Mineral Nutrition in Plants

Plant nutrition: essentiality, mechanism of absorption, role in plant metabolism.

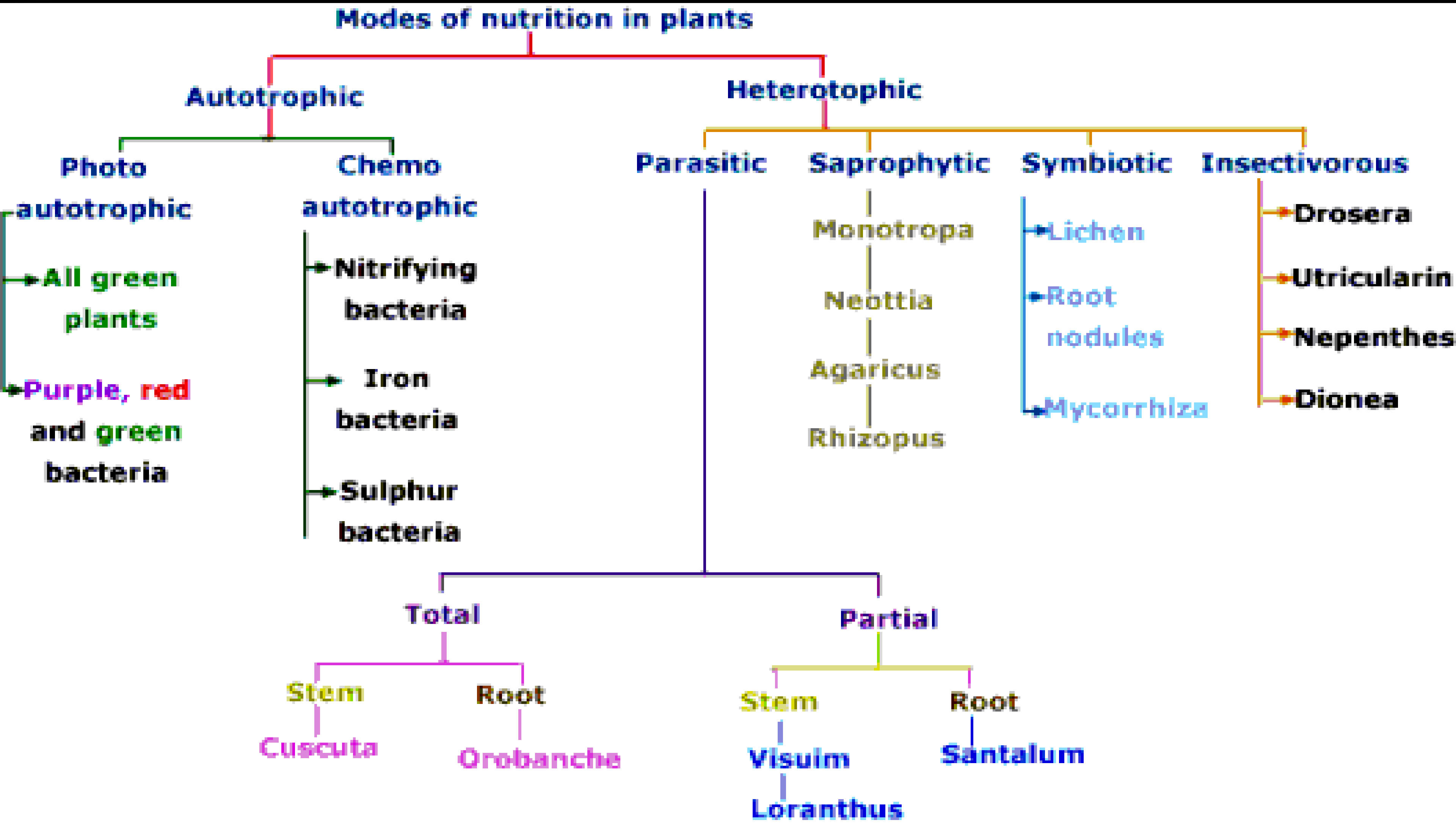
“Mineral”: **An inorganic element**

“Nutrient”: **A substance needed to survive or necessary for the synthesis of organic compounds**

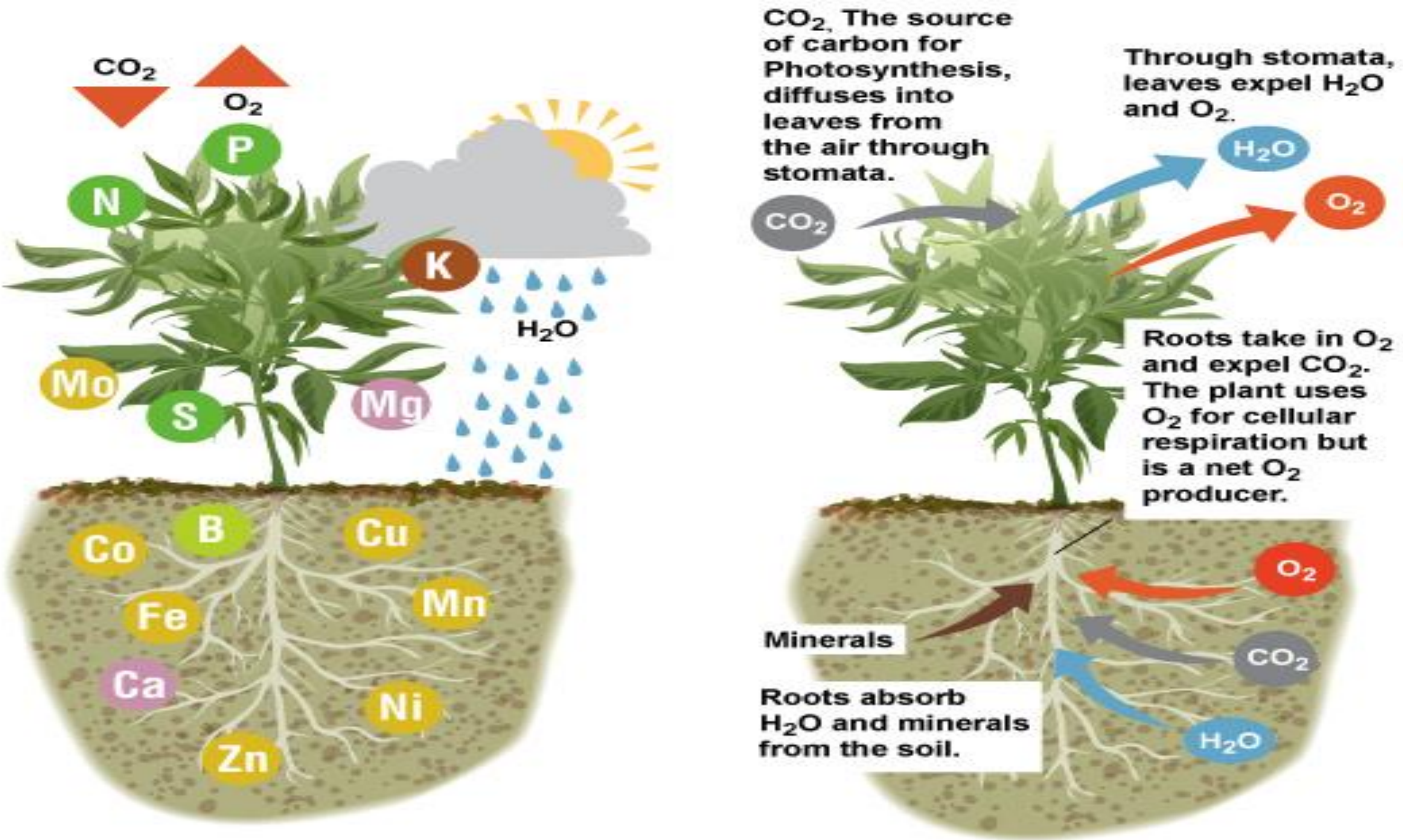
MINERAL NUTRIENTS: are elements acquired primarily in the form of inorganic ions from the soil

MINERAL NUTRITION :

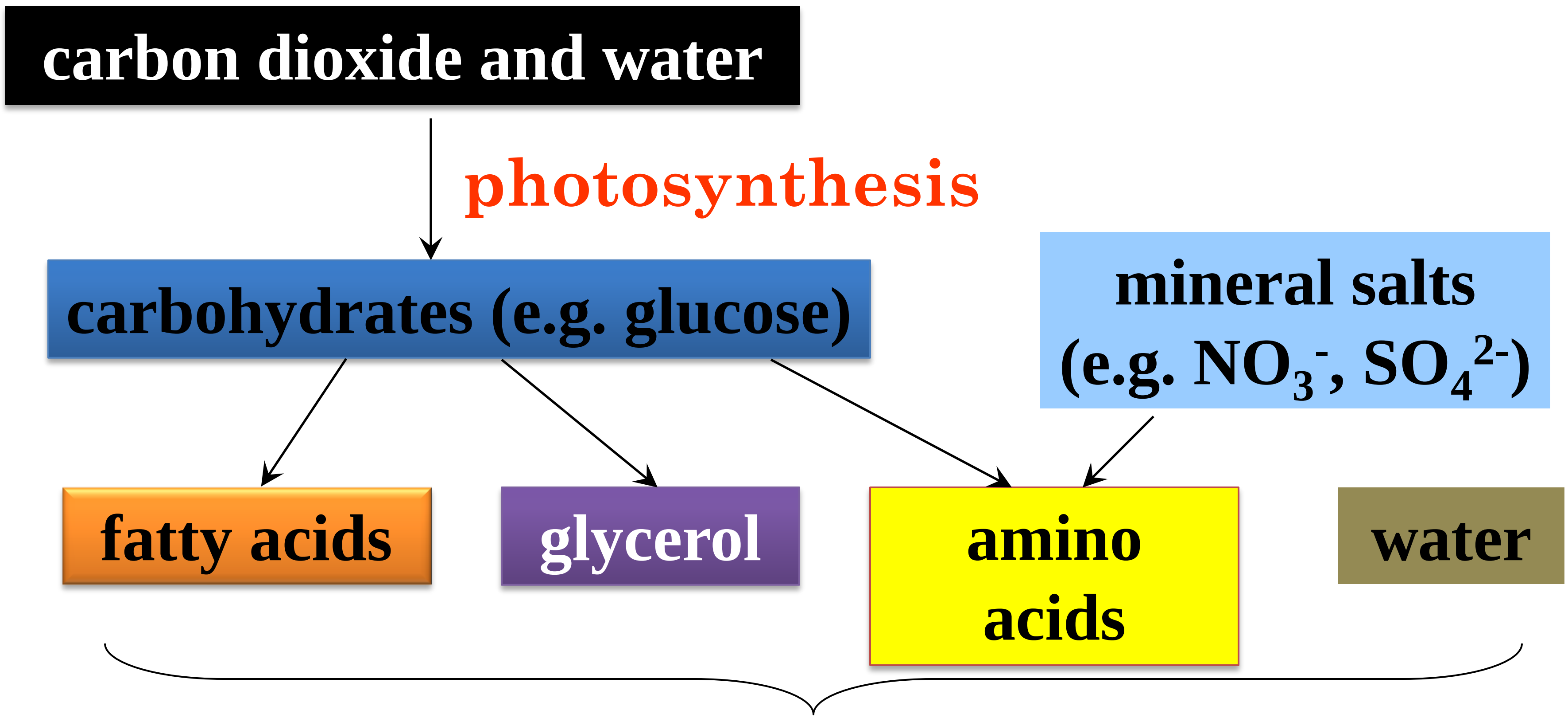
Study of how plants obtain, distribute, metabolize, and utilize mineral nutrients


Modes of nutrition in plants
Autotrophic
Heterotophic
Photo autotrophic
Chemo autotrophic
All green plants
Purple, red and green bacteria
Nitrifying bacteria
Iron bacteria
Sulphur bacteria
Parasitic
Saprophytic
Symbiotic
Insectivorous
Monotropa
Neottia
Agaricus
Rhizopus
Lichen
Root nodules
Mycorrhiza
Drosera
Utricularin
Nepenthes
Dionea
Total
Partial
Stem
Root
Cuscuta
Orobanche
Stem
Root
Visuim
Loranthus
Santalum

Overview of nutrition in green plants



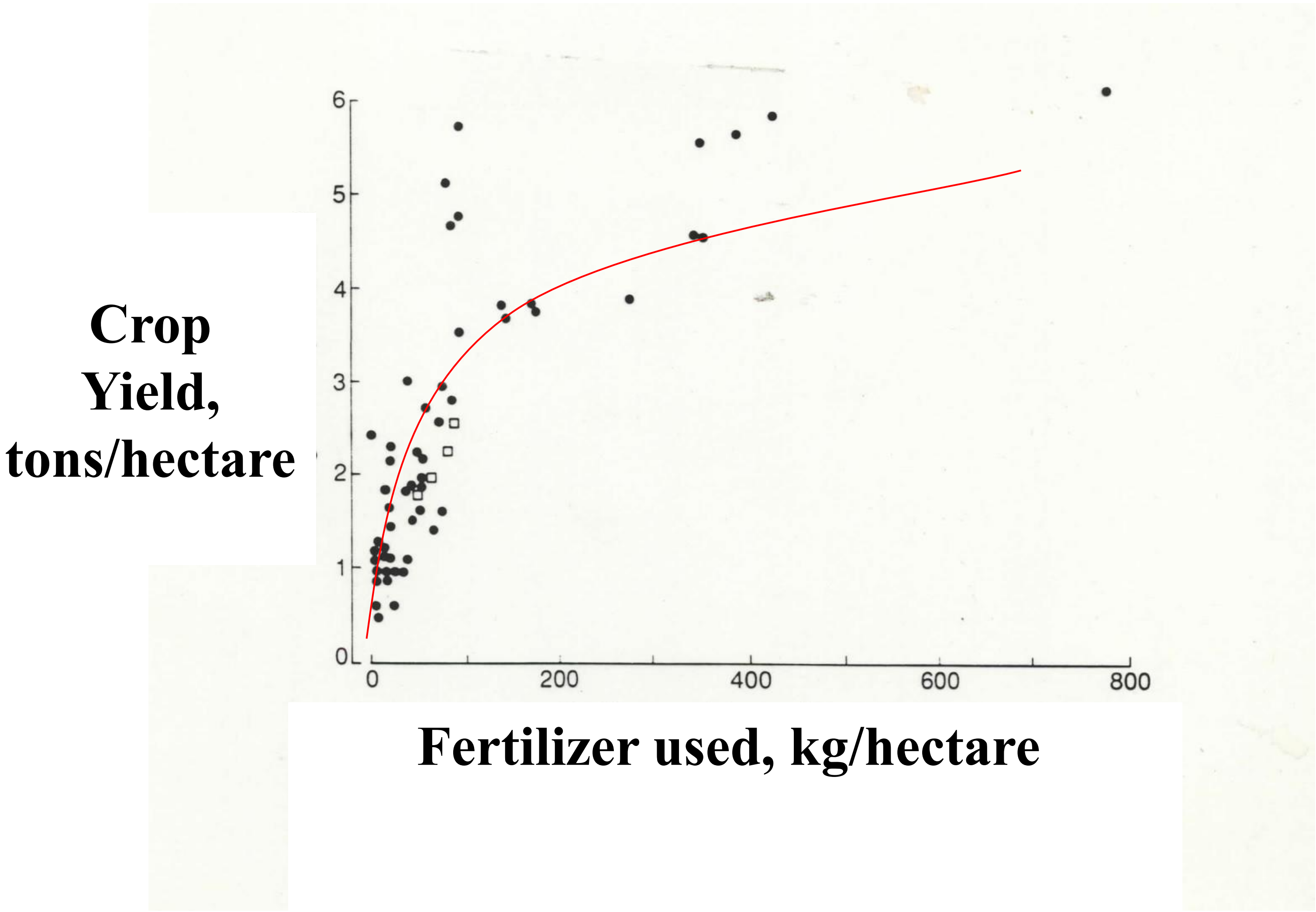
Overview of nutrition in green plants

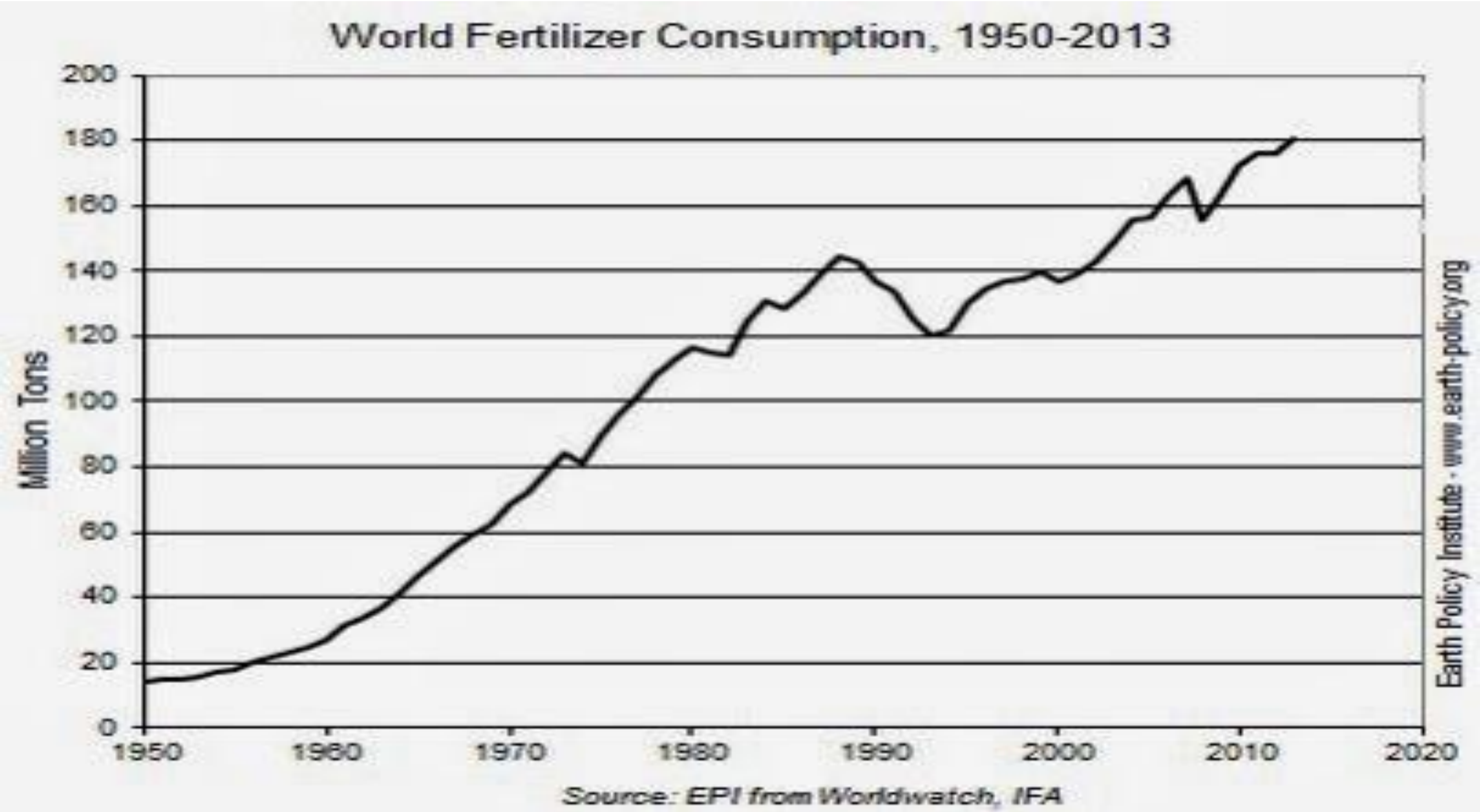


nutrients for plants can be used to produce all plant materials (e.g. enzymes, cell wall, cytoplasm, cell membrane, chlorophyll)

