Plant Nutrition

This course is designed for advanced graduate students interested in the principles of mineral nutrition in plants. The focus of the course will be on the factors and processes influencing the supply, absorption, transports, and utilization of the essential elements required by higher plants. Various aspects of plant physiology and metabolism will be covered, mainly from the stand point of how and to what extent they are affected or regulated by plant nutrition.

1- Essential plant Nutrition and Their General Functions

-Definition and Terminology

- Classification of Plant Nutrients

- General Functions

2- Nutrient Content and Composition

- Terminology in Plant Tissue Nutrient Content- Unit of measurement

- Determining plant Nutrient Content (Diagnostic Criteria)

- Factors and Consideration Influencing Plant Nutrient Content

- Typical Range of Nutrients in Plants

3-Nutrient Acquisition by Plant

- plasma membrane
- Ion Uptake kinetic

4-Nitrogen Nutrition

- Plant N Fractions
- N Transformation in Plant nutrition- the N Cycle
- N utilization and assimilation
- Ammonium vs. Nitrate vs. Mixed –N Nutrition

5- Plant Water Relationship

- Water Potential

- Water Uptake and Movement
- Stamatas
- Development of Water Stress in Plant
- Solute Translocation in Phloem

6- Plant Nutrition in Solution Culture (Lab.)

References :

1- Plant physiology. Salisbury and Ross.

2- Mineral Nutrition of plant, principle and perspective . Epstein.

3- Transport of nutrients in plants.Peel.

4- Principle of plant nutrition .Mengel and Kirkby.

5- Soil nutrient bioavailability. Barber ,S.

6- Transport in plant .Luttge and Higinbothem.

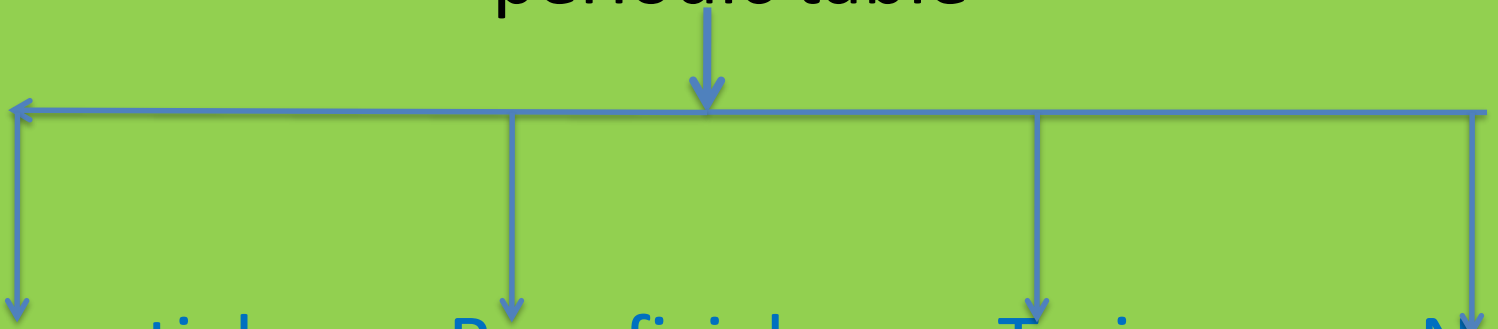
7- Handbook of plant nutrition (2007) .

Essential elements and their roles in plants.

Nutrition : growth and metabolism

nutrients : inorganic elements used by plants.

periodic table



Essential Beneficial Toxic No effect

For an element to be essential three criteria must be met :-

- Deficiency of the element makes it impossible for the plant to complete its life cycle . (direct effect on plant growth and reproduction).
- No other element substitutes for the element.
- All plants require the element. (?)

For beneficial element :-

elements that might enhance growth or that have function in some plants. (sparing effect)

Toxic :-

at natural level has no effect, but at high conc. It is toxic.

No effect :- present in nature at low conc.

Essential elements , their date of acceptance as essential…….

Table 1.1 in handbook of plant nutrition p.4

essential elements :-

Conc. Has Varity effect

too high → toxic

optimum → very good

too low → deficiency

TABLE 1.1
Listing of Essential Elements, Their Date of Acceptance as Essential, and Discoverers of Essentiality

Element	Date of Essentiality[a]	Researcher[a]
Nitrogen	1804	de Saussure[b]
	1851–1855	Boussingault[b]
Phosphorus	1839	Liebig[c]
	1861	Ville[b]
Potassium	1866	Birner & Lucanus[b]
Calcium	1862	Stohmann[b]
Magnesium	1875	Boehm[b]
Sulfur	1866	Birner & Lucanus[b]
Iron	1843	Gris[c]
Manganese	1922	McHargue[c]
Copper	1925	McHargue[c]
Boron	1926	Sommer & Lipman[c]
Zinc	1926	Sommer & Lipman[c]
Molybdenum	1939	Arnon & Stout[c]
Chlorine	1954	Broyer, Carlton, Johnson, & Stout[c]
Nickel	1987	Brown, Welch, & Cary (11)

[a]The dates and researchers that are listed are those on which published articles amassed enough information to convince other researchers that the elements were plant nutrients. Earlier work preceding the dates and other researchers may have suggested that the elements were nutrients.

[b]Cited by Reed (22).

[c]Cited by Chapman (13).

Functions of essential elements in plants and deficiency symptoms :-

Table 2.1 in soil fertility management for sustainable agriculture p 6-8., tables 37.1 and 37.2 in plant nutrition chpt. and tables 5.1 and 5.2 in chapter 5 in Mineral Nutrition (hand out) .

Basis for classification of essential nutrients X

1- Quantity :- on the basis on the amount required by plants

a- macro nutrients : taken up by plant in large amount include C, H, O,N,P,K,S,Ca , and Mg.

b- micro nutrients : taken up by plant in small amount include Zn, Mn, Fe, cu, B , Mo, Cl.

Other classification :

a- primary nutrients (N, P , and K) : taken up by crop by largest amount.

b- Secondary nutrients (Ca, Mg ,and S) :

These elements are taken by plants in the next largest amount.

c- micro (minor) nutrients (the rest of essential nutrients) . Taken up in the smallest amount.

2- Mobility in plants : transfer of nutrients from one part to other.

mobile	immobile
N, K, Mg, P, Cl	Ca, S, Fe , B, and Cu
Na, Zn, and Mo	

3 – Biochemical functions in plants

1st group

C,H,O,N ,and S

2nd group

P, B , and Si

3th group

K , Na, Mg , Ca , Mn , and Cl.

