism** (拮抗作用): Where an excess of one ion inhibits the uptake of another (e.g., excessive K^+ can interfere with Mg^{2+} or Ca^{2+} absorption).

Review Questions

1. **The "Two-Pump" Logic:** Why must an ion cross at least two plasma membranes to move from the soil solution into the xylem vessels? Identify the specific anatomical locations of these two "pumps."
2. **Mobility & Diagnosis:** If you observe chlorosis (yellowing) in the **older, bottom leaves** of a plant while the top leaves remain green, which group of elements is likely deficient? List three elements that fit this pattern.
3. **Form & Function:** In what chemical form is Nitrogen primarily transported through the xylem to reduce toxicity? Why is phosphorus transported as an inorganic orthophosphate ($H_2PO_4^-$) rather than an organic complex?
4. **Source-Sink Rhythms:** Define the **"Critical Period of Nutrition"** and explain why fertilization during this stage is more impactful than during the **"Period of Maximum Efficiency."**

Homework Assignments

Scenario A: A farmer observes that his tomato crop has "Blossom End Rot" (black, sunken spots on the bottom of the fruit), while the rest of the plant's leaves look healthy and dark green.

- ✓ **Task 1:** Identify the most likely nutrient(s) associated with this physiological disorder and justify your answer based on the observed symptoms.
- ✓ **Task 2:** Using the transpiration stream theory, explain why fruits may show this deficiency even when soil nutrients are sufficient.
- ✓ **Task 3:** Suggest a quick strategy to correct the problem.

Scenario B: A commercial grower applies a large amount of potassium during the tomato fruiting stage to increase sugar content. Soon after, interveinal chlorosis on older leaves appears, indicating magnesium deficiency.

- ✓ **Task 1:** explain why excessive potassium application can lead to magnesium deficiency.
- ✓ **Task 2:** If potassium nitrate (KNO_3) had been used instead of KCl, could the synergistic effect of nitrate help reduce the magnesium deficiency? Explain using the concept of nitrate promoting cation uptake.

The End