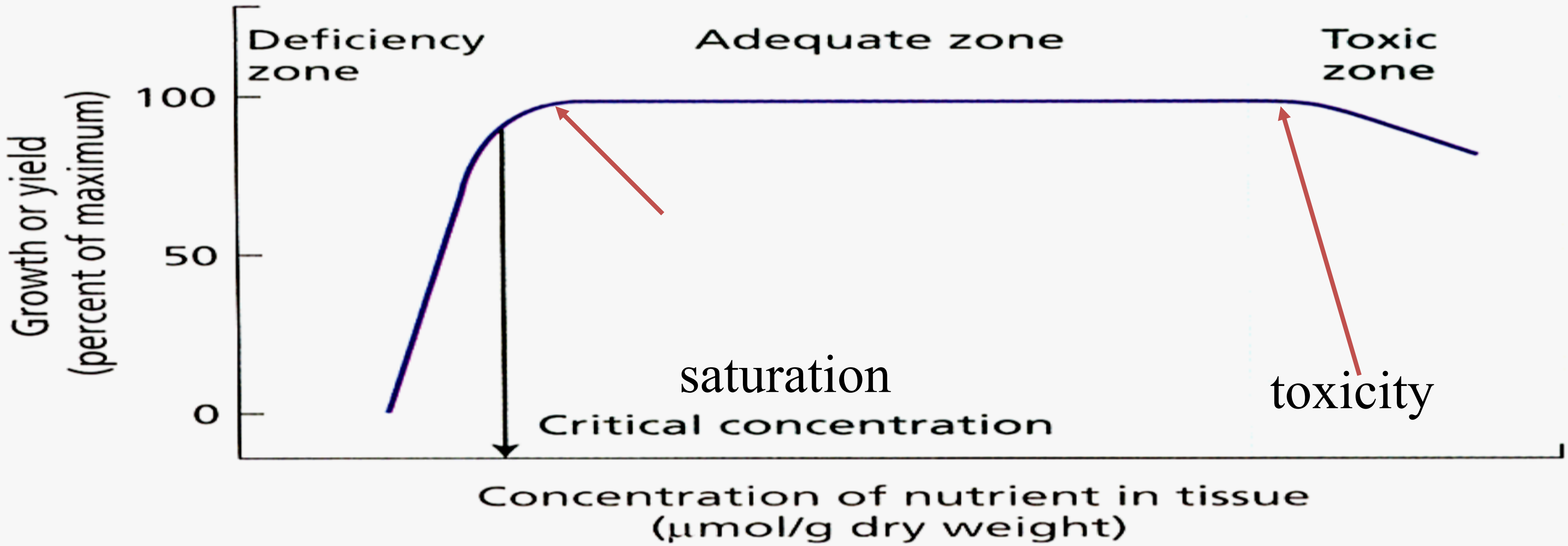
Why is mineral nutrition important?

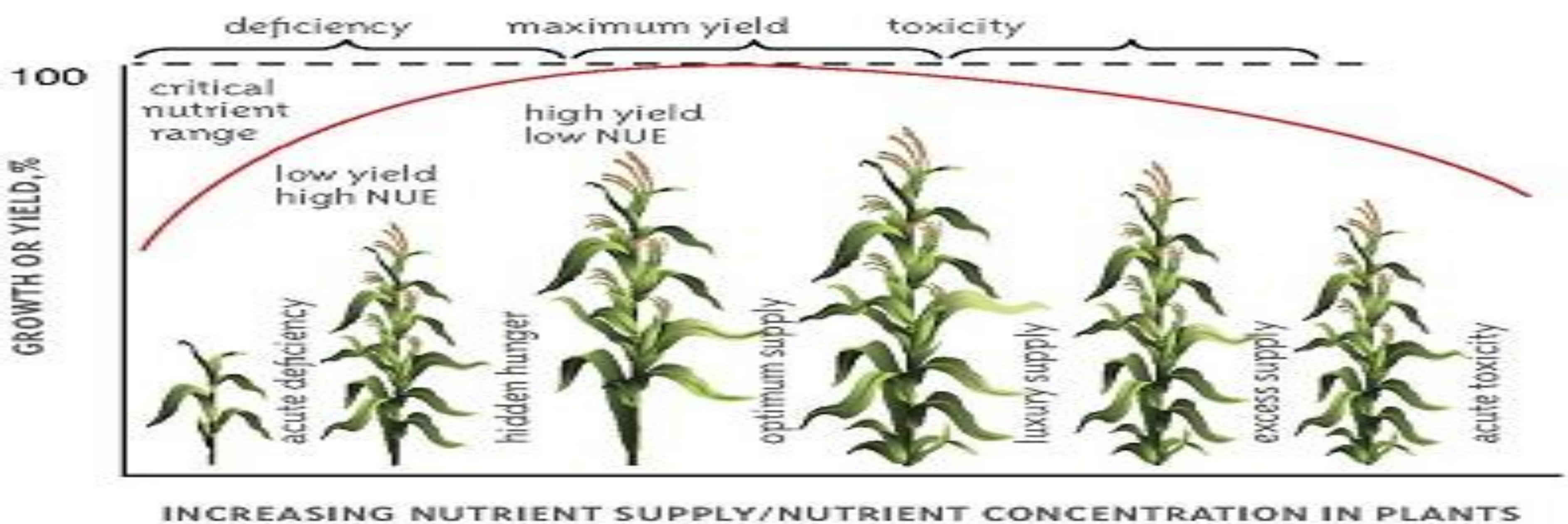
Fertilization increases crop production



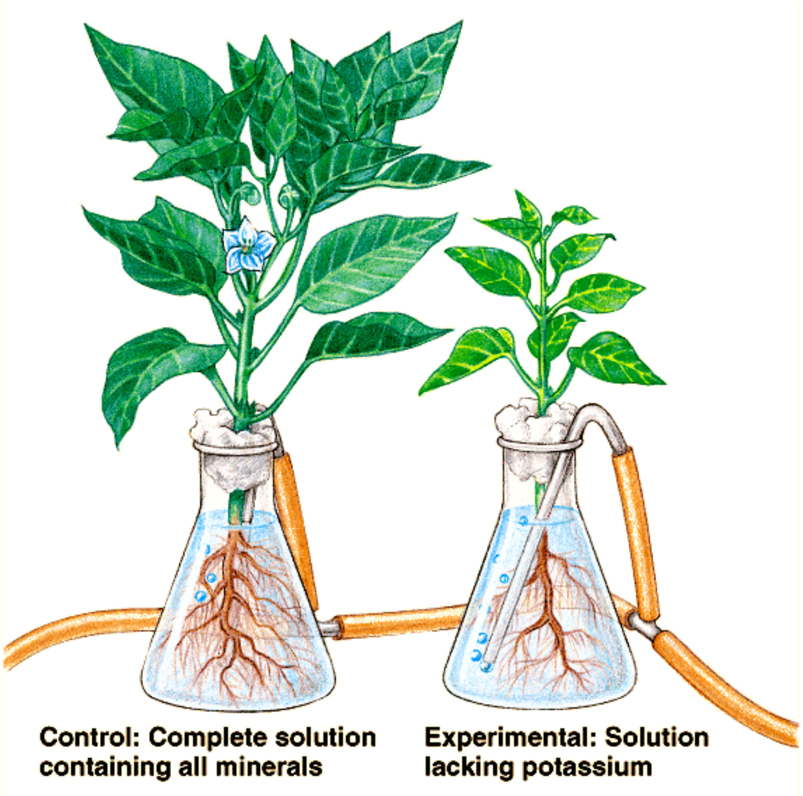

World Fertilizer Consumption, 1950-2013
Million Tons
200
180
160
140
120
100
80
60
40
20
0
1950
1960
1970
1980
1990
2000
2010
2020
Source: EPI from Worldwatch, IFA
Earth Policy Institute - www.earth-policy.org

Dose Response Curves





Nutrient Deficiencies



Hydroponics

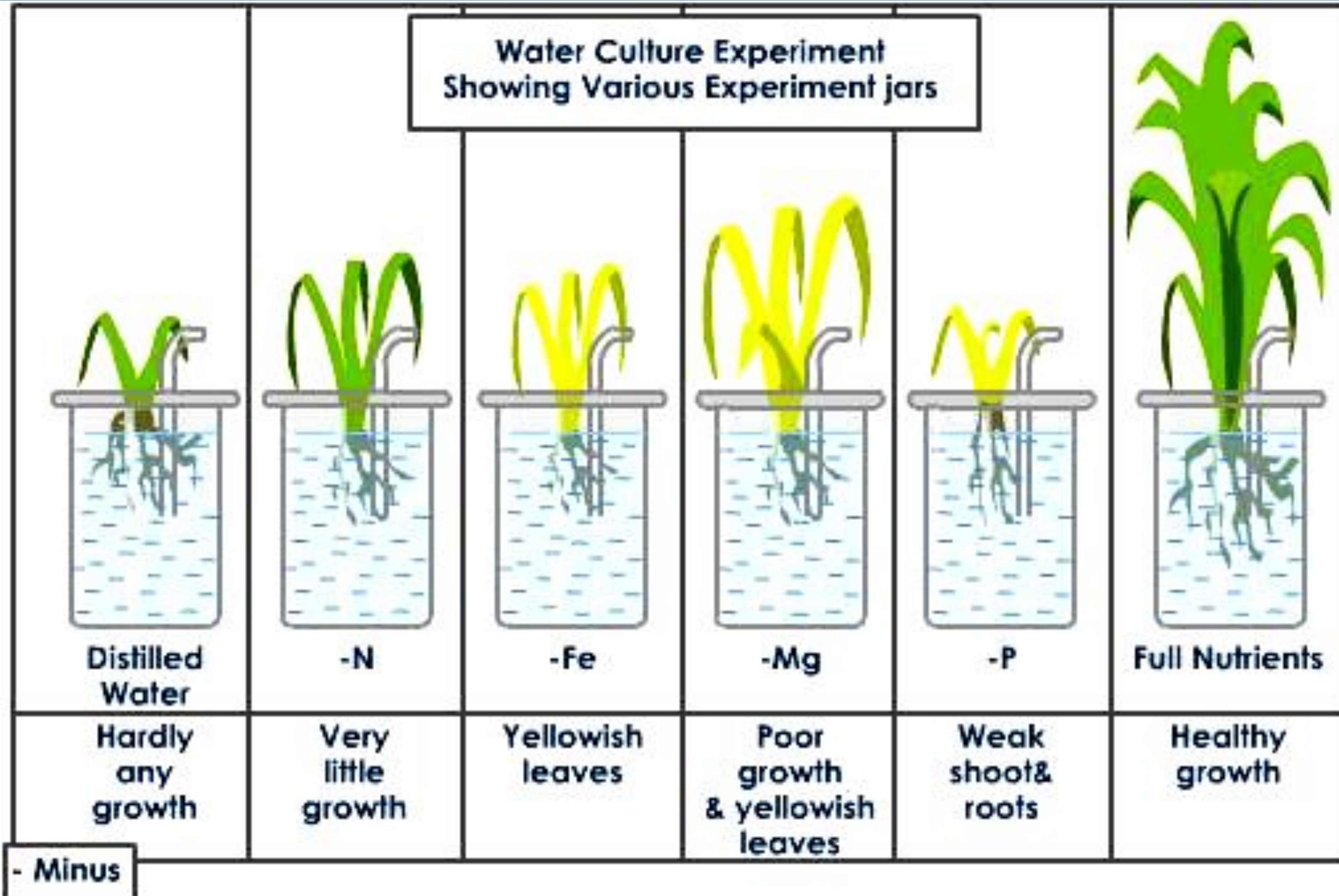
- Mineral deficiencies are relatively easy to identify in controlled conditions.

Difficult in Soils

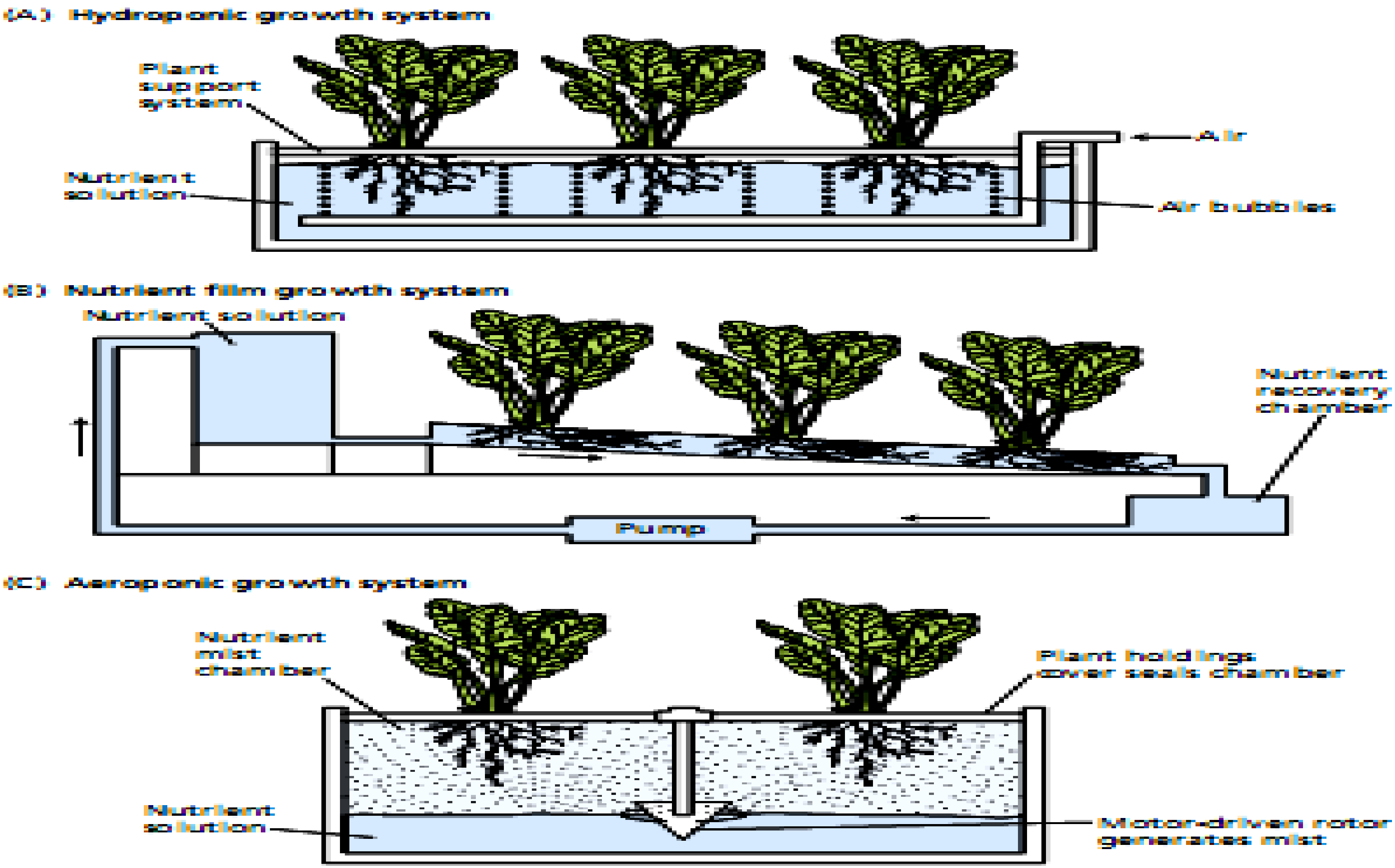
Chronic and acute deficiencies of several nutrients may occur simultaneously,

Deficiencies (or excess) of one element may induce deficiencies (or excess of another element.,

Pathogens often induce symptoms similar to nutrient deficiencies.


Water Culture Experiment
Showing Various Experiment jars
Distilled Water
-N
-Fe
-Mg
-P
Full Nutrients
Hardly any growth
Very little growth
Yellowish leaves
Poor growth & yellowish leaves
Weak shoot& roots
Healthy growth
- Minus

Hydroponics and Aeroponics



Advantages of hydroponics over geoponics:

- Controlled condition
- No immobilization
- No weed
- No tillage
- Plant growth can be controlled

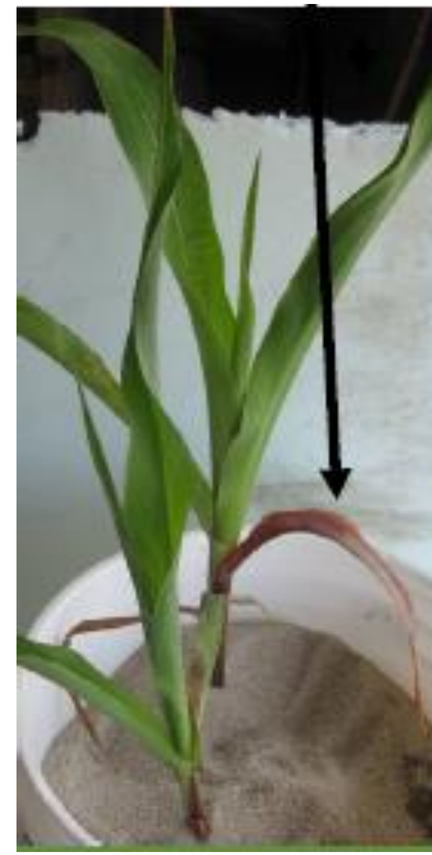
General types of Nutrient deficiency symptoms