4th group

Fe ,Cu , Zn , and Mo

table in mengel and Kirkby p.13l

Role of other elements in plants

Li : Some plants accumulated Li (doesn't mean it is necessary)

Li ⟶ spared for K (not most , less frequently)

not essential (but it does some roles in plants)

F: required by animals mostly (teeth) , not required by plants, however, recent research shows it is present in plants.

F vs Cl ⟶ plant has to discriminate by plant membrane and taken by plants.

- Organic F is very common can be accumulated by plants

tea accumulate O. F. ⟶ 70---300 ppm.

F- acetate , F- oleric acid , F- citric acid

↓

(toxic principle) .

No evidence at all that F is essential to plants

Na :

- required by animals ⟶ serve in place of K
- in plants:

i-may be a macronutrient

(in some halophytes)

ii- micro nutrient → certain plants

Corn ,suqarbeet and some other C_4 plants.

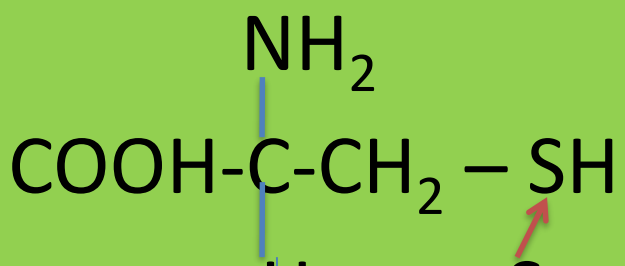
iii- beneficial → sugarbeet

iv- sparing effect(very limited) for K (osmotic)

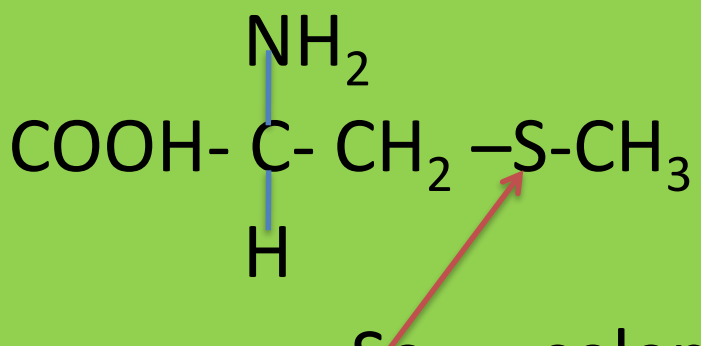
Selenium (SeO_4^{--}) :

- not essential for plants
- in sulfamino acid

i- cysteine

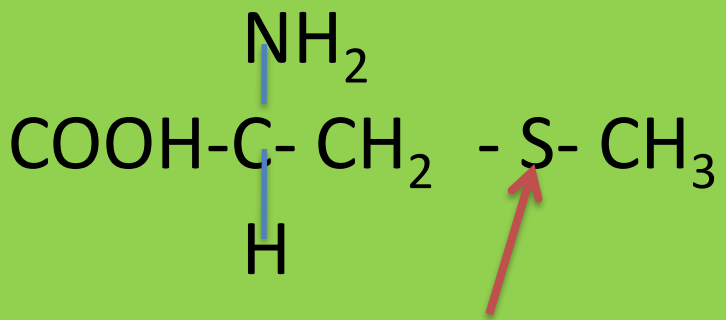


ii- Methionine



Se - selenomethionione

iii- Methyl cysteine



Se- methyl cysteine all above may convert to protein (inactive protein)

recently, it has been suggested to enhance plant growth .

Silicon :

diatoms → required by animals

grass → cell wall

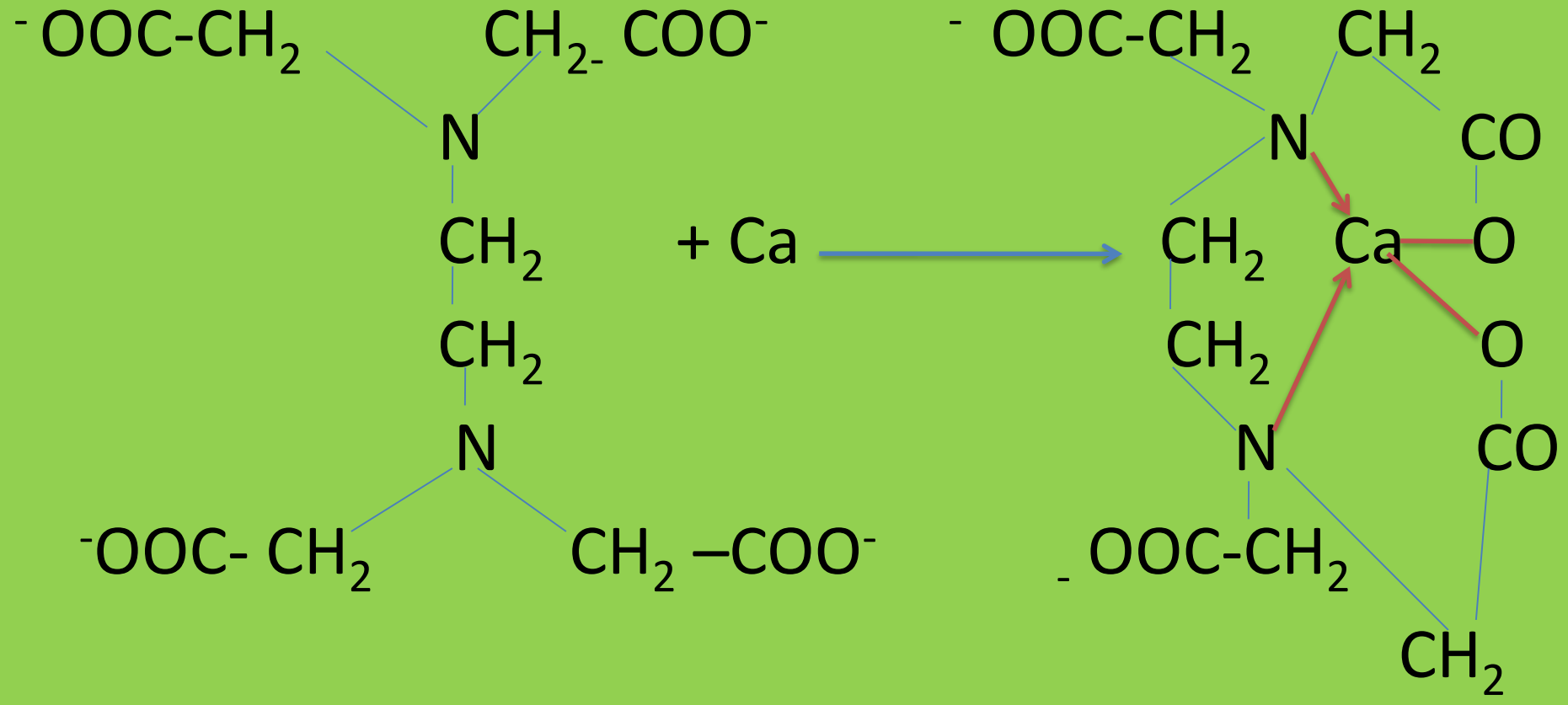
Chelating groups X

* Solubility products of chalet differ for different elements.
* affinity of chelating differs for different elements.

elements of groups 3 &4 form chelating compounds in plants

chelating compounds : when an element bonds with organic molecule in more than one bond to form ring structure such as

Ca and EDTA to form ring structure



EDTA chelate

Ca-EDTA chelate

complex structure with low water solubility

* different forms of chelat in plants depend on :

- metal → determine the kind of bonds

  a- charge

  b- degree of hydration

  c- ionic radius

- the nature of ligand

  No. of functional groups on the protein available to combine with metal.

- environments in which binding take place like temp., pH, solvent(as H_2O) -----etc.

forms of ligands in plants :-

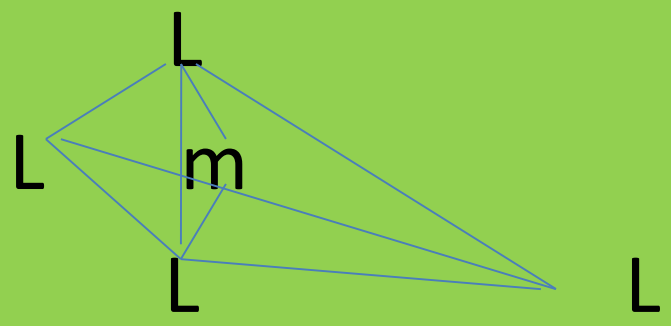
1- linear

L-----m -------L (two binding sites)

not important biologically.

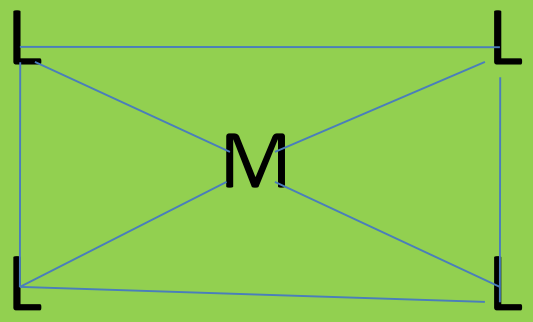
2- tetrahedral

more important biologically found in Mg and Zn



Four bonds

3- planar



4- octahedral

very important biologically

Functional groups of ligands :-

(-O-) enalate, amino group (NH_2),

azo group(-N= N) , ring N-N, carboxyl

(COOH), carbonyl (C=O), SH ,PO_4 , SO_2 O^-

* most important ligand compounds in plants those of heam group and chlorophyll

- heam group is an Fe porphyrin

  Fig. In Mengel and Krikby p.

- chlorophyll is similar to heam group but Mg replace Fe

  Fig. 5.2 in chpt.5 in mineral nutrition paper

  Fe binds to DTPA (in soil as Fe chealting fertilizer)

Nutrient content and composition (L2)

nutrient concentration vs nutrient uptake

% (macro),ppm(micro) ppt (macro)

wt./area, pot, etc

nutrient absorbed (mostly decrease with time of season) express as soluble or total

nutrient assimilated (as total mostly increase with time) total amount of a nutrient

uptake= conc. x dry wt.

Diagnostic Criteria:

1- Visual Diagnosis

* Metabolic disruption resulting from nutrient deficiencies provide links between the function of an element and the appearance of a specific visible abnormality.

* Symptoms on foliage have been classified into five types:-

  - chlorsis, which maybe uniform or inter-venial
  - necrosis, which may be at leaf tips or margins

- lack of new growth, which may result in death of terminal or axillary buds and leaves, dieback, or resetting.
- accumulation of anthocyanin, which results in overall red color.
- stunting with normal green color or an off-green or yellow color.

* different symptoms for different elements.
* deficiency symptoms of macro vs. micro nutrients.
* hidden hunger.

* symptoms similar to nutrients deficiency can develop on plants as a result of conditions that are not related to nutrient deficiency.

2- Plant Analysis

* plant analysis was one of the means used by scientists in the 1800s to determine the essentiality of chemical elements as plant nutrients.

* Kinds of Analyses:

i- total or quantitative (total chemical analysis)

ii- relative quantity or semiqantative(rapid tissue test).

i- The total or quantitative analysis

measure both the elements that have already been incorporated into tissues and those that are still present as soluble constituents of the plant sap.

ii- The semi- quantitative analysis (rapid tissue test)

measure the unassimilated, soluble contents of plant sap. In essence, the constituents that are measured are on route from the point of entry to the site of utilization within the plant. For K, the test is essentially the total amt. Why?

General purpose of plant analyses :- L3

a- To diagnosis or confirm diagnosis of visible symptoms.

b- To identify hidden trouble:

many nutrients deficiencies produce no specific symptoms on plants other than a general lack of vigor growth and reduced yield. Plant analysis may help to identify these hidden problems.

c- To locate areas of incipient deficiencies:

visible deficiency symptoms are seldom a useful guide for micronutrients until the deficiencies are relatively acute .Plant analysis capable of indicating shortage of nutrients that are not sever to produce recognizable symptoms.

d- To indicate whether applied nutrients entered the plant:

Where there is neither a recognizable symptoms nor a yield increase following nutrients application, the researcher needs to know whether nutrient uptake by some soil reactions or by unfavorable placement, or whether nutrient was absorbed but was ineffective in promoting growth.

E- To indicate interactions or antagonisms among nutrients:

Addition on of a nutrient may enhance or reduce absorption of other nutrient. In some cases, growth may be stimulated by a nutrient to the point that other nutrients become deficient , and further growth cannot occur. Plant analyses can help to detect changes in plant composition or growth that are synergistic or antagonistic with crop fertilization.