- Chlorosis
- Mottled
- Necrosis
- Etiolation

Chlorosis

Necrosis

Discoloration



Interveinal chlorosis

Molting

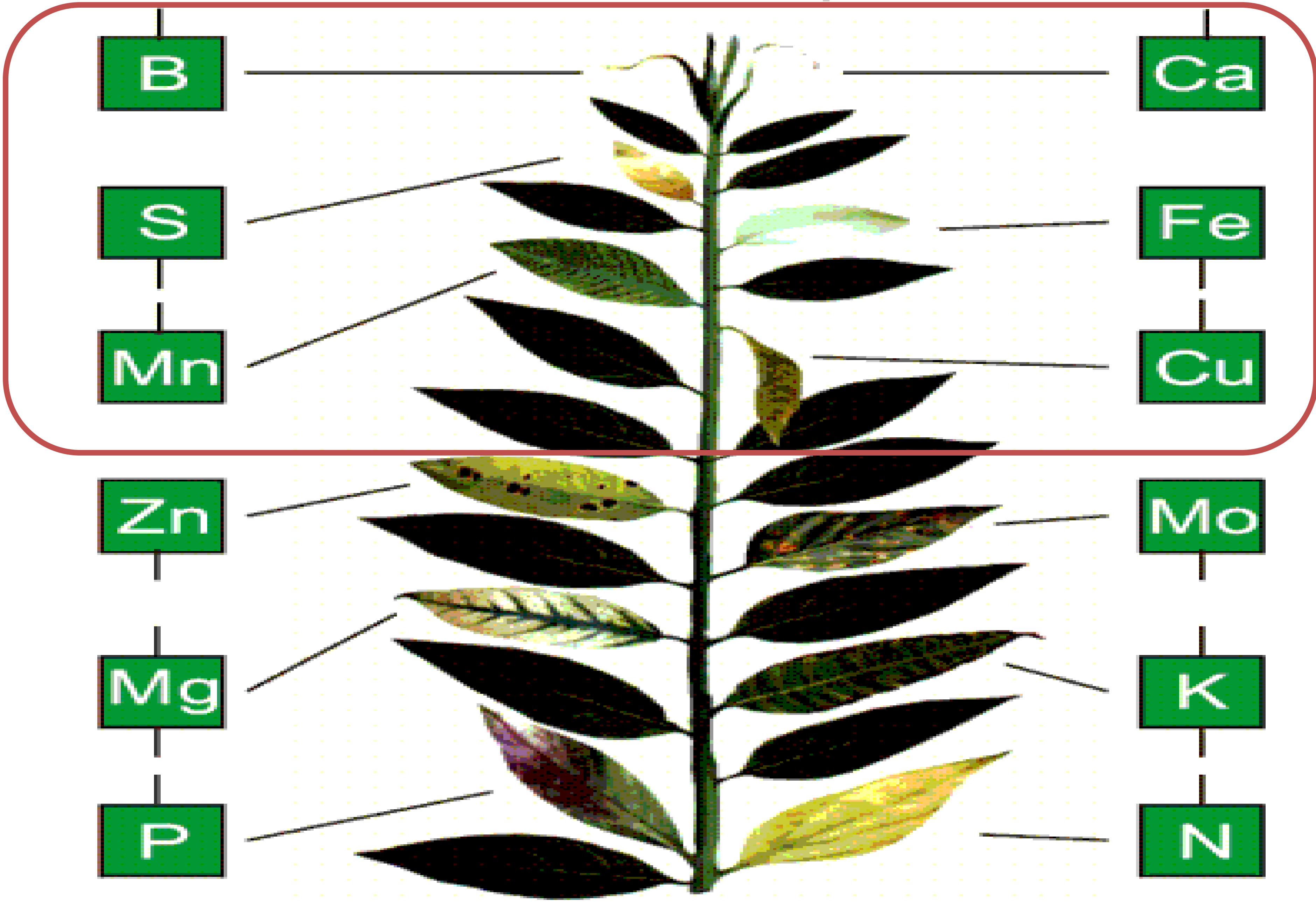
Recognizing Deficiencies

Mobile	Immobile
Nitrogen	Calcium
Potassium	Sulfur
Magnesium	Iron
Phosphorus	Boron
Chlorine	Copper
Sodium	
Zinc	
Molybdenum	

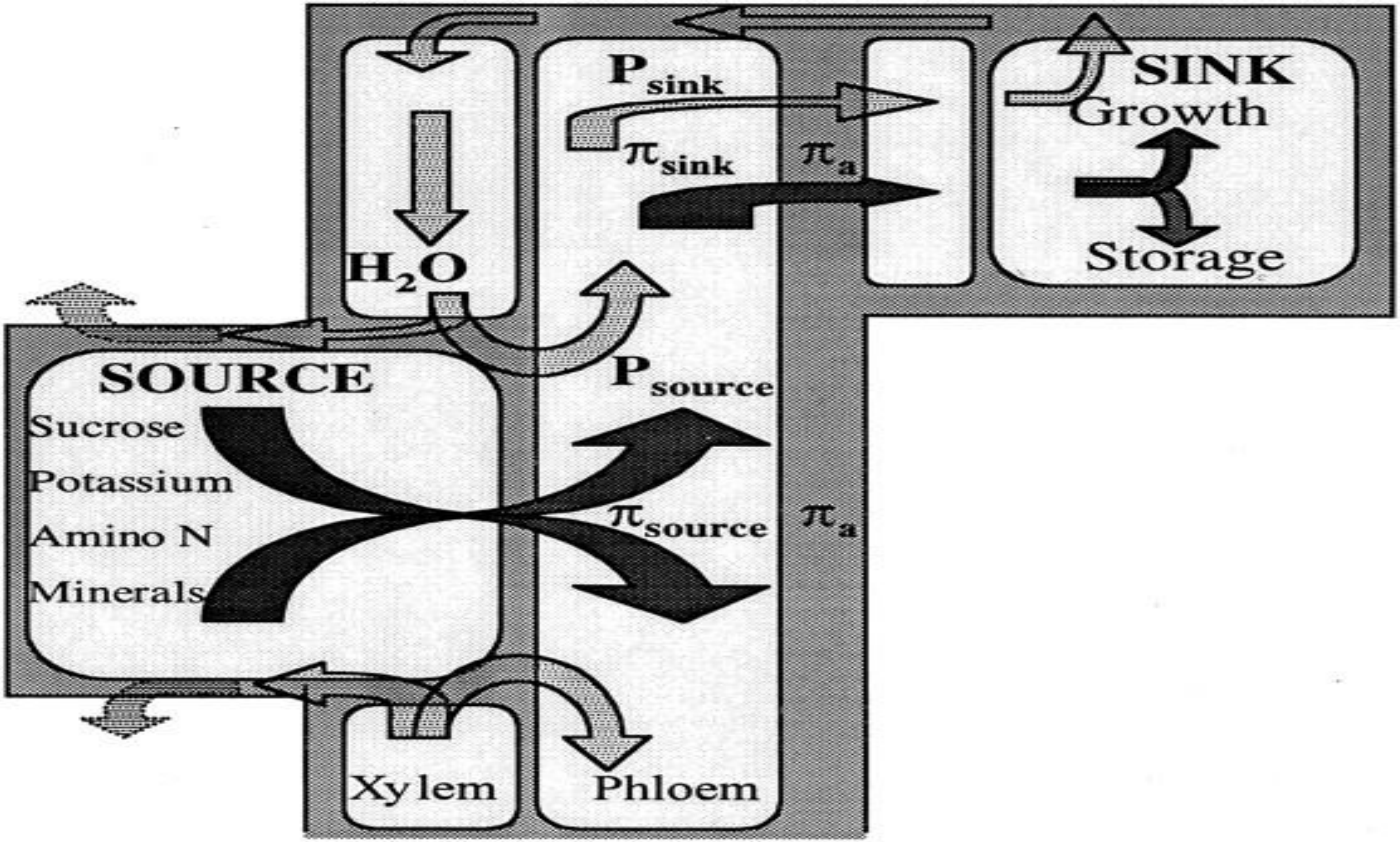
Nutrients classified based on their tendency to re-translocate during deficiencies.

- Leaf Clues;
  - if an essential nutrient is relatively mobile, symptoms generally appear first in older leaves,
  - deficiencies in relatively immobile nutrients generally appear in young leaves.

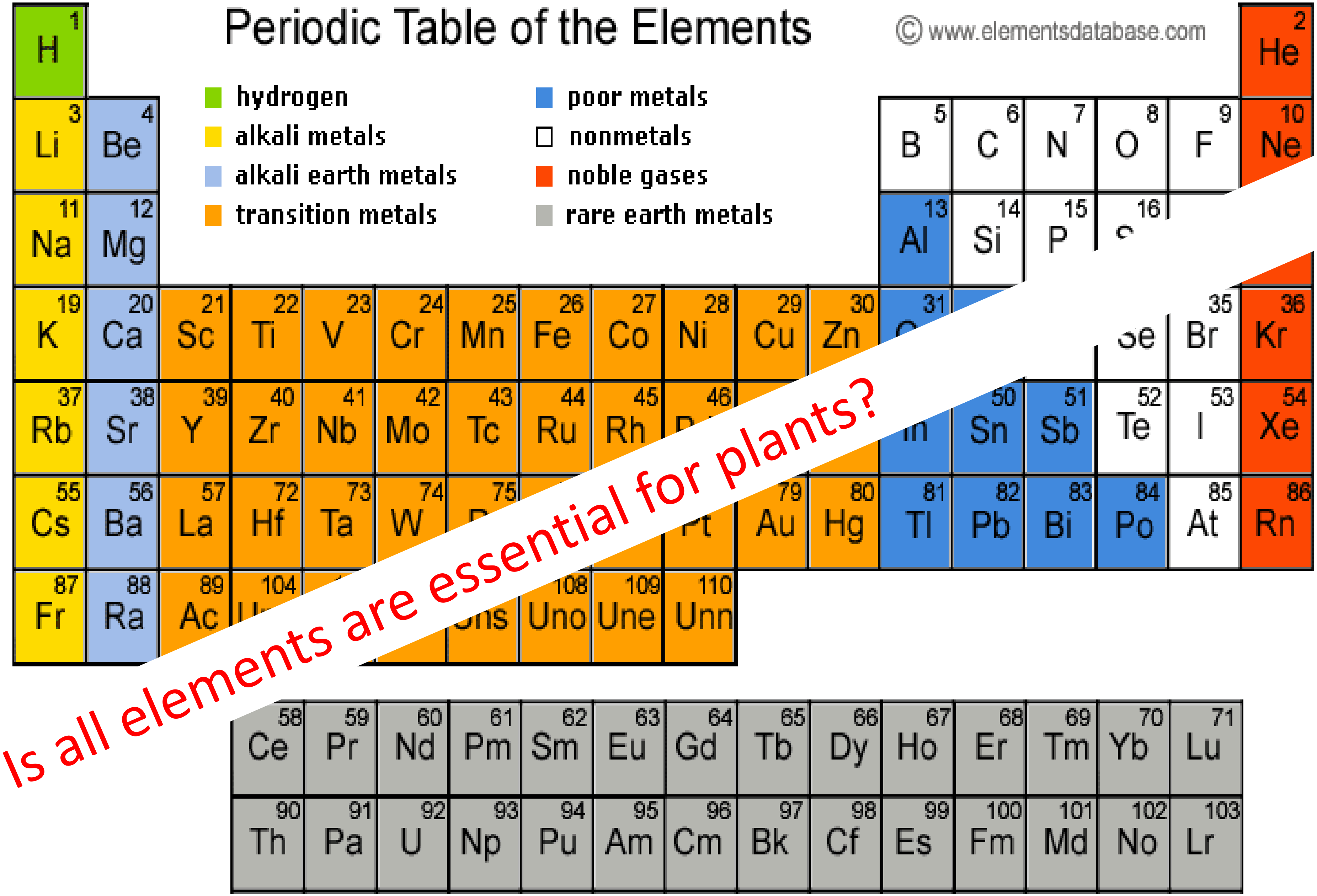
ON TERMINAL BUDS : - Ca & B
ON YOUNG LEAVES : - Cu, S, Fe & Mn
ON OLD LEAVES : - N, P, K, Mg, Zn & Mo



Inter organ redistribution of nutrients is essential



SINK
Growth
Storage
P_{sink}
π_{sink}
π_a
H_2O
SOURCE
Sucrose
Potassium
Amino N
Minerals
P_{source}
π_{source}
π_a
Xylem
Phloem



Is all elements are essential for plants?

Plant Ash – 40 Elements

Essential Elements

Non Essential Elements

CRITERIA FOR ESSENTIALITY

(ARNON and STOUT)

- ❖ **Plant unable to complete its life cycle in the absence of that element**

- ❖ **The function of element must not replaceable by another element**

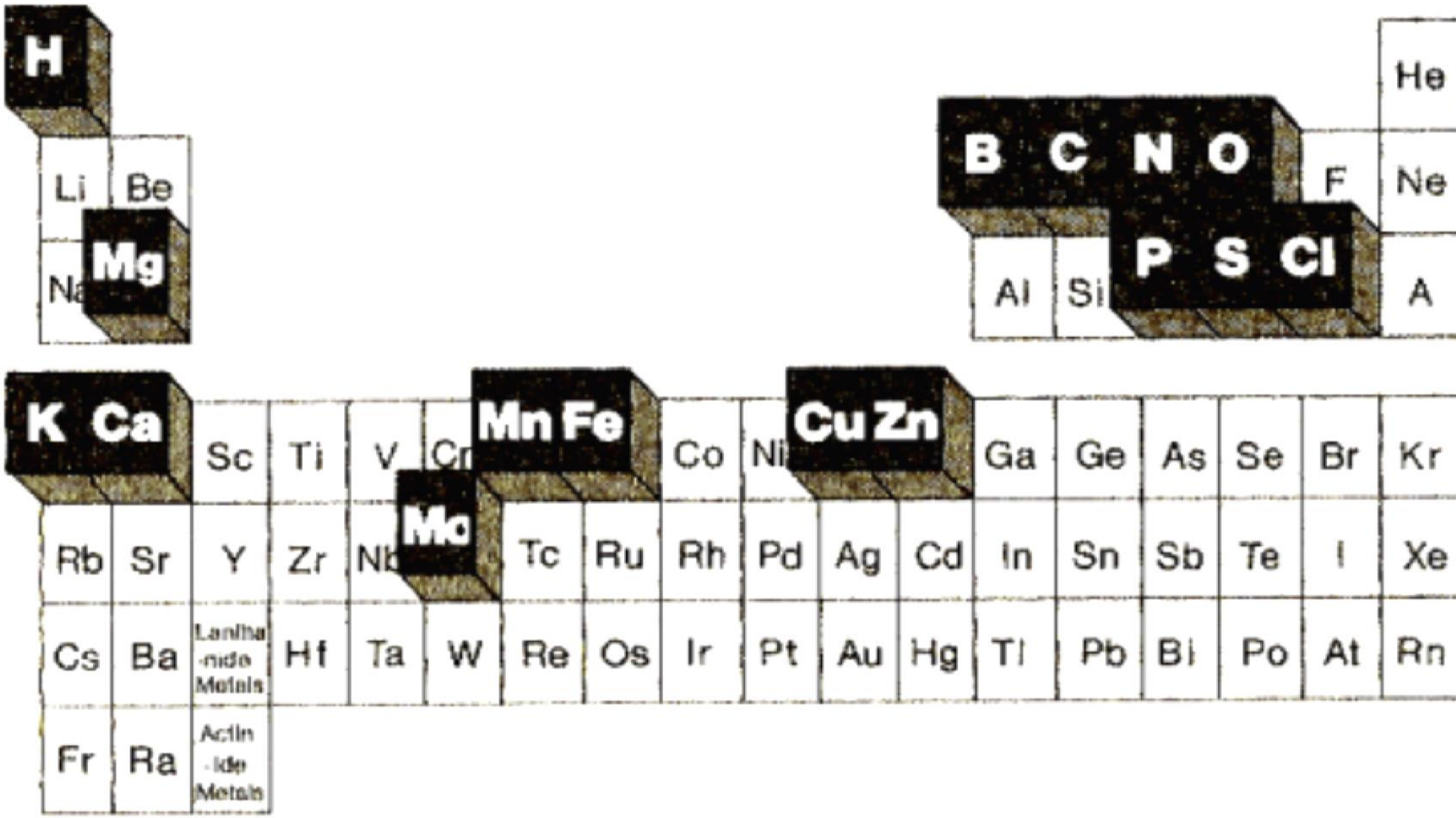
- ❖**The element must be directly involved in plant metabolism.**

TABLE 5.1
Adequate tissue levels of elements that may be required by plants

Element	Chemical symbol	Concentration in dry matter (% or ppm)[a]	Relative number of atoms with respect to molybdenum
Obtained from water or carbon dioxide			
Hydrogen	H	6	60,000,000
Carbon	C	45	40,000,000
Oxygen	O	45	30,000,000
Obtained from the soil			
Macronutrients			
Nitrogen	N	1.5	1,000,000
Potassium	K	1.0	250,000
Calcium	Ca	0.5	125,000
Magnesium	Mg	0.2	80,000
Phosphorus	P	0.2	60,000
Sulfur	S	0.1	30,000
Silicon	Si	0.1	30,000
Micronutrients			
Chlorine	Cl	100	3,000
Iron	Fe	100	2,000
Boron	B	20	2,000
Manganese	Mn	50	1,000
Sodium	Na	10	400
Zinc	Zn	20	300
Copper	Cu	6	100
Nickel	Ni	0.1	2
Molybdenum	Mo	0.1	1

Source: Epstein 1972, 1999.

Sixteen Essential Elements



Element	Date of Essentiality[a]
Nitrogen	1804
	1851–1855
Phosphorus	1839
	1861
Potassium	1866
Calcium	1862
Magnesium	1875
Sulfur	1866
Iron	1843
Manganese	1922
Copper	1925
Boron	1926
Zinc	1926
Molybdenum	1939
Chlorine	1954
Nickel	1987

ESSENTIAL ELEMENTS (17)

MACRO NUTRIENTS
or
MAJOR ELEMENTS

C, H, O, N, P, K, Ca, Mg S

9 ELEMENTS

MICRO NUTRIENTS
or
MINOR ELEMENTS
or
TRACE ELEMENTS

Fe, Zn, B, Cu, Mn, Mo, Cl, Ni

8 ELEMENTS

MACRO NUTRIENTS

- FRAME WORK ELEMENTS → **C, H, O.**
- PRIMARY NUTRIENTS → **N, P, K.**
- SECONDARY NUTRIENTS → **Ca, Mg, S**

Element	Available form	Typical concentration (mmol kg^{-1} dry weight of plant)
Macronutrients		
Hydrogen	H_2O	60 000
Carbon	CO_2	40 000
Oxygen	O_2, CO_2, H_2O	30 000
Nitrogen	NO_3^- (nitrate)	1000
	NH_4^+ (ammonium)	
Potassium	K^+	250
Calcium	Ca^{2+}	125
Magnesium	Mg^{2+}	80
Phosphorus	HPO_4^- (phosphate)	60
	HPO_4^{2-}	
Sulfur	SO_4^{2-} (sulfate)	30
Micronutrients		
Chlorine	Cl^- (chloride)	3
Iron	Fe^{2+} (ferric)	2
	Fe^{3+} (ferrous)	
Boron	BO_3^{3-}	2
Manganese	Mn^{2+}	1
Zinc	Zn^{2+}	0.3
Copper	Cu^{2+}	0.1
Nickel	Ni^{2+}	0.05
Molybdenum	MoO_4^{2-} (molybdate)	0.001

"C. Hopkins Cafe closing; mob coming with machine guns"

- C H O P K N S Ca Fe Cl Zn; Mo B Cu Mn Mg

Classification of Plant nutrients on the basis of physiological functions

Group 1 Nutrients that are part of carbon compounds

Mineral nutrient	Functions
N,	Constituent of amino acids, amides, proteins, nucleic acids, nucleotides, coenzymes, hexoamines, etc.
S	Component of cysteine, cystine, methionine, and proteins.Constituent of lipoic acid, coenzyme A,thiamine pyrophosphate, glutathione, biotin, adenosine-5′-phosphosulfate, and 3- phosphoadenosine.

Cont..

Group 2 Nutrients that are important in energy storage or structural integrity

P Component of sugar phosphates, nucleic acids, nucleotides, coenzymes, phospholipids, phytic acid, etc.
Has a key role in reactions that involve ATP.

Si Deposited as amorphous silica in cell walls. Contributes to cell wall mechanical properties, including rigidity and elasticity.