F- As an aid to understanding internal functioning of plants:

Periodic analysis of whole plants or plant parts through the season, under varied conditions, show great differences among crops and even among varieties or hybrids of same crop.

G- To suggest tests to identify the trouble:

Sometimes plant analyses point to the need for soil tests to identify the specific cause of trouble

Table: plant analyses and soil tests form corn with yellow and necrotic streaked at tasseling stage

Plant analyses							
B	Fe	Mn	Zn	Ca	Mg	K	P
ppm				%			
17	222	999	53	0.41	0.07	2.0	0.46
Soil Test							
Bray P1			130				
K			400				
PH			4.7—5.0 (low for corn)				

Principle in plant analysis : X

Plant analysis in a narrow sense is the determination of the conc. of an element or extractable fraction of an element in a sample of a particular part or portion of a crop sampled at a certain time or stage of morphological development.

Basic principle :

Plant analyses is based on the principle that the conc. of a nutrient with plant is an integral value of all the factors that have interacted to effect it.

a- Yield in relation to nutrient conc. and supply

Fig.1 p.225 in soil testing and plant analysis

- entire yield curve would be sigmoid curve with increasing nutrient supply, but the relation with nutrient conc. would change relatively little. In field only segment of continuous curves are involved.

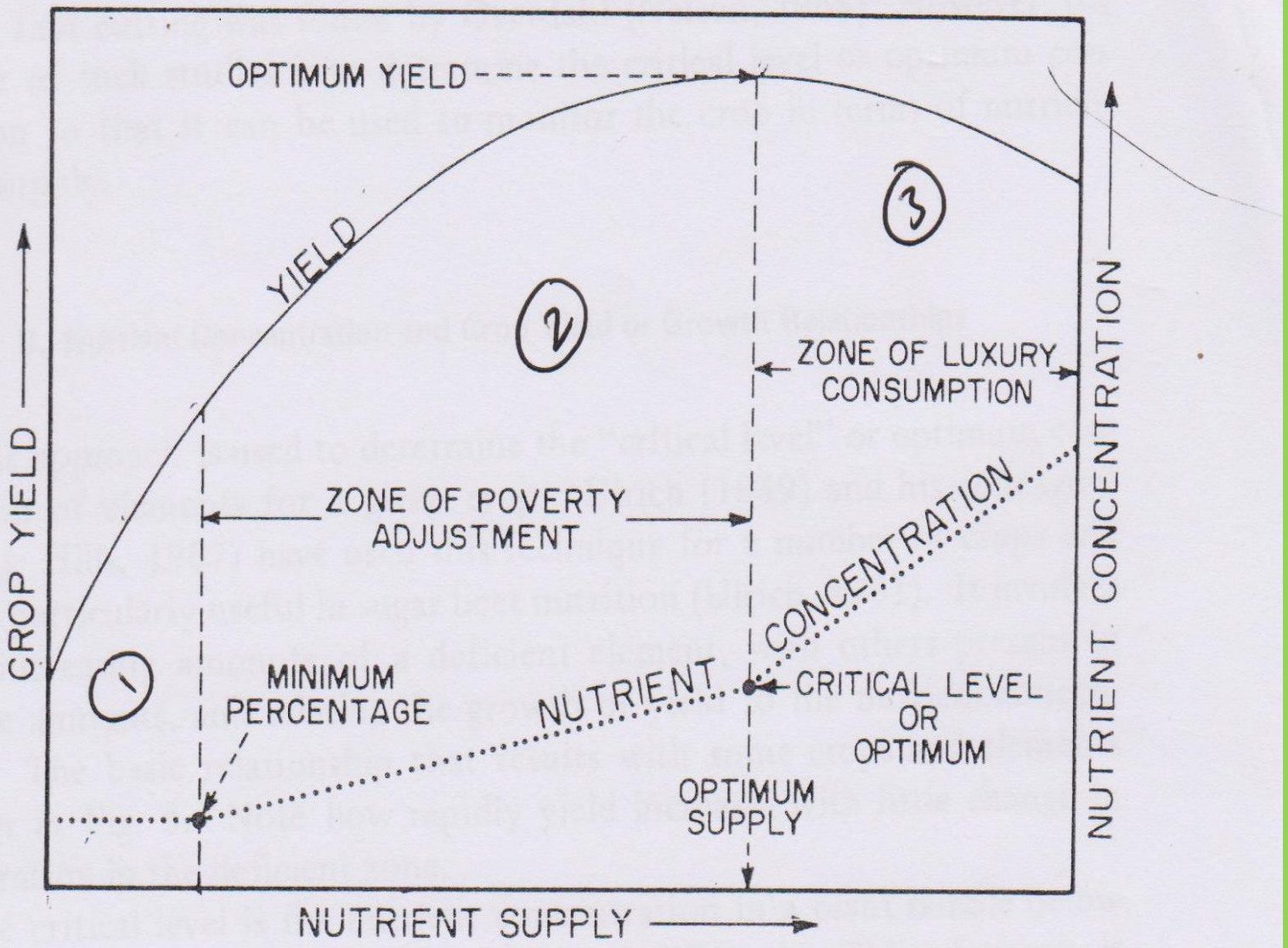


Fig. 1—Schematic graph of the manner in which nutrient concentration and crop yield varies with the supply of the nutrient (Brown, 1970).

Fig.2 p.225 in soil testing and plant analysis

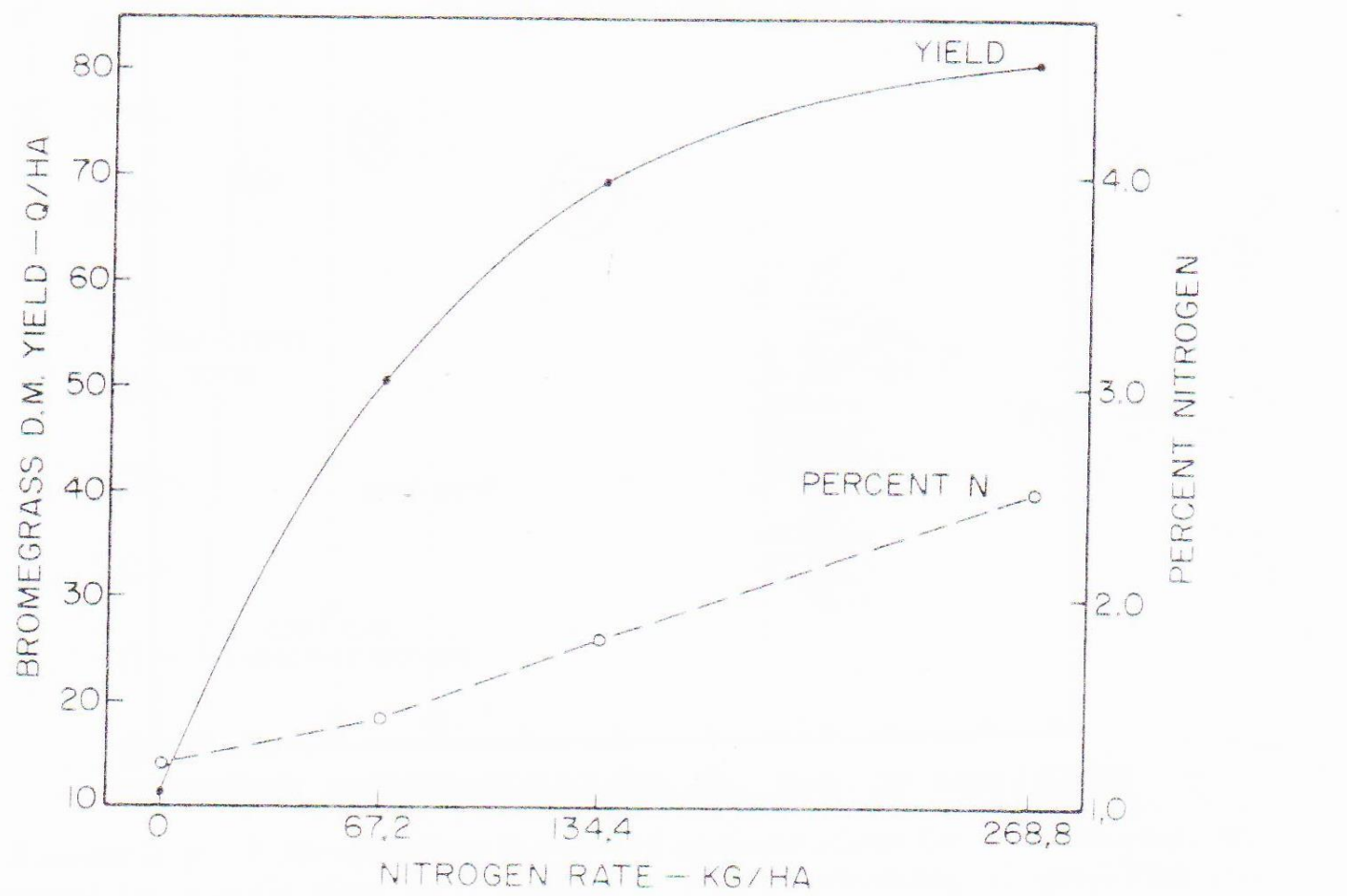


Fig. 2—Yield of the first cutting of bromegrass and its N concentration as related to N applied as ammonium nitrate (Russell et al., 1954).

b- Nutrient conc. and crop yield or growth relation

Fig.3 p.226 in soil testing and plant analysis .This approach is used to determine the critical level or optimum concentration for elements a given crop.

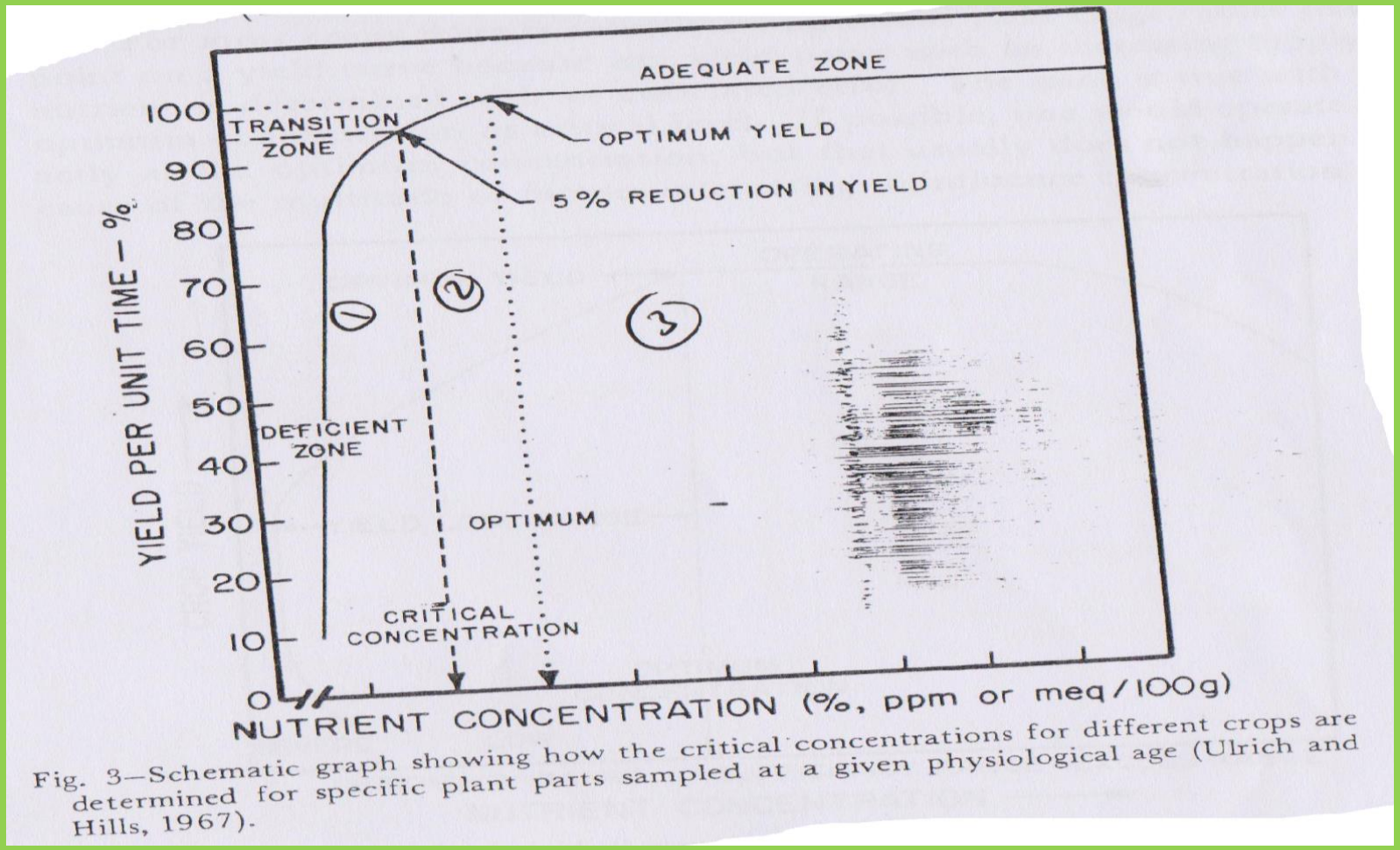


Fig. 3—Schematic graph showing how the critical concentrations for different crops are determined for specific plant parts sampled at a given physiological age (Ulrich and Hills, 1967).