B Complexes with mannitol, mannan, polymannuronic acid, and other constituents of cell walls. Involved in cell elongation and nucleic acid metabolism.

Group 3 Nutrients that remain in ionic form

K	Required as a cofactor for more than 40 enzymes. Principal cation in establishing cell turgor and maintaining cell electroneutrality
Ca	Constituent of the middle lamella of cell walls. Required as a cofactor by some enzymes involved in the hydrolysis of ATP and phospholipids. Acts as a second messenger in metabolic regulation.
Mg	Required by many enzymes involved in phosphate transfer. Constituent of the chlorophyll molecule
Cl	Required for the photosynthetic reactions involved in O2 evolution.
Mn	Required for activity of some dehydrogenases, decarboxylases, kinases, oxidases, and peroxidases. Involved with other cation-activated enzymes and photosynthetic O2 evolution
Na	Involved with the regeneration of phosphoenolpyruvate in C4 and CAM plants. Substitutes for potassium in some functions

Group 4 Nutrients that are involved in red-ox reactions

Fe	Constituent of cytochromes and nonheme iron proteins involved in photosynthesis, N_2 fixation, and respiration
Zn	Constituent of alcohol dehydrogenase, glutamic dehydrogenase, carbonic anhydrase, etc.
Cu	Component of ascorbic acid oxidase, tyrosinase,monoamine oxidase, uricase, cytochrome oxidase, phenolase, laccase, and plastocyanin.
Ni	Constituent of urease. In N_2-fixing bacteria, constituent of hydrogenases.
Mo	Constituent of nitrogenase, nitrate reductase, and xanthine dehydrogenase.

Specific roles of essential mineral elements

Nitrogen

Nitrogen is important constituent of proteins, nucleic acids, porphyrins (chlorophylls & cytochromes) alkaloids, some vitamins, coenzymes etc

N plays very important role in metabolism, growth, reproduction and heredity

Phosphorus

It is important constituent of nucleic acids, phospholipids, coenzymes NADP, $NADPH_2$ and ATP

Phospholipids along with proteins may be important constituents of cell membranes.

P- plays important role in protein synthesis through nucleic acids and ATP through coenzymes NAD, NADP and ATP, it plays important role in energy transfer reactions of cell metabolism eg. Photosynthesis, respiration and fat metabolism etc

Potassium

It is essential for the process of respiration and photosynthesis

It acts as an activator of many enzymes involved in carbohydrate metabolism and protein synthesis

It regulates stomatal movement

Regulates water balance

Calcium

It is important constituent of cell wall

It is essential in the formation of cell membranes

It helps to stabilize the structure of chromosome

It may be an activation of may enzymes

Magnesium

- It is very important constituent of chlorophylls
- It acts as activation of many enzymes in nucleic acid synthesis and carbohydrate metabolism
- It plays important role in binding ribosomal particles during protein synthesis

Sulphur

✓It is important constituent of some amino acids (cystine, cysteine and methionine) with which other amino acids form the protein

✓S helps to stabilize the protein structure

✓It is also important constituent of vitamin i.e biotin, thiamine and coenzyme A

✓Sulpho-hydryl groups are necessary for the activity of many enzymes

Iron

➢Important constituent of iron porphyrin – proteins like cytochromes, peroxidase, catalases, etc.

➢It is essential for chlorophyll synthesis

➢It is very important constituent of ferredoxin which plays important role in photochemical reaction in photosynthesis and in biological nitrogen fixation

Zinc

- It is involved in the biosynthesis of growth hormone auxin (Indole 3 acetic acid)
- It acts activator of many enzymes like carbonic anhydrase and alcohol dehydrogenase, etc.

Manganese

- It is an activator of many respiratory enzymes
- It is also an activator of the enzyme nitrite reductase
- It is necessary for the evolution of oxygen (photolysis) during photosynthesis

Copper

- It is an important constituent of plastocyanin (copper containing protein)
- It is also a constituent of several oxidizing enzymes.

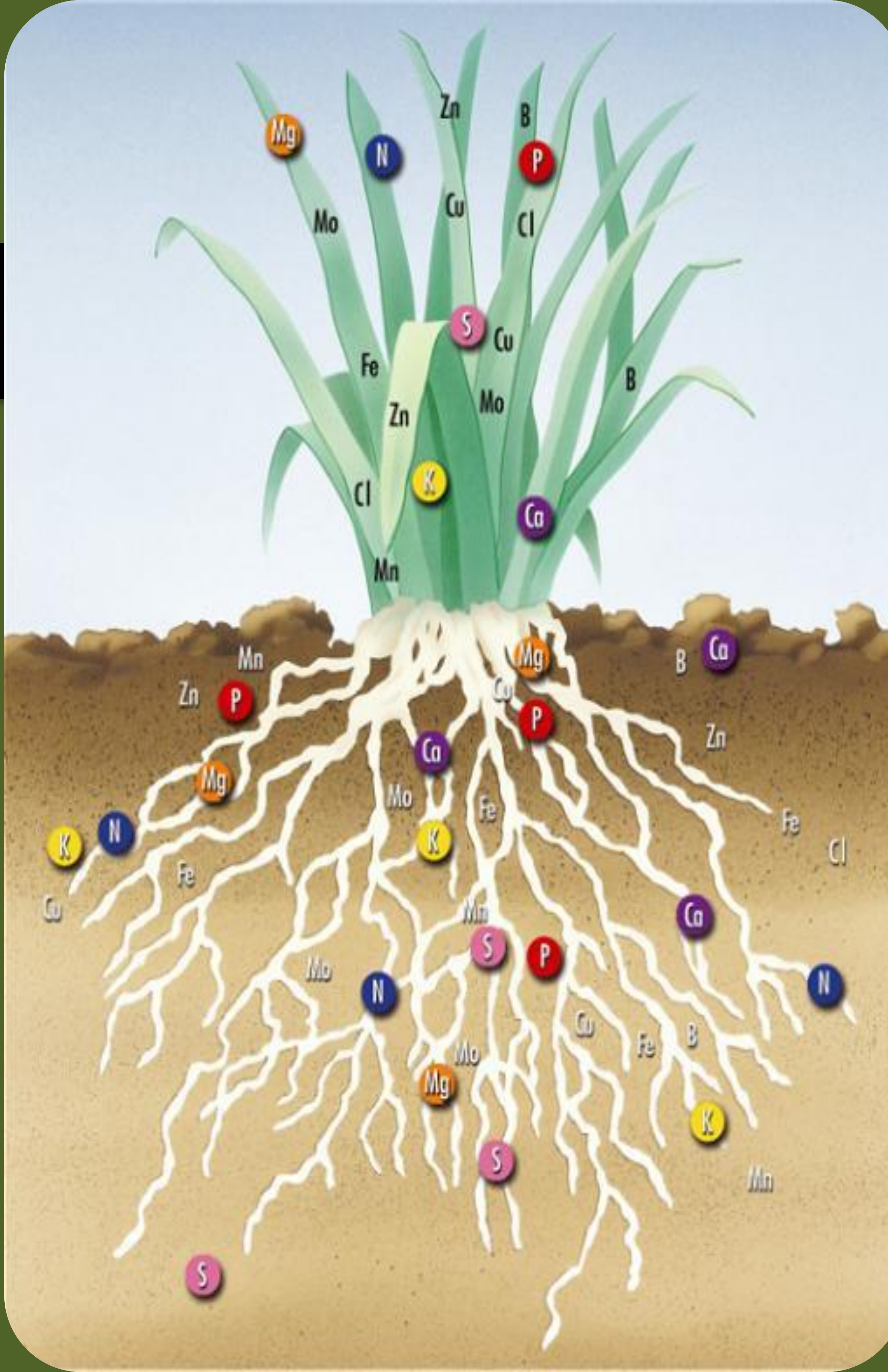
Boron

- Boron facilitates the translocation of sugars by forming sugar borate complex.
- It involves in cell differentiation and development since boron is essential for DNA synthesis
- Also involves in fertilization, hormone metabolism etc.

Molybdenum

- It is constituent of the enzyme nitrate reductase and thus plays an important role in nitrogen metabolism
- It is essential for flower formation and fruit set.

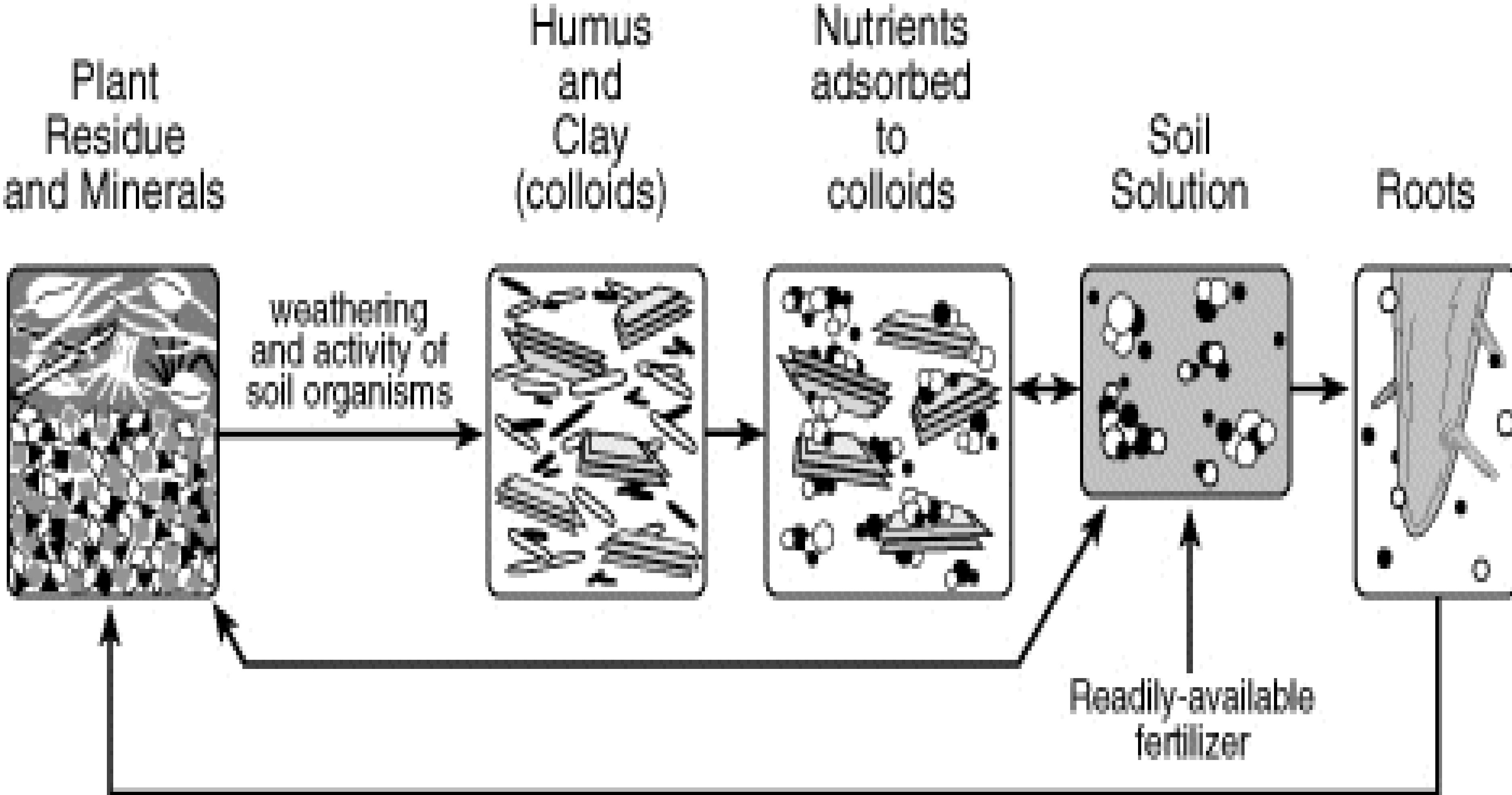
Mineral Uptake



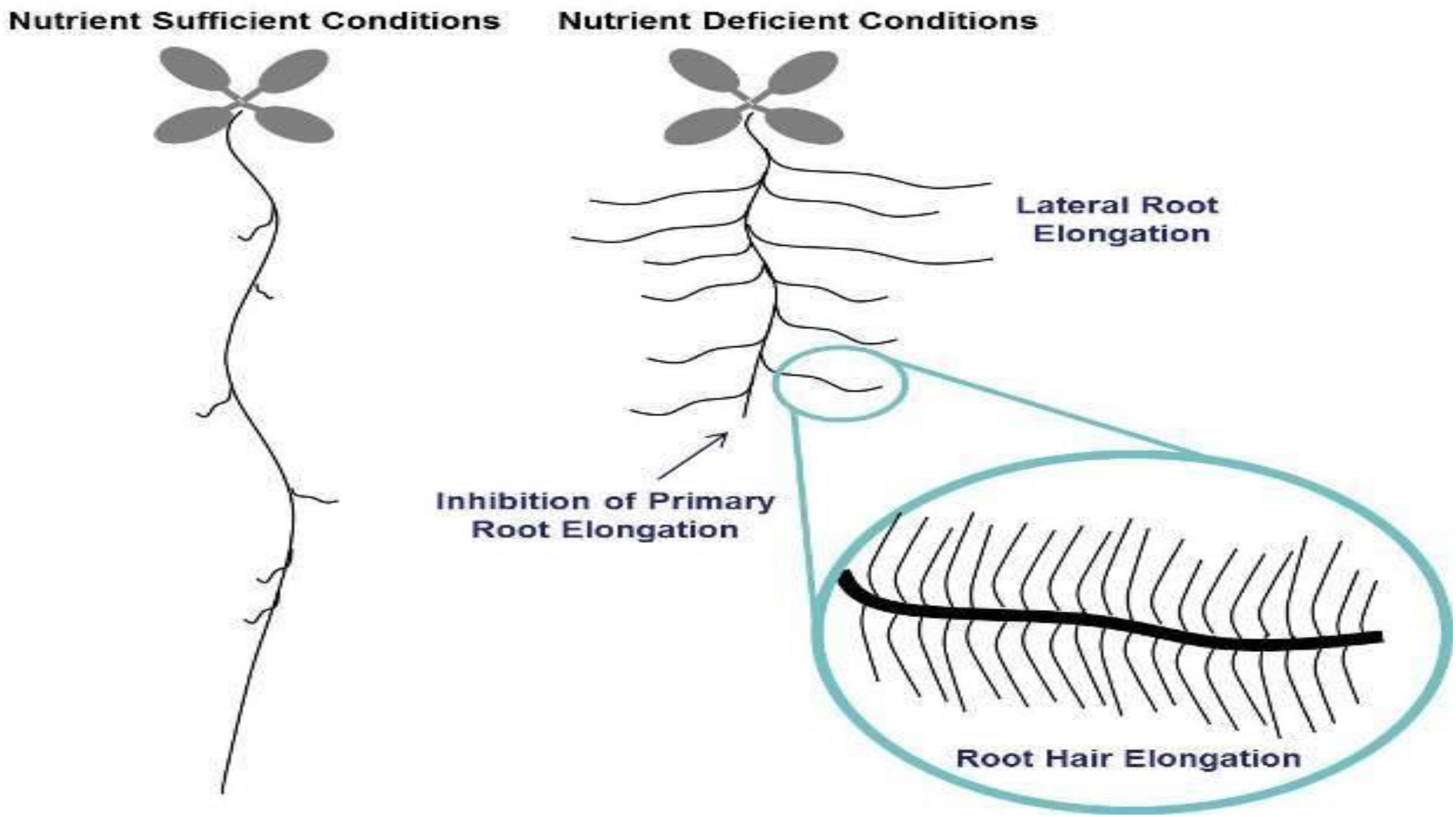
"Plant must regulate nutrient uptake and must respond to changes in the soil as well as within the plant for survival"

Ways in which a Plant gets its Mineral Nutrients Ways in which a Plant gets its Mineral Nutrients