Fig.4 in soil testing and plant analysis p.227 (chapman)

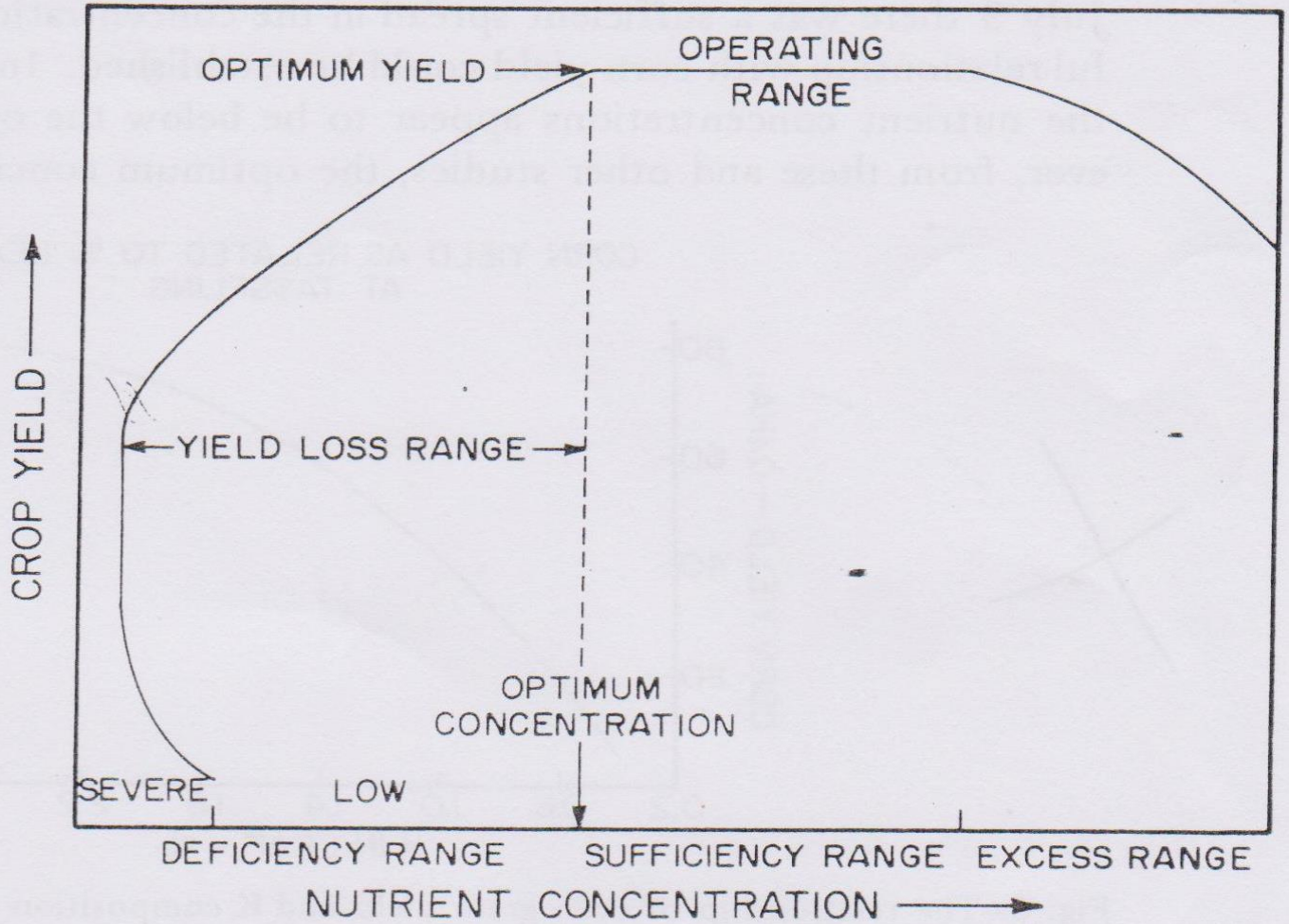


Fig. 4—Schematic graph of yield or growth of a crop as related to nutrient concentrations and interpretive ranges (Chapman, 1967).

Fig. 5 in soil test ……p. 228 effect of time of sampling

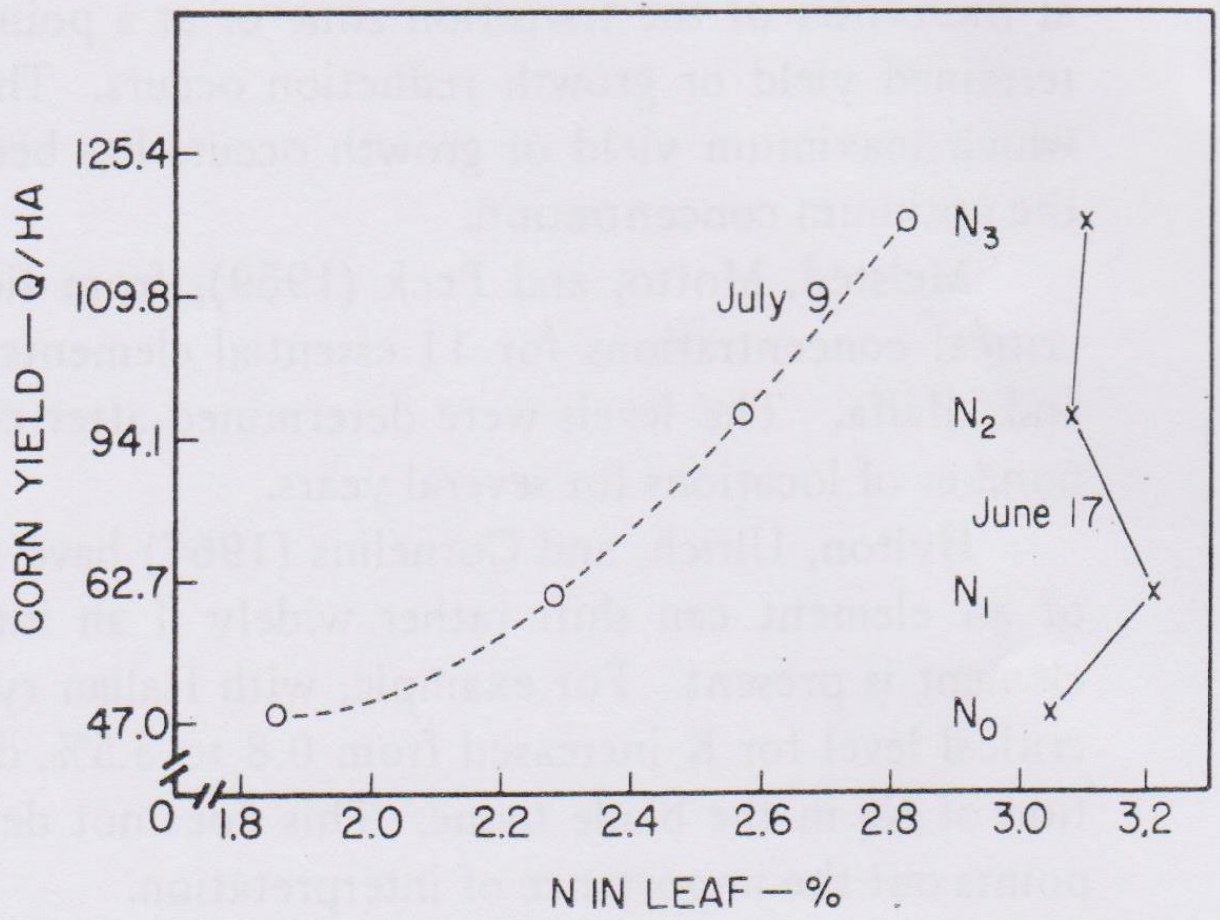


Fig. 5—The relationship of corn grain yield and N leaf composition when sampled June 17 and July 9—0, 44.8, 98.6 and 179.2 kg of N/ha applied as anhydrous ammonia (Viets et al., 1954).

c- Nutrient conc. and physiological maturity of crops

Fig.7 in soil testing and ……p.230

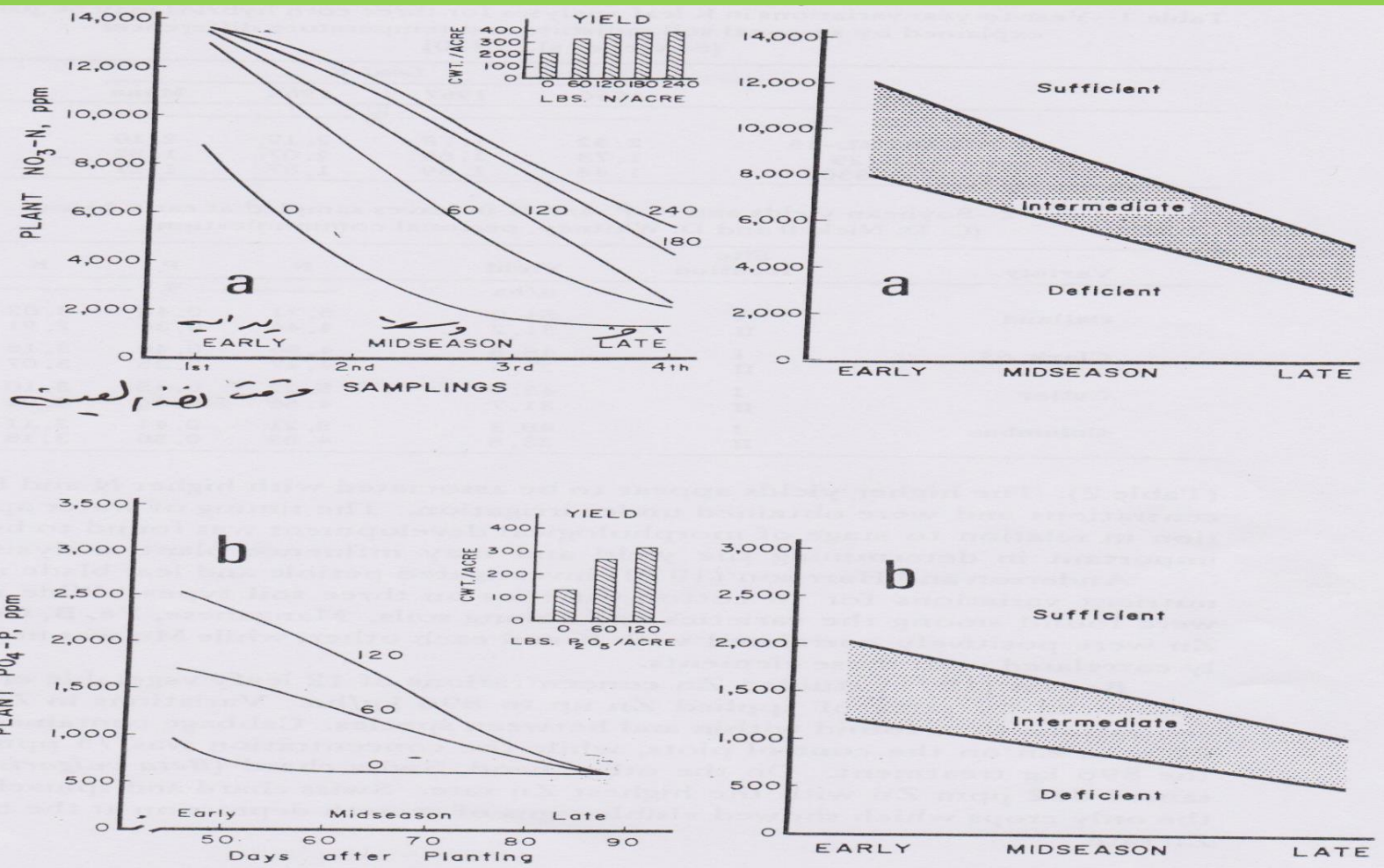


Fig. 7a, 7b, 7c—The NO_3-N, PO_4-P, and K concentrations in potato petioles change with time and physiological maturity of the crop, as well as with the level of fertilization. From such information the period of sampling for plant analysis can be extended and ranges of sufficiency and deficiency can be established (Tyler & Lorenz, 1962).