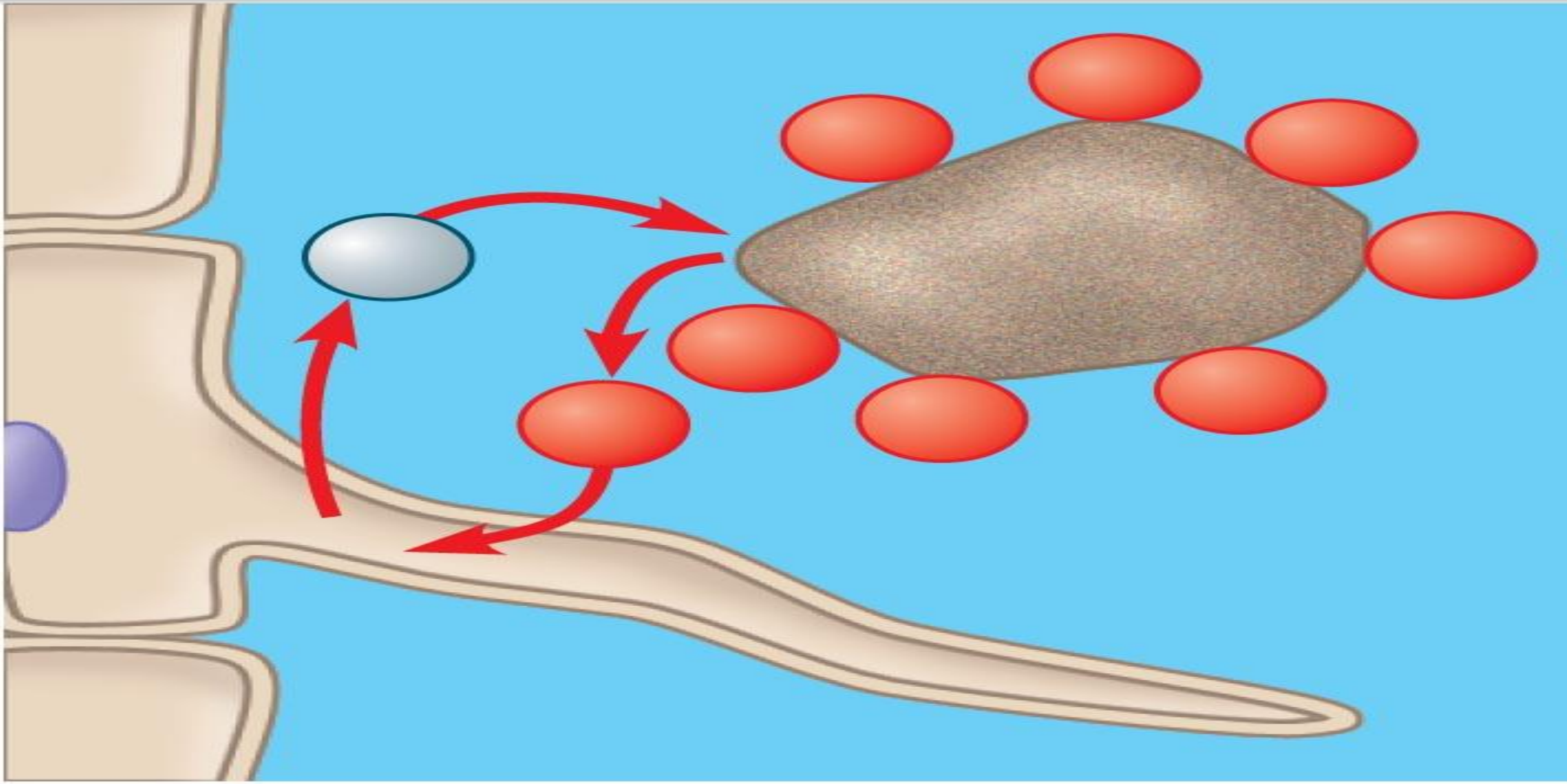
Nutrient sources



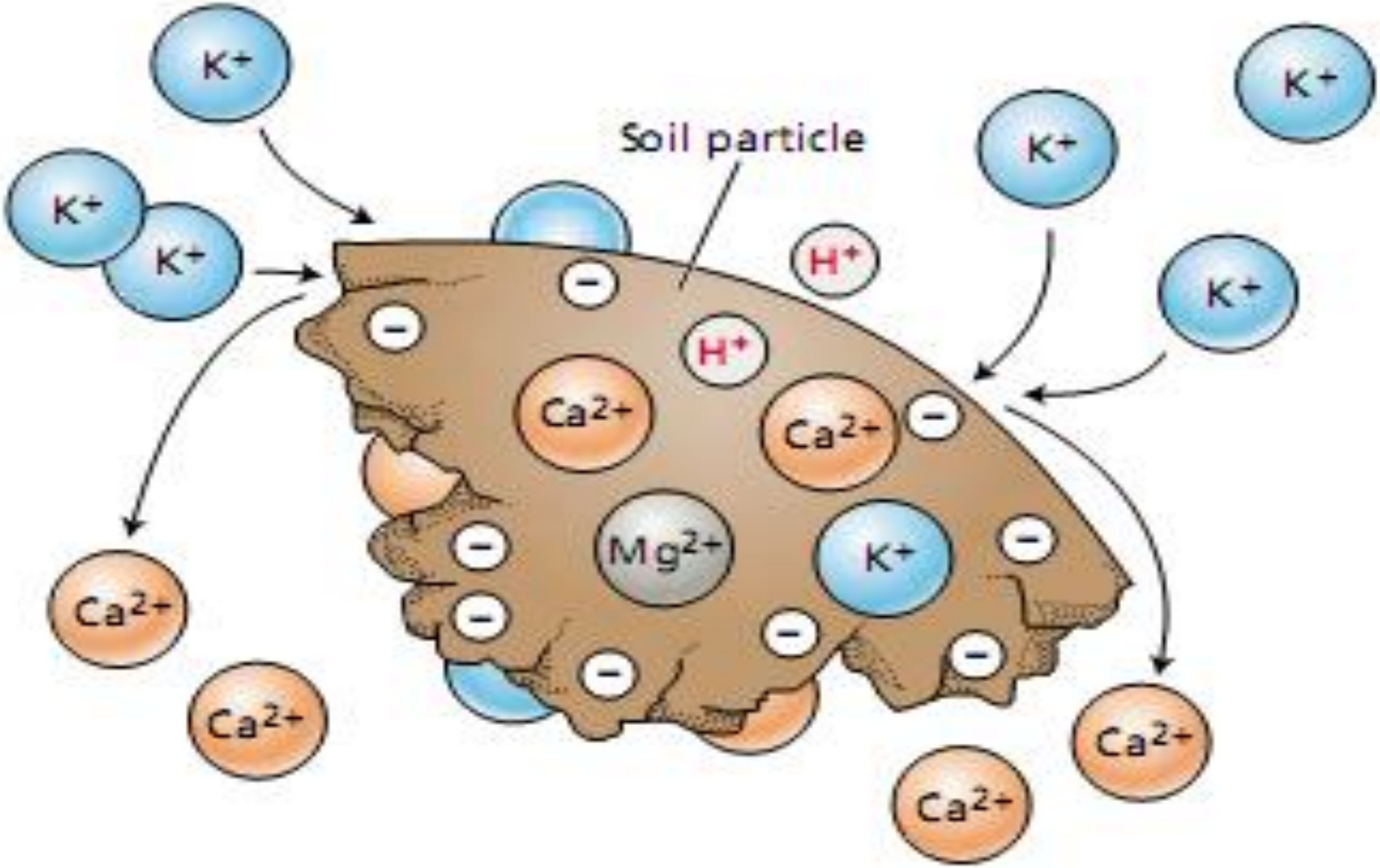
Plant root architectures changes in response to nutrient deficiency

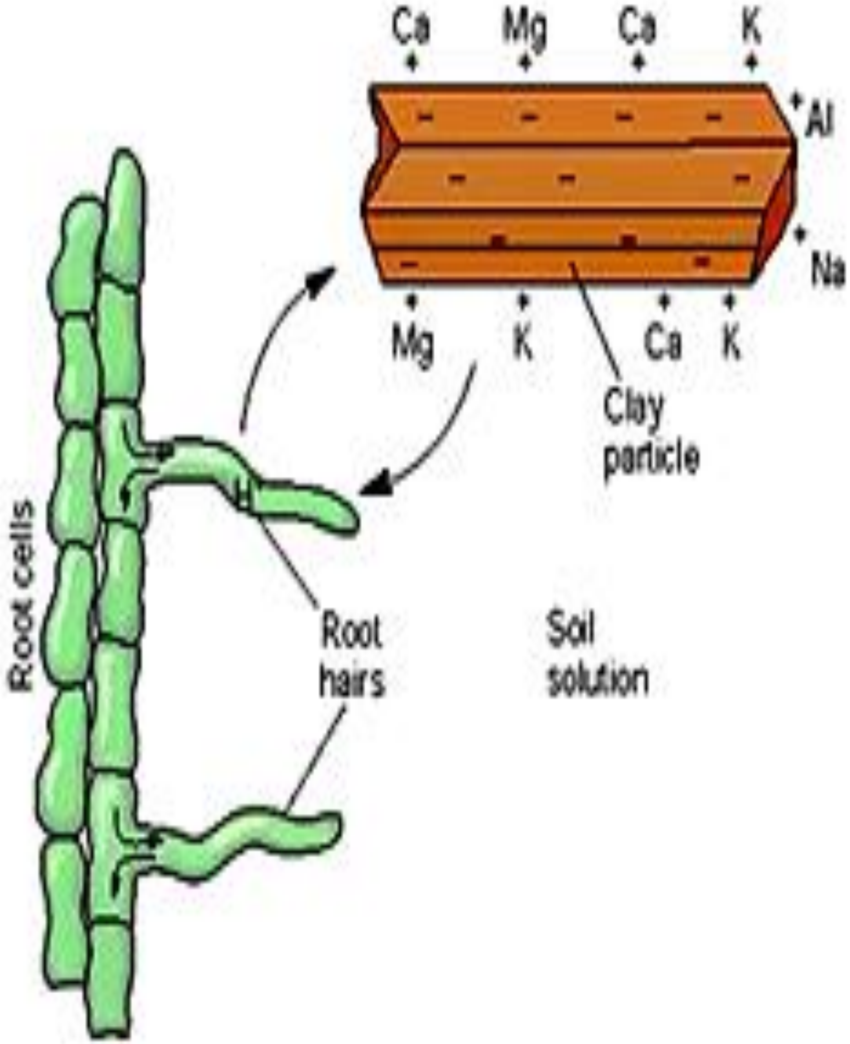


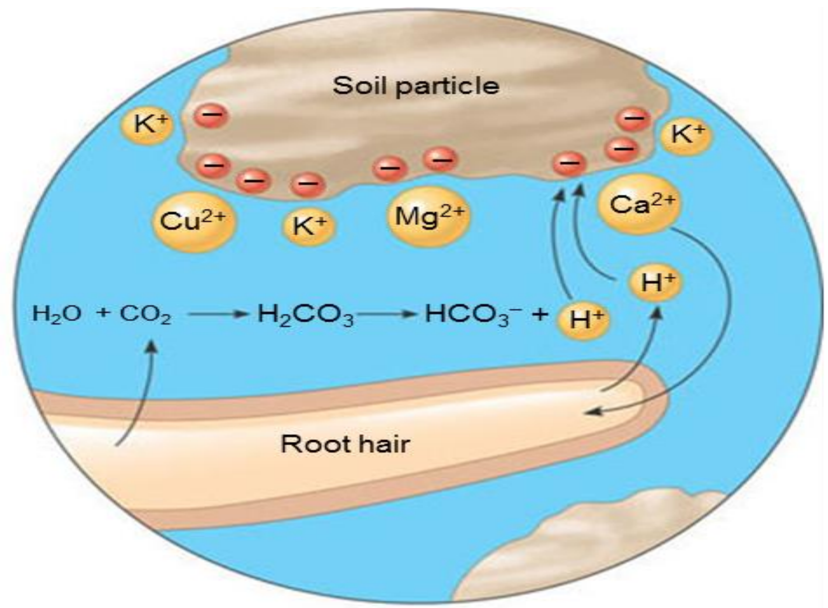
Nutrient availability



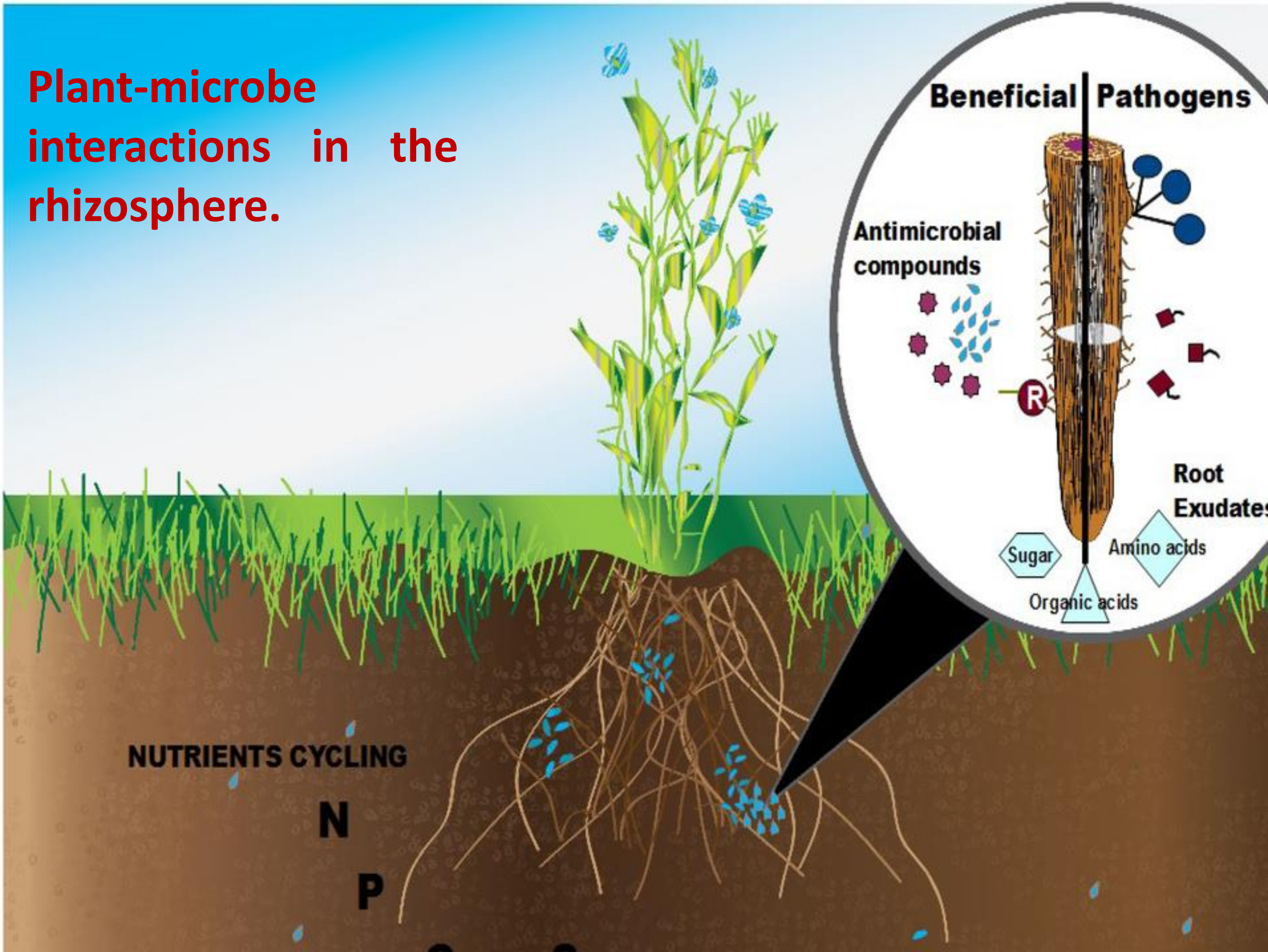
Cation Exchange Capacity

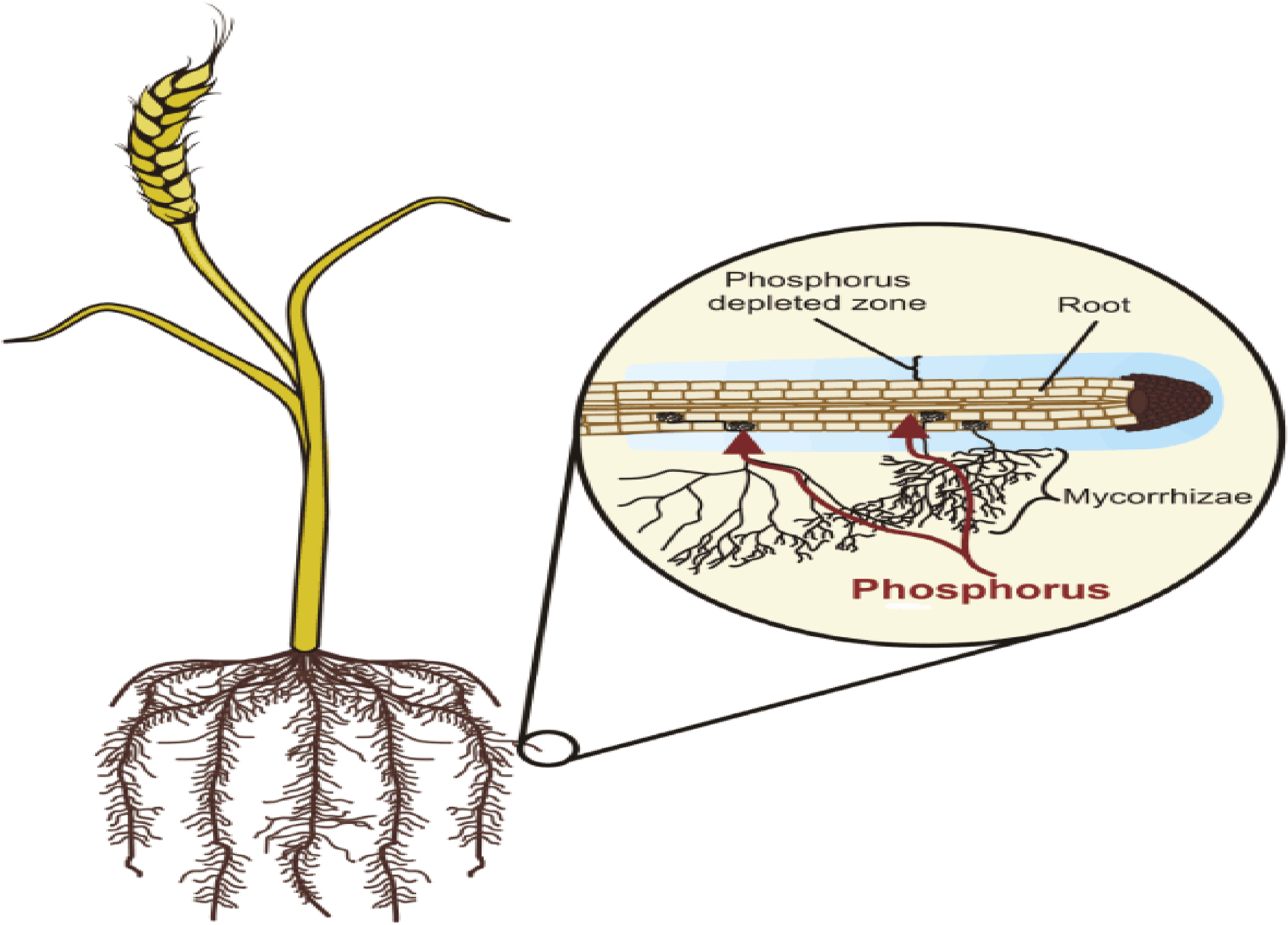



Ca
Mg
Ca
K
Al
Na
Mg
K
Ca
K
Clay particle
Root cells
Root hairs
Soil solution

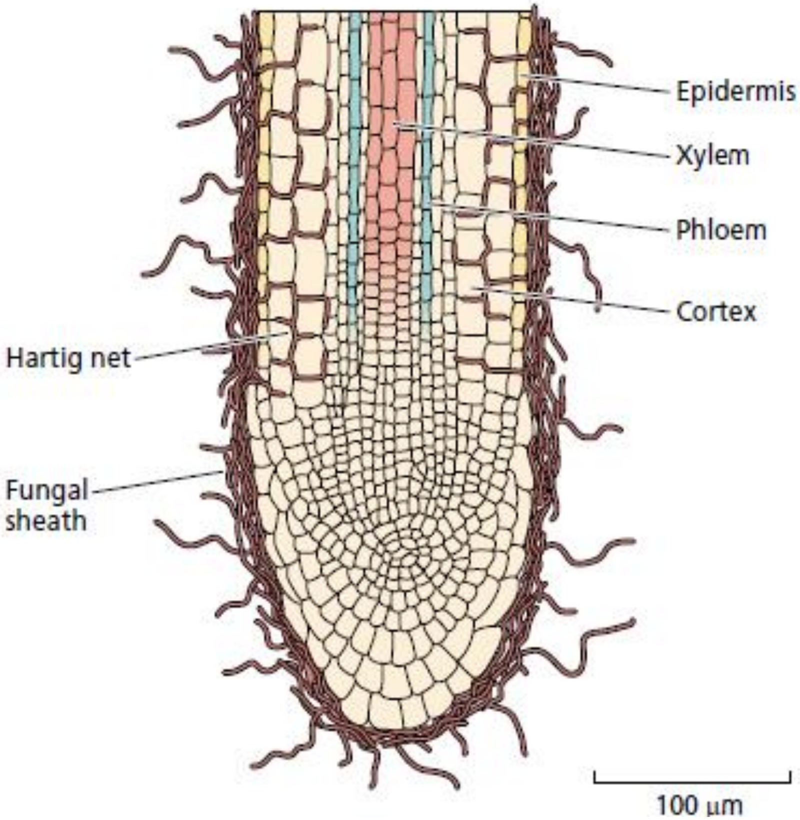

Soil particle
K^+
K^+
Cu^{2+}
K^+
Mg^{2+}
Ca^{2+}
H^+
$H_2O + CO_2 \rightarrow H_2CO_3 \rightarrow HCO_3^- + H^+$
Root hair

Plant-microbe interactions in the rhizosphere.

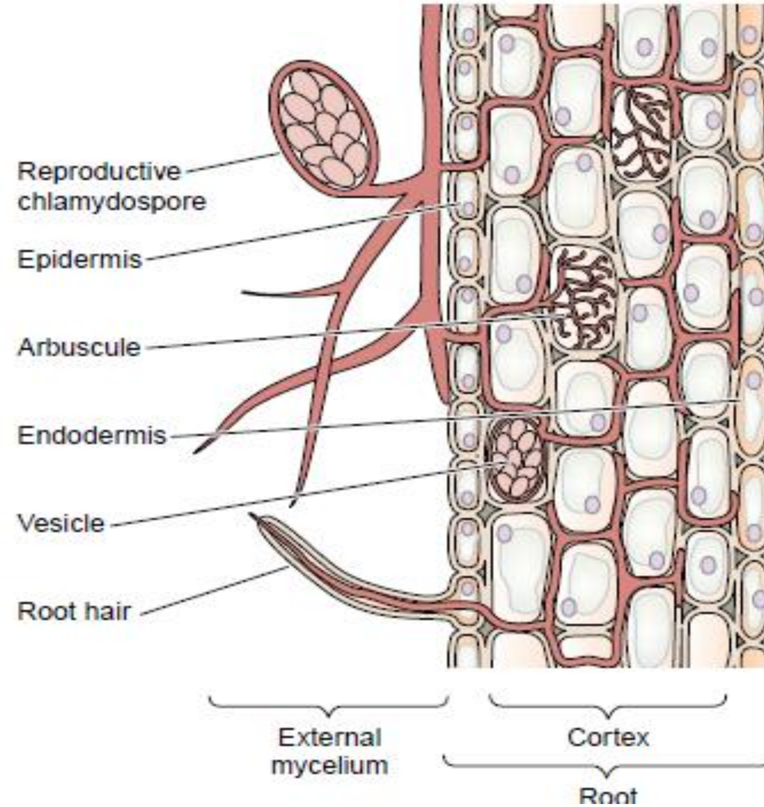




Phosphorus depleted zone
Root
Mycorrhizae
Phosphorus

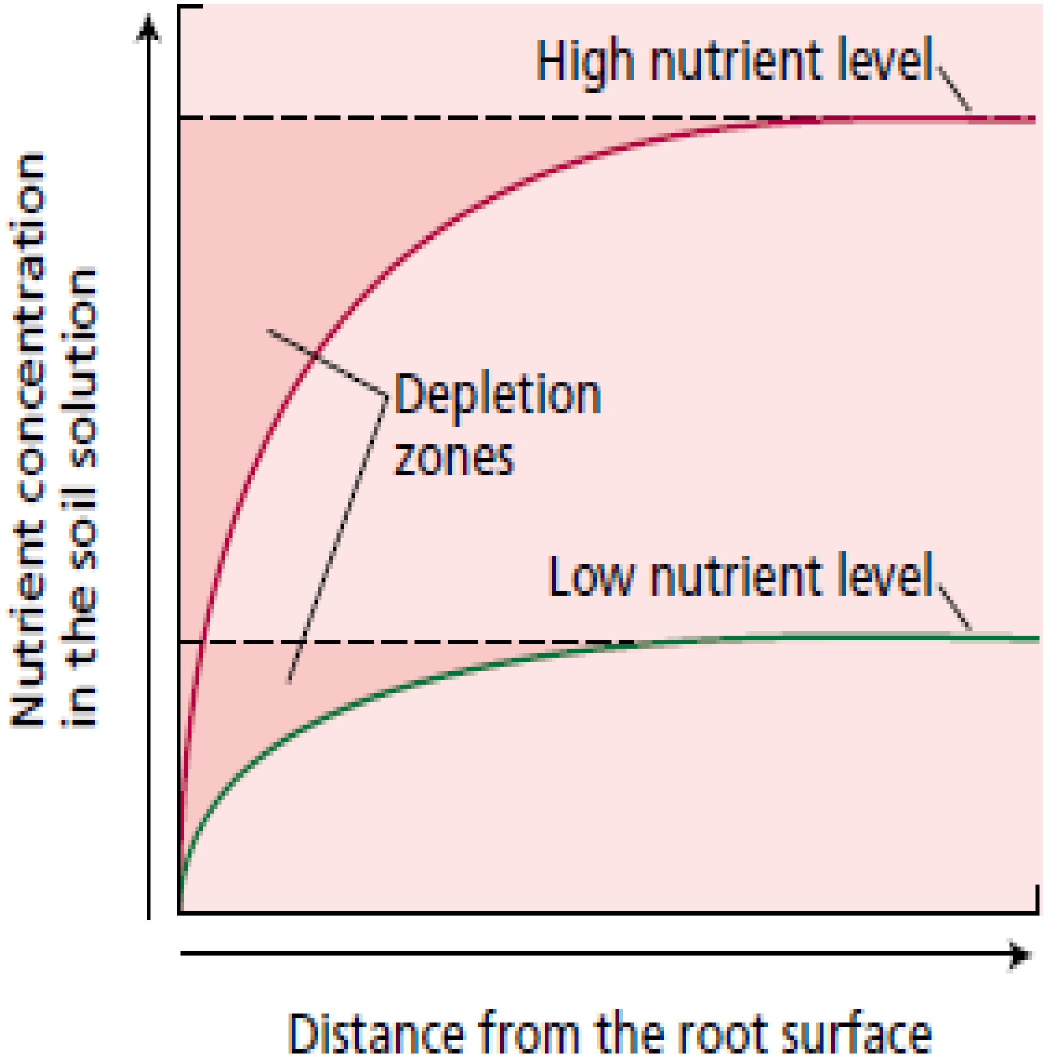


Root infected with ectotrophic mycorrhizal fungi.

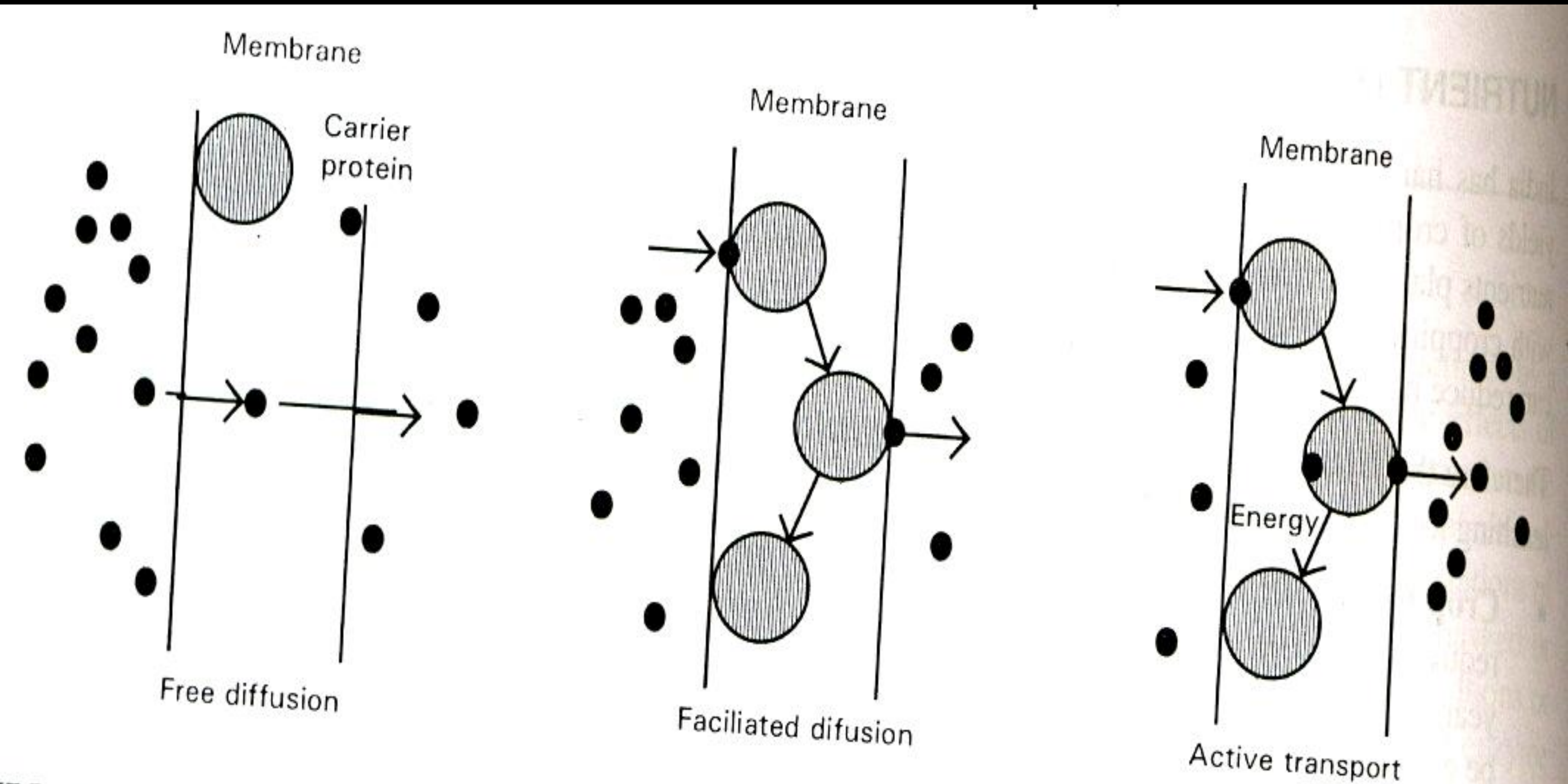


Association of vesicular-arbuscular mycorrhizal fungi with a section of a plant root.

Within the soil, nutrients can move to the root surface both by bulk flow and by diffusion



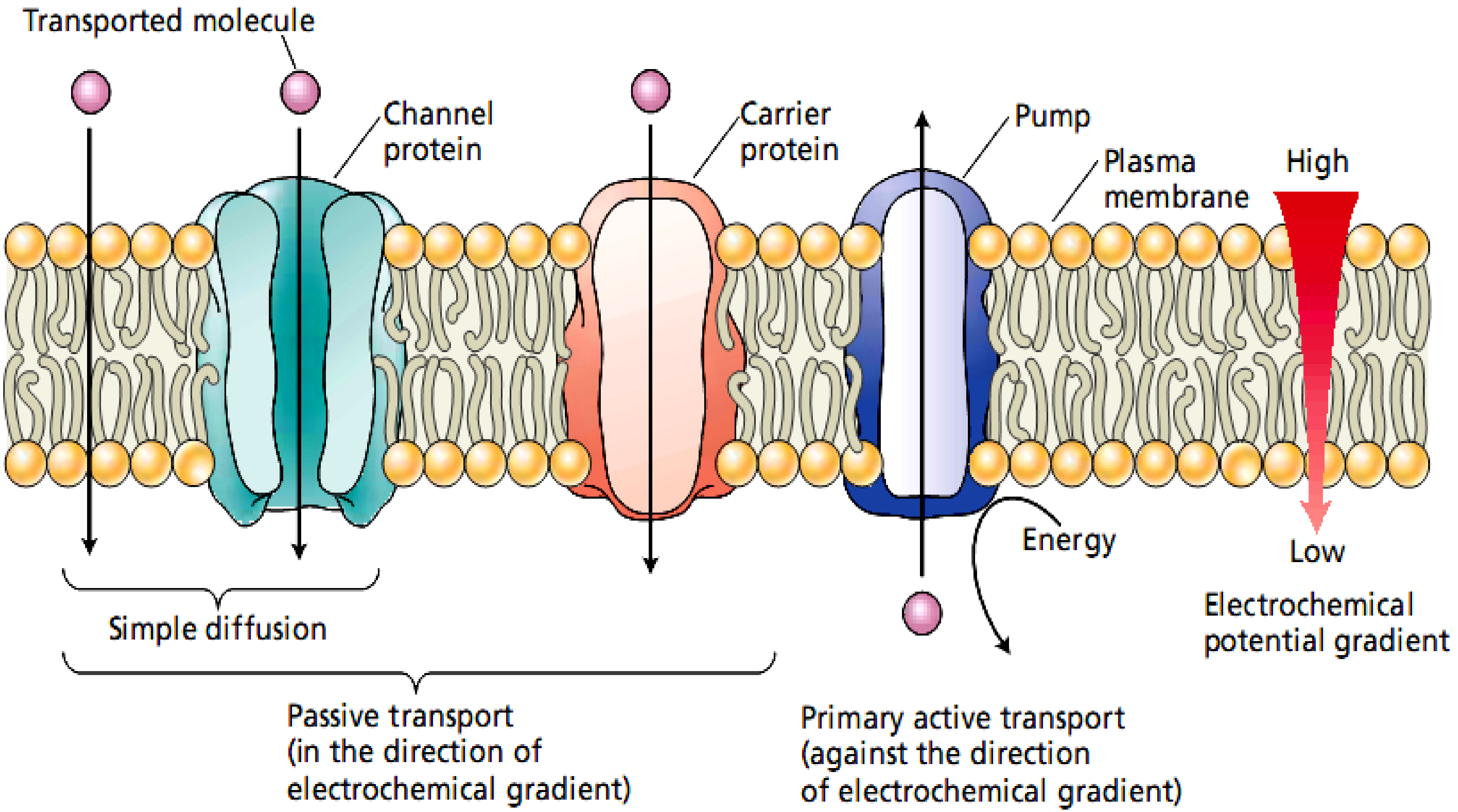
ION UPTAKE IS BOTH ACTIVE AND PASSIVE

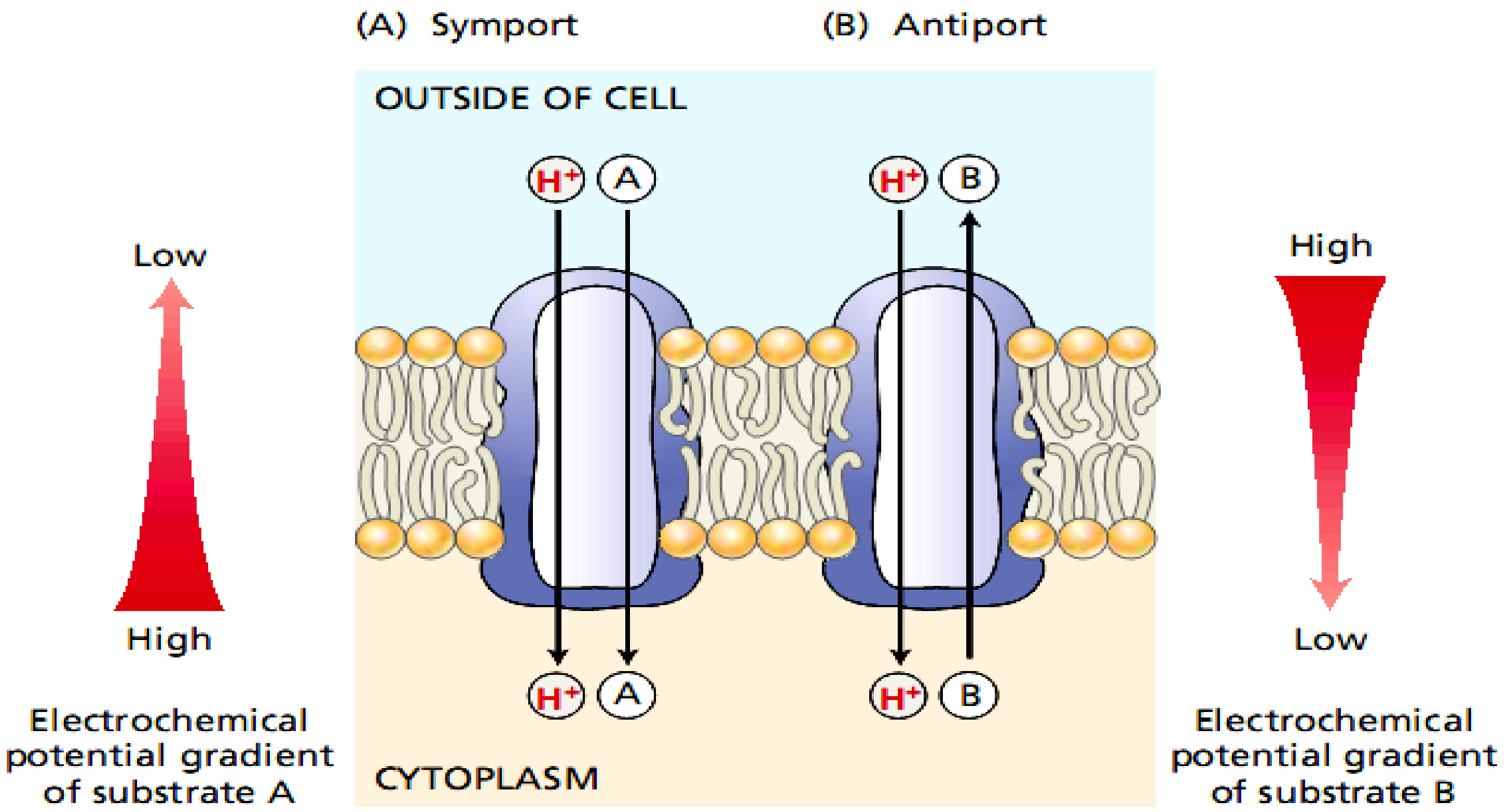


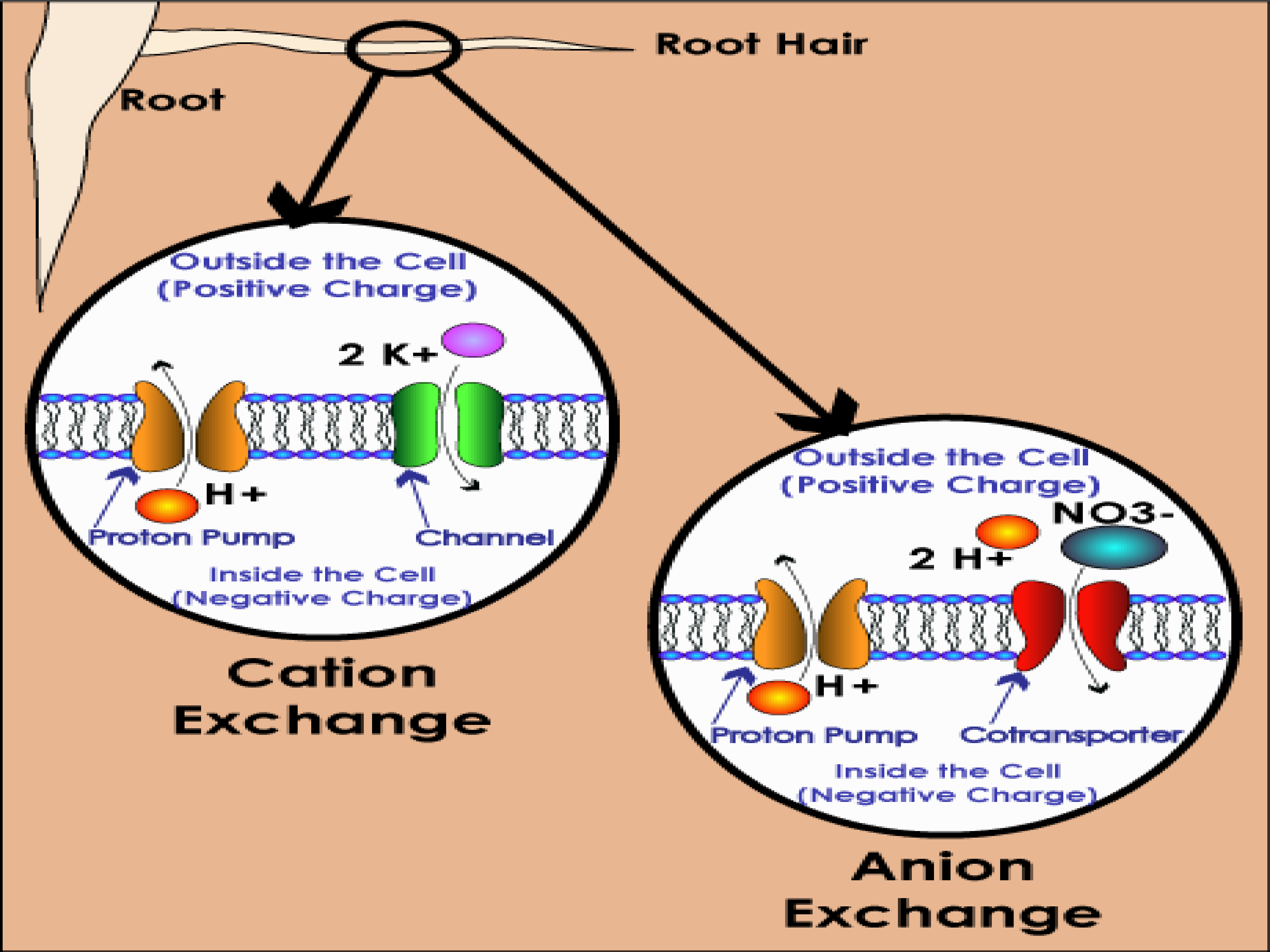
Diffusion

Faciliated Diffusion

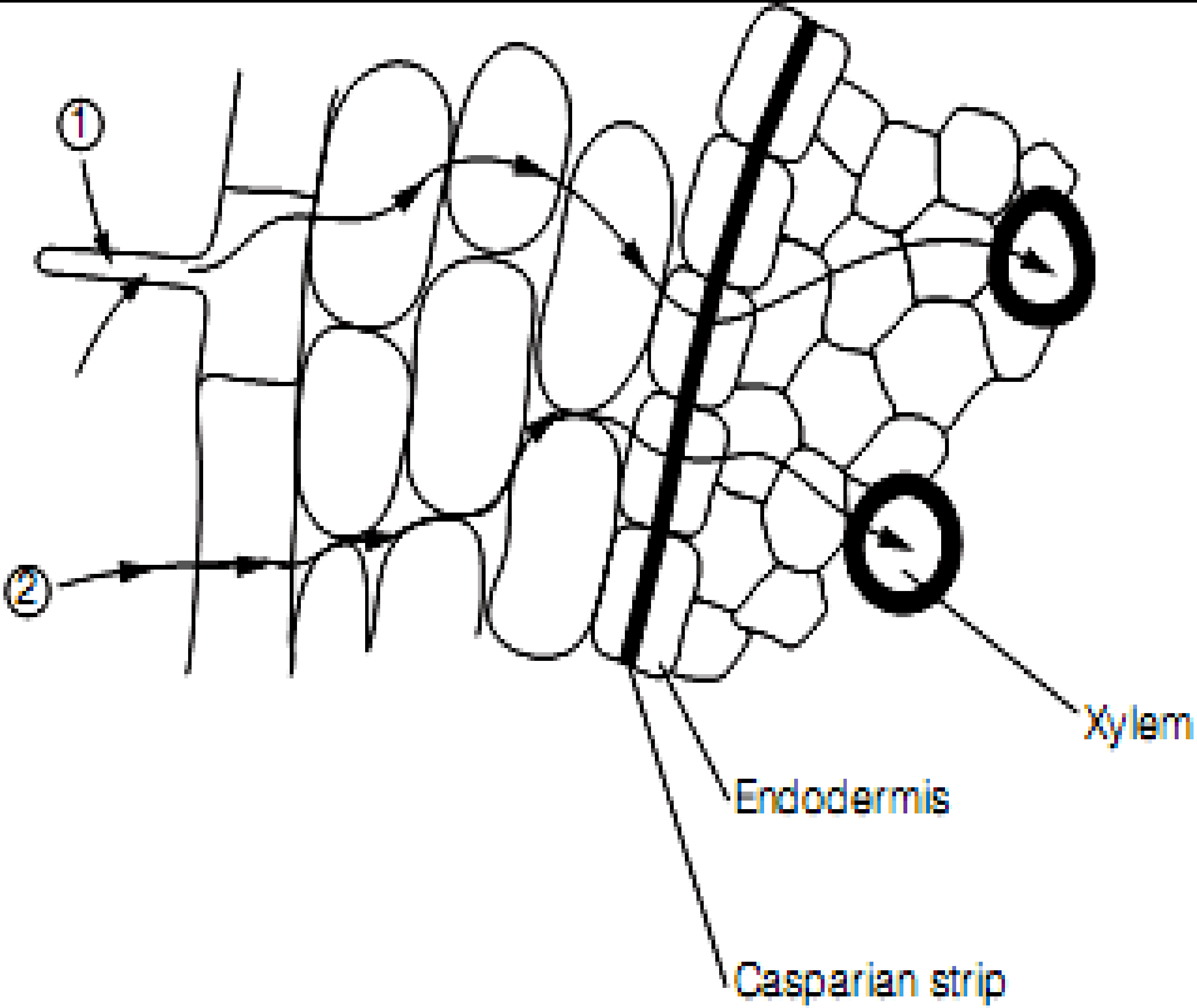
Active Transport


Transported molecule
Channel protein
Carrier protein
Pump
Plasma membrane
High
Low
Energy
Electrochemical potential gradient
Simple diffusion
Passive transport (in the direction of electrochemical gradient)
Primary active transport (against the direction of electrochemical gradient)

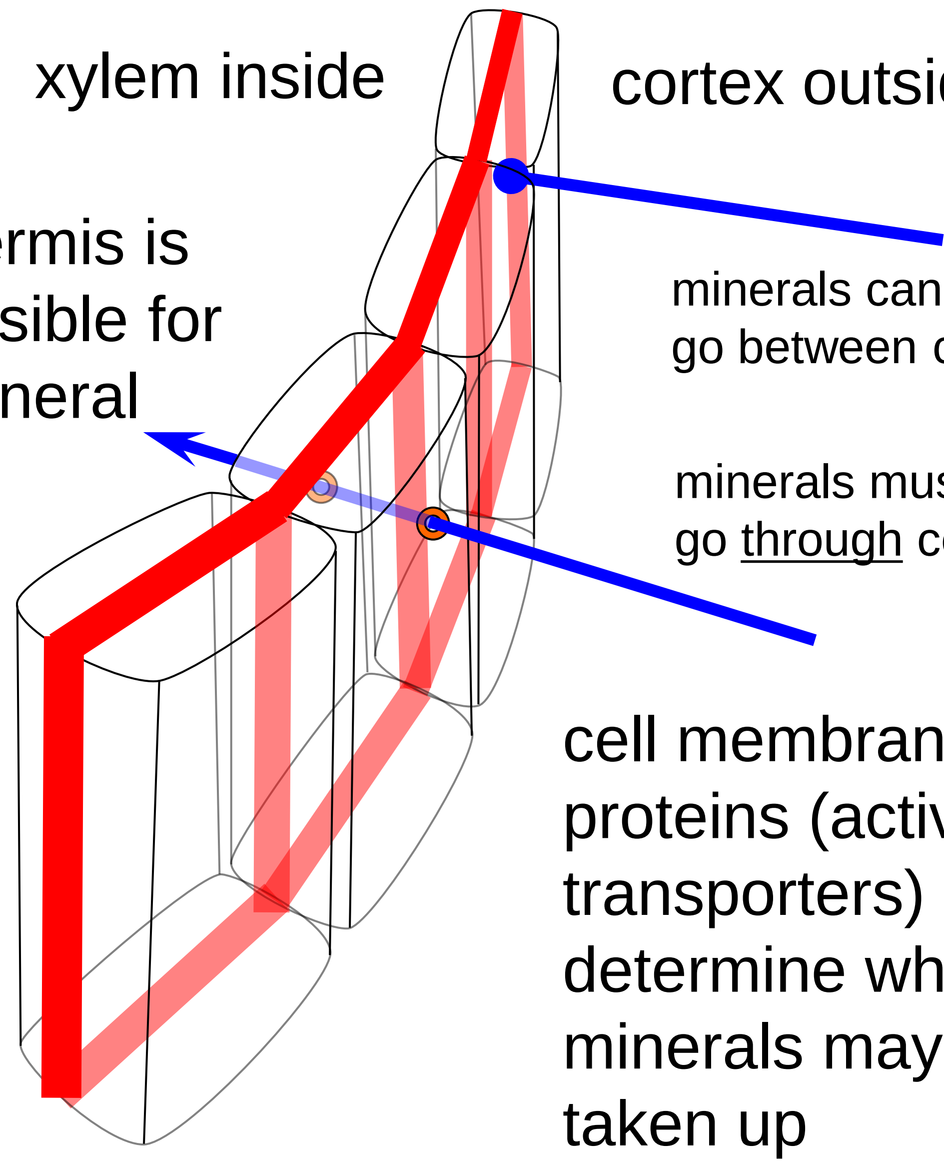

(A) Symport
(B) Antiport
OUTSIDE OF CELL
H+
A
H+
B
Low
High
High
Low
H+
A
H+
B
CYTOPLASM
Electrochemical potential gradient of substrate A
Electrochemical potential gradient of substrate B

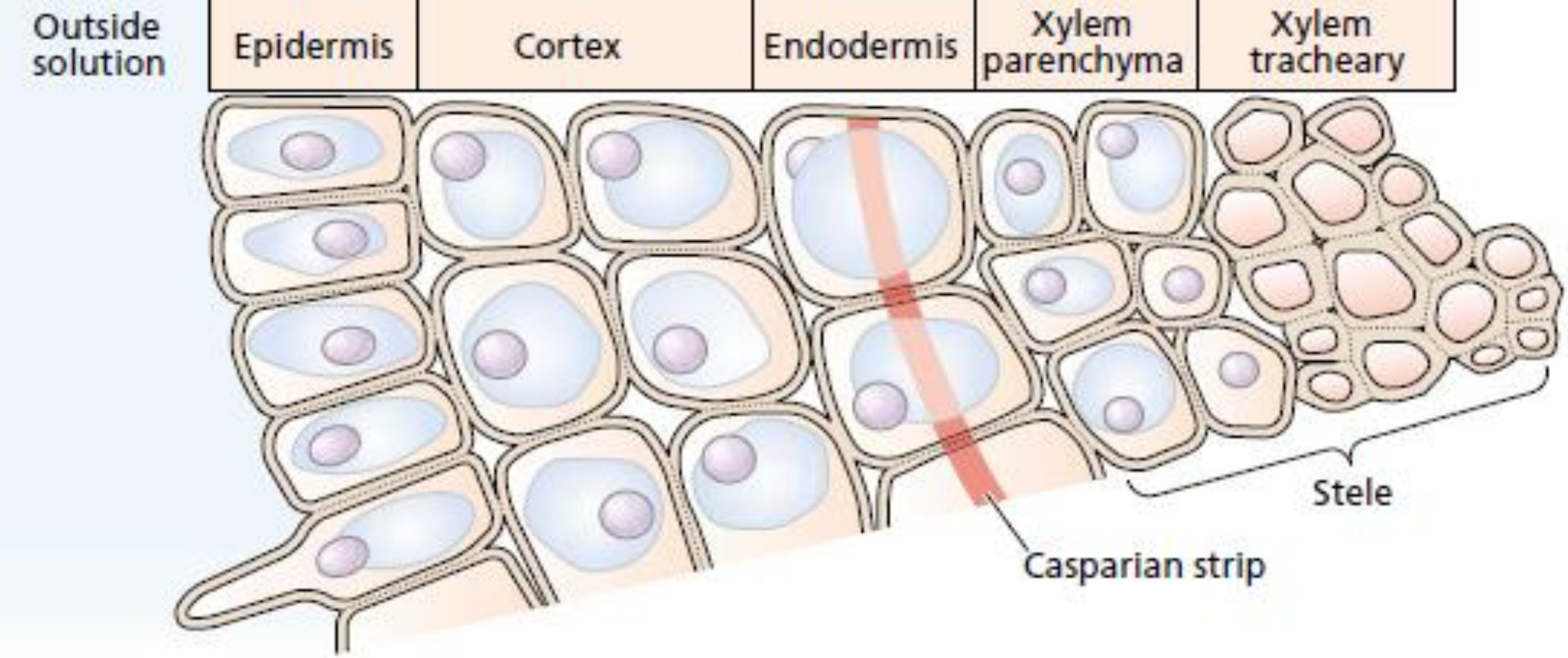

Root Hair
Root
Outside the Cell
(Positive Charge)
2 K+
H+
Proton Pump
Channel
Inside the Cell
(Negative Charge)
Cation Exchange
Outside the Cell
(Positive Charge)
NO3-
2 H+
H+
Proton Pump
Cotransporter
Inside the Cell
(Negative Charge)
Anion Exchange

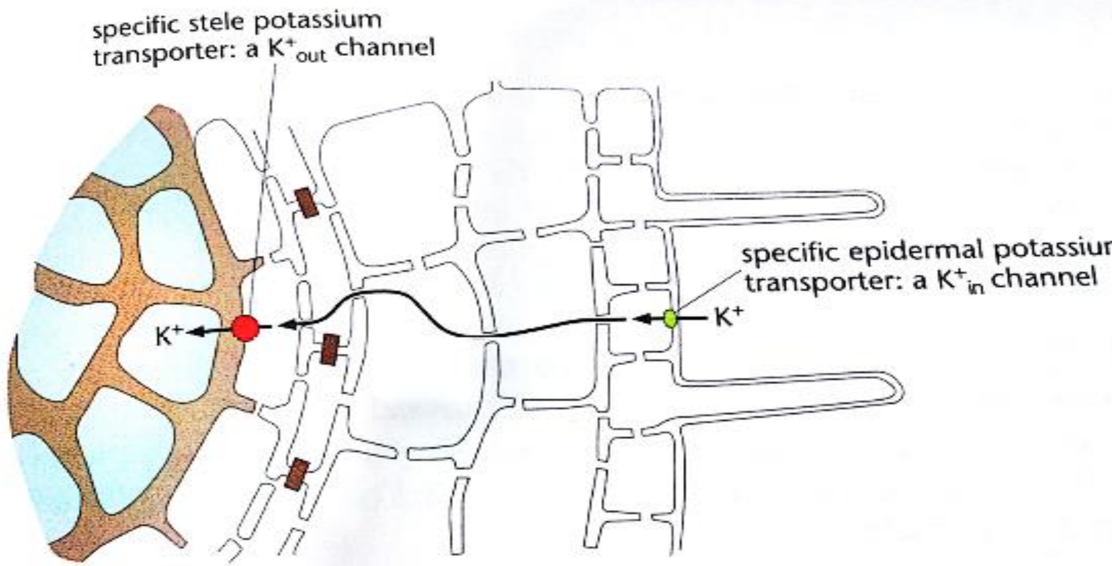
Nutrient route

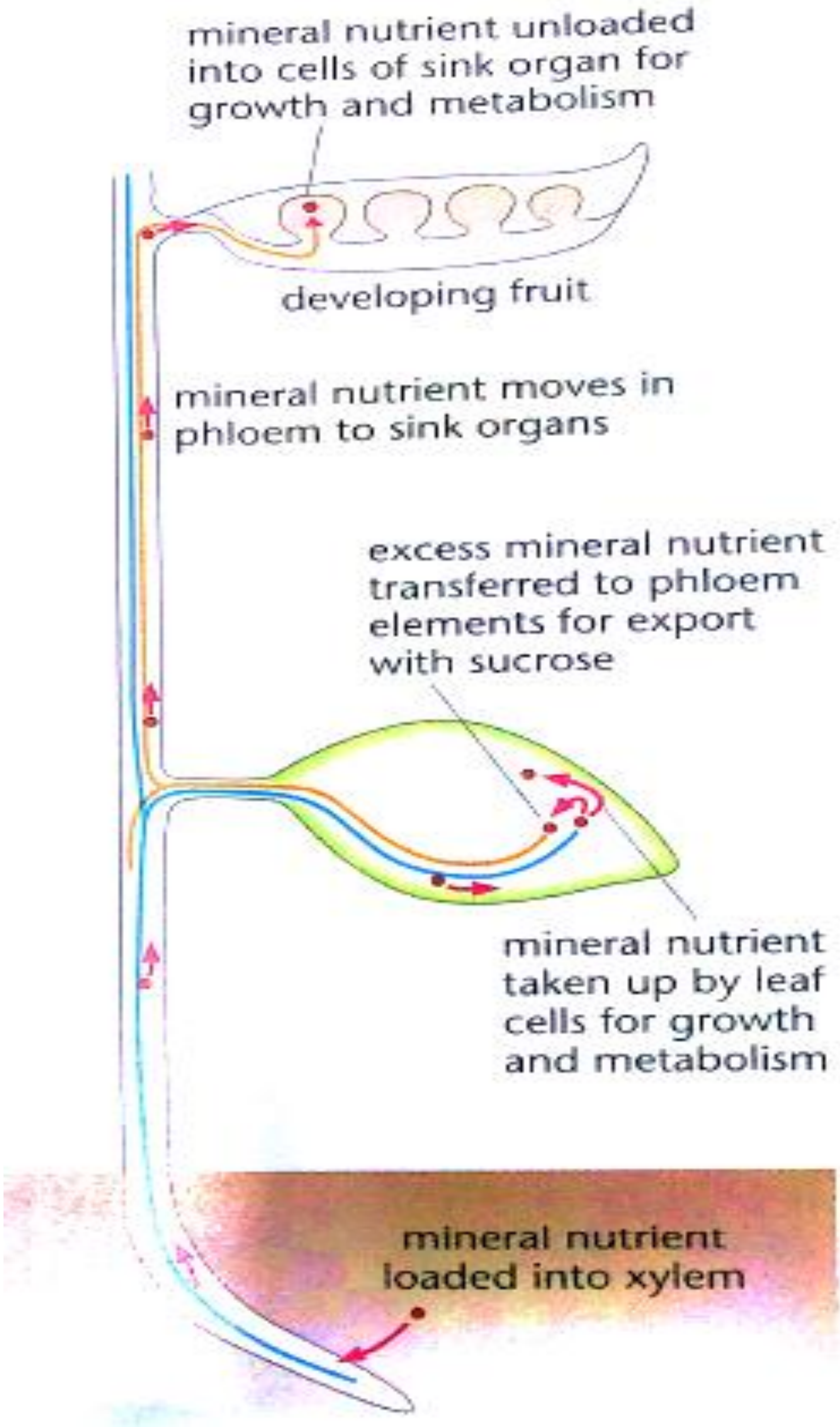


The endodermis is thus responsible for selective mineral uptake.

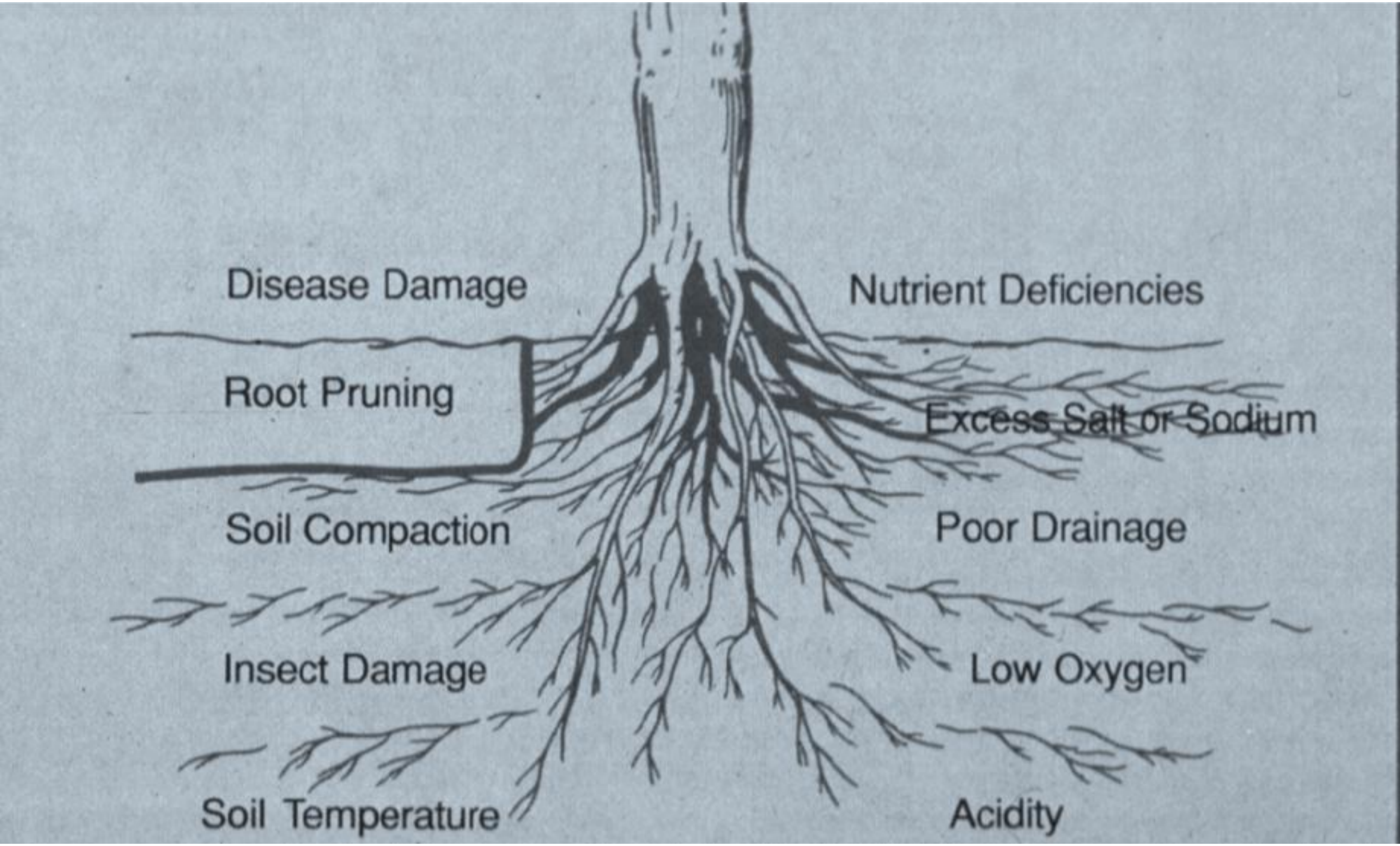



Outside solution
Epidermis
Cortex
Endodermis
Xylem parenchyma
Xylem tracheary
Stele
Casparian strip


specific stele potassium transporter: a K^+_{out} channel
K^+
specific epidermal potassium transporter: a K^+_{in} channel
K^+

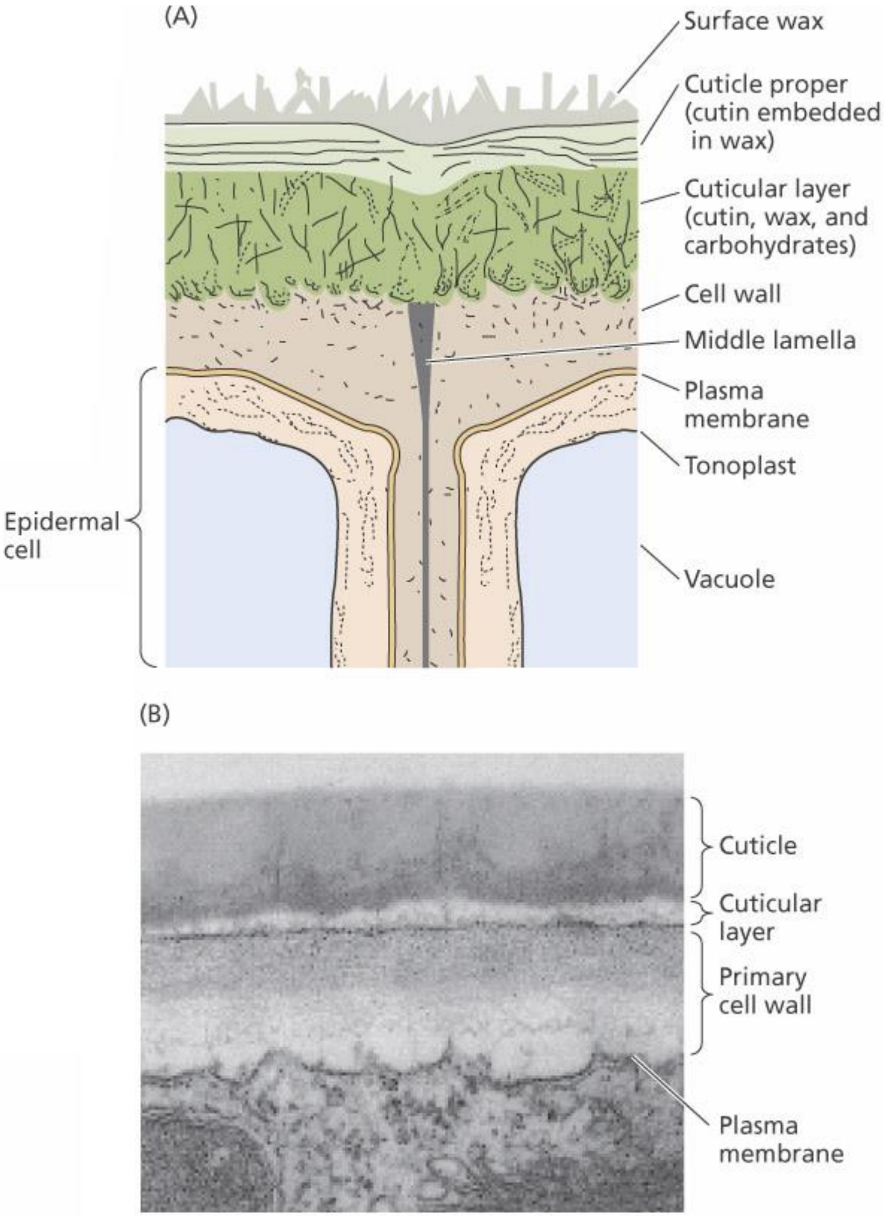

mineral nutrient unloaded into cells of sink organ for growth and metabolism
developing fruit
mineral nutrient moves in phloem to sink organs
excess mineral nutrient transferred to phloem elements for export with sucrose
mineral nutrient taken up by leaf cells for growth and metabolism
mineral nutrient loaded into xylem

Anything which restricts root growth reduces nutrient uptake



Nutrients can also be absorbed by leaves

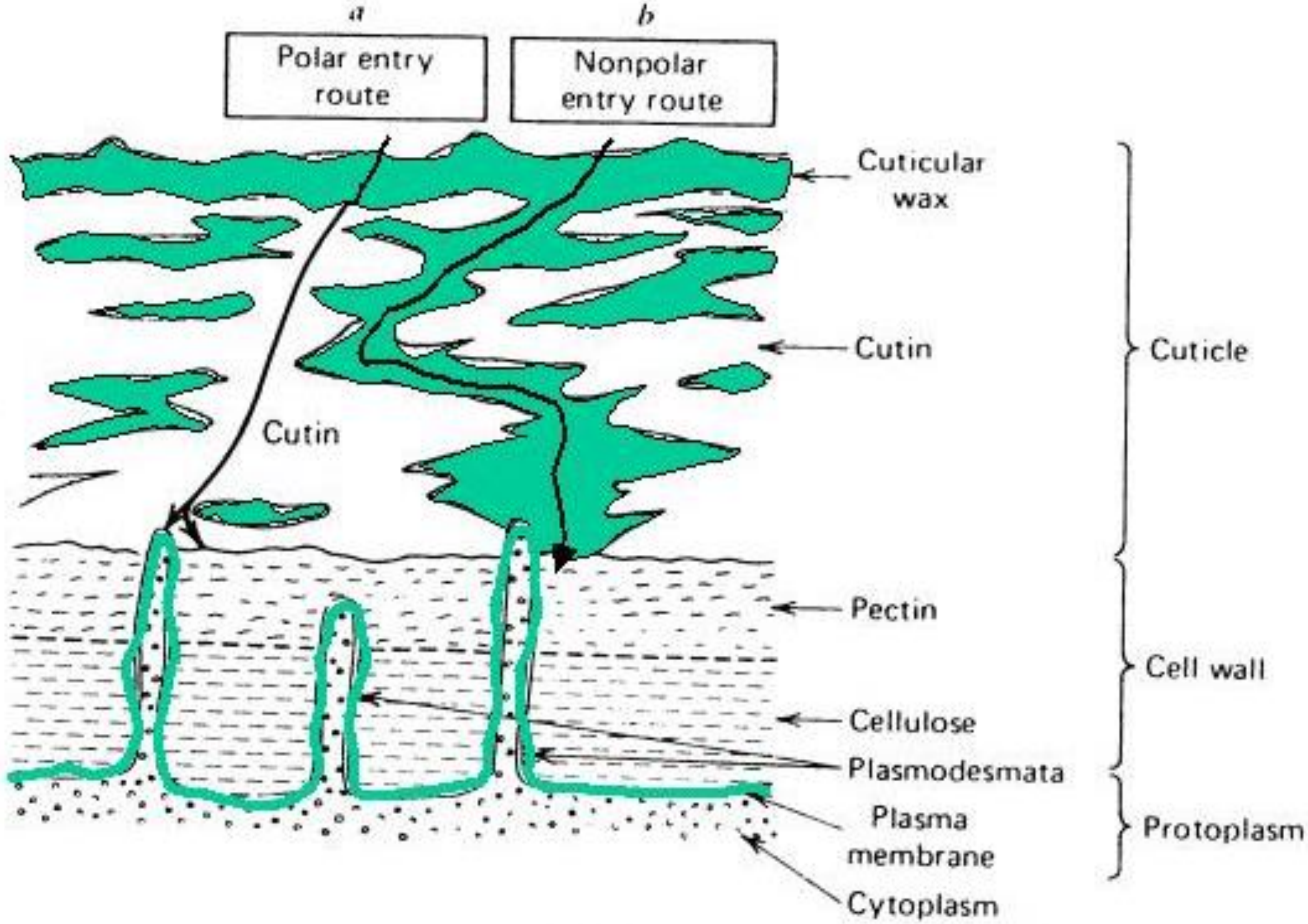
Mechanism of Foliar Fertilization



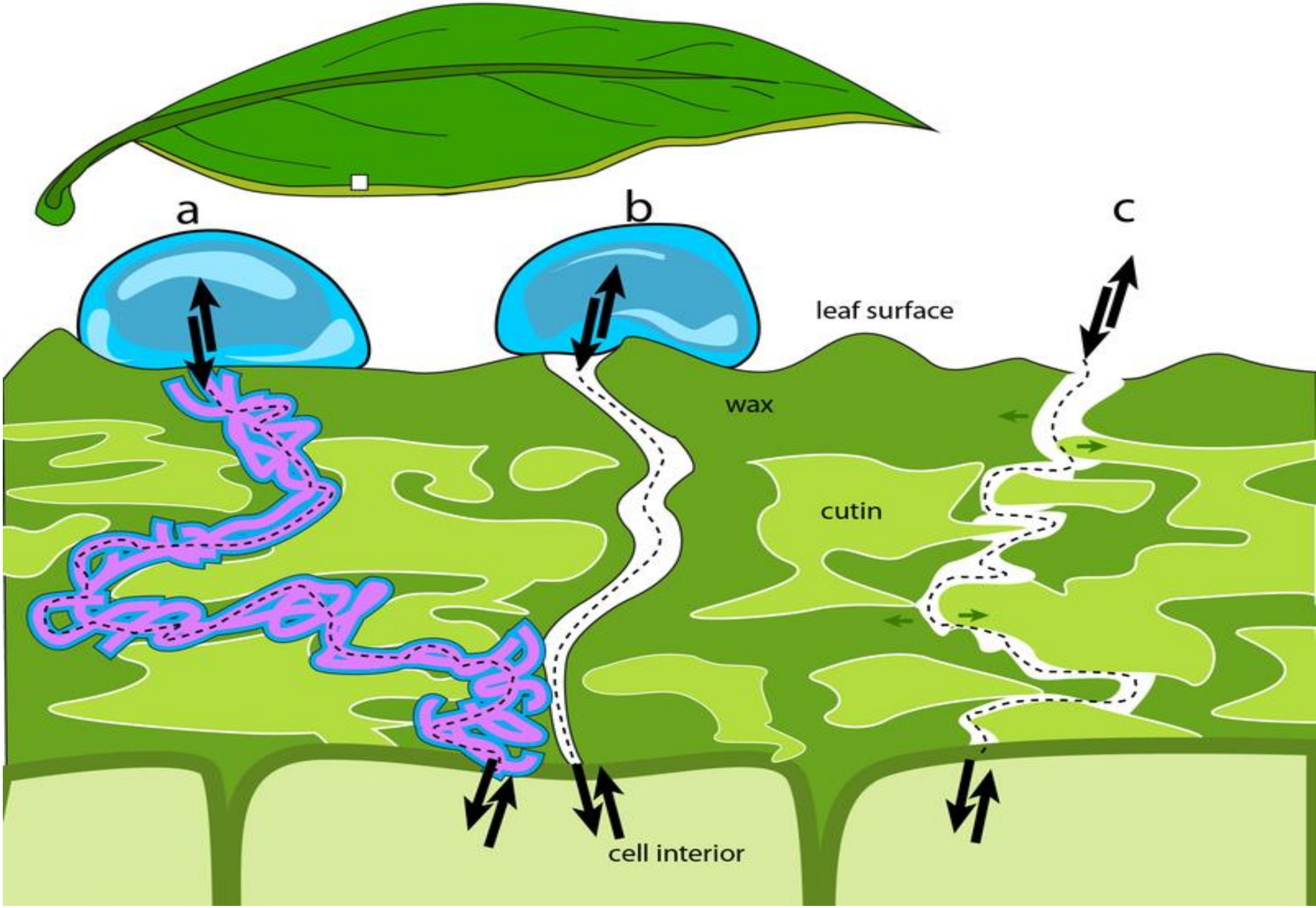
In order for a foliar fertilizer nutrient to be utilized by the plant for growth, it must first gain entry into the leaf prior to entering the cytoplasm of a cell in the leaf.

To achieve this the nutrient must effectively penetrate the outer cuticle and the wall of the underlying epidermal cell.

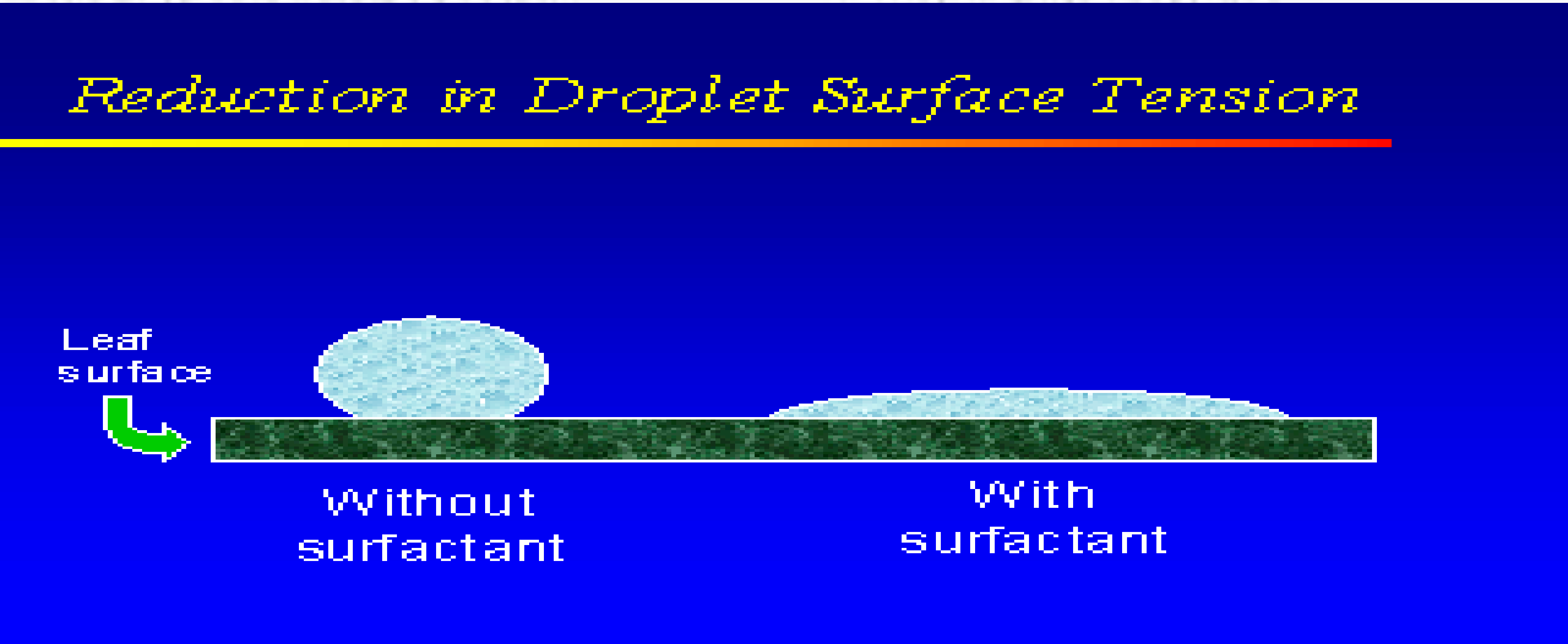
Once penetration has occurred, nutrient absorption by the cell is similar to absorption by the roots.



Green areas represent lipophilic regions: epicuticular wax, cell membrane (plasma membrane).


a
b
c
leaf surface
wax
cutin
cell interior


Without surfactant
With surfactant


Reduction in Droplet Surface Tension
Leaf surface
Without surfactant
With surfactant

Advantages and Disadvantages:

- Can react rapidly to symptoms or tissue analysis
- Rapid plant response for correcting deficiency
- Avoids soil problems
- Relatively low cost
- Only use small amounts of fertilize

- Only a limited amount of the nutrient can be applied at one time.
- Cost of multiple applications can be prohibitive.
- Possibility of foliar burn (with high concentrations).
- Low solubility of some fertilizers especially in cold water.
- Incompatibility with certain other agrochemicals.


Thank You