d- Nutrient conc. and varieties Tables 1 and 2 in soil testing and ……..p.234

Table 1—Year-to-year variations in K leaf analyses for three corn hybrids may be partially explained by seasonal soil moisture and temperature differences (Stivers et al., 1970)

	Leaf K			
	1966	1967	1968	Mean
	%			
DeKalb XL-45	2.32	1.78	2.19	2.10
PAG SX-29	1.73	1.65	2.07	1.82
Pioneer 3306	1.48	1.39	1.67	1.51

Table 2—Soybean yields and N, P, and K in leaves sampled at early bloom (C. D. Nickell and D. Whitney, personal communication)

Variety	Site location	Yield	N	P	K
		q/ha	%		
Calland	I	54.0	5.71	0.48	3.02
	II	31.2	4.46	0.36	2.91
Clark 63	I	45.5	4.96	0.40	3.16
	II	27.4	4.47	0.35	3.07
Cutler	I	43.9	5.22	0.45	3.10
	II	31.7	4.56	0.36	3.01
Columbus	I	40.3	5.21	0.41	3.11
	II	33.5	4.82	0.36	3.18

Table 2 suggested sampling procedures for field and vegetable crops …….. P.254 in soil testing and plant analysis.

Table 2—Suggested sampling procedures for field and vegetable crops, fruit and nuts, and ornamentals (Jones et al., 1971)

Stage of growth	Plant part to sample	Number of plants to sample
FIELD CROPS		
Corn		
1) Seedling stage (less than 12 inches) or	All the above ground portion	20-30
2) Prior to tasselling or	The entire leaf fully developed below the whorl	15-25
3) From tasselling and shooting to silking	The entire leaf at the ear node (or immediately above or below it	15-25
Soybeans or Other Beans		
1) Seedling stage (less than 12 inches) or	All the above ground portion	20-30
2) Prior to or during initial flowering	Two or three fully developed leaves at the top of the plant	20-30
Sampling after pods begin to set not recommended		
Small Grain (Including Rice)		
1) Seedling stage (less than 12 inches) or	All the above ground portion	50-100
2) Prior to heading	The 4 uppermost leaves	
Sampling after heading not recommended		
Hay, Pasture, or Forage Grasses		
Prior to seed head emergence or at the optimum stage for best quality forage	The 4 uppermost leaf blades	40-50

Stage of growth	Plant part to sample	Number of plants to sample
VEGETABLE CROPS		
Potato		
Prior to or during early bloom	Third to sixth leaf from growing tip	20-30
Head Crops (Cabbage, etc.)		
Prior to heading	First mature leaves from center of whorl	10-20
Tomato (Field)		
Prior to or during early bloom stage	Third or fourth leaf from growth tip	20-25
Tomato (Greenhouse)		
Prior to or during fruit set	1 Young plants: leaves adjacent to 2nd and 3rd clusters	20-25
	2 Older plants: leaves from 4th to 6th clusters	20-25
Beans		
1) Seedling stage (less than 12 inches)	All the above gound portion	20-30
2) Prior to or during initial flowering	Two or three fully developed leaves at the top of the plant	20-30
Root Crops (Carrots, Onions, Beets, etc.)		
Prior to root or bulb enlargement	Center mature leaves	20-30
Celery		
Mid-growth (12-15 inches tall)	Petiole of youngest mature leaf	15-30

E- Interpretation of plant analysis : references tables std. values for different plants

table 1- Sufficiency range for soybean leaves p. 317 in soil testing and plant analysis

Table 1—Sufficiency ranges for soybean leaves*

Element	Sufficiency range†
N, %	4.26-5.50
P, %	0.26-0.50
K, %	1.71-2.50
Ca, %	0.36-2.00
Mg, %	0.26-1.00
Mn, ppm	21-100
Fe, ppm	51-350
B, ppm	21- 55
Cu, ppm	10- 30
Zn, ppm	21- 50
Mo, ppm	1.0-5.0

* Upper fully developed trifoliate leaves sampled prior to pod set. Petioles were discarded.

† Ohio State University Plant Analysis Laboratory, unpublished data, 1971.

table 6 range for wheat and barley. p. 343 in soil testing.

Table 6—Interpretation of plant analyses for oats, wheat, and barley based on aboveground samples collected as the head emerges from the boot (stage 10.1)

Nutrient	Nutrient concentration in dry tissue			
	Deficient	Low	Sufficient	High
	%			
N (winter grains)	<1.25	1.25-1.74	1.75-3.00	>3.00
(spring grains)	<1.50	1.50-1.99	2.00-3.00	>3.00
P	<0.15	0.15-0.19	0.20-0.50	>0.50
K	<1.25	1.25-1.49	1.50-3.00	>3.00
Ca (except barley)		<0.20	0.20-0.50	>0.50
(barley)		<0.30	0.30-1.20	>1.20
Mg		<0.15	0.15-0.50	>0.50
S		<0.15	0.15-0.40	>0.40
	ppm			
Mn	<5	5-24	25-100	>100
Zn		<15	15-70	> 70
Cu		< 5	5-25	> 25
Fe			50-150*	
B			5-10*	
Mo			0.3-5*	

* Range reported in the literature.

3- Biochemical Tests L4

- activities of specific enzymes can provides rapid and sensitive indicators of nutrient deficiencies in plants.
- deficiencies of micronutrients can lead to inhibited activities of enzymes for which the nutrient is part of the specific enzyme molecule

* the enzymatic assays do not give conc. of nutrient in plants, but it gives an indication of sufficiency or deficiency of a nutrient.
* the assays are run on crude extracts or leaf disks to provide quick tests.

peroxidase assays

- have been used to distinguish Fe from Mn deficiency in plants in citrus.
- are heme-contaning enzymes that use hydrogen peroxides as electron acceptor to catalyzed no. of oxidative reactions.
- Fe deficiency → activity inhibited
- Mn deficiency → activity increased
- Fe is constituent of peroxidase while Mn is not.

* Fe deficiency resulted in low activities of catalse, peroxidase and nitrate reductase in corn.
(many other examples are shown in text)

* macronutrients have numerous functions in plants and association of specific enzymatic activity with deficiencies of macronutrients is difficult. However, some assays have developed :

nitrate reductase → N deficiency

glutamate-oxloactate aminotransferase

↓

phosphorus deficiency

4- Soil Test

* chemical and physical properties of soil properties based on a sample of soil.
* provide assessments of the amount of available nutrients.
* recommendation for fertilization may be based on results of soil test.
* results of soil test must be calibrated to crop response (growth or yield) in the soil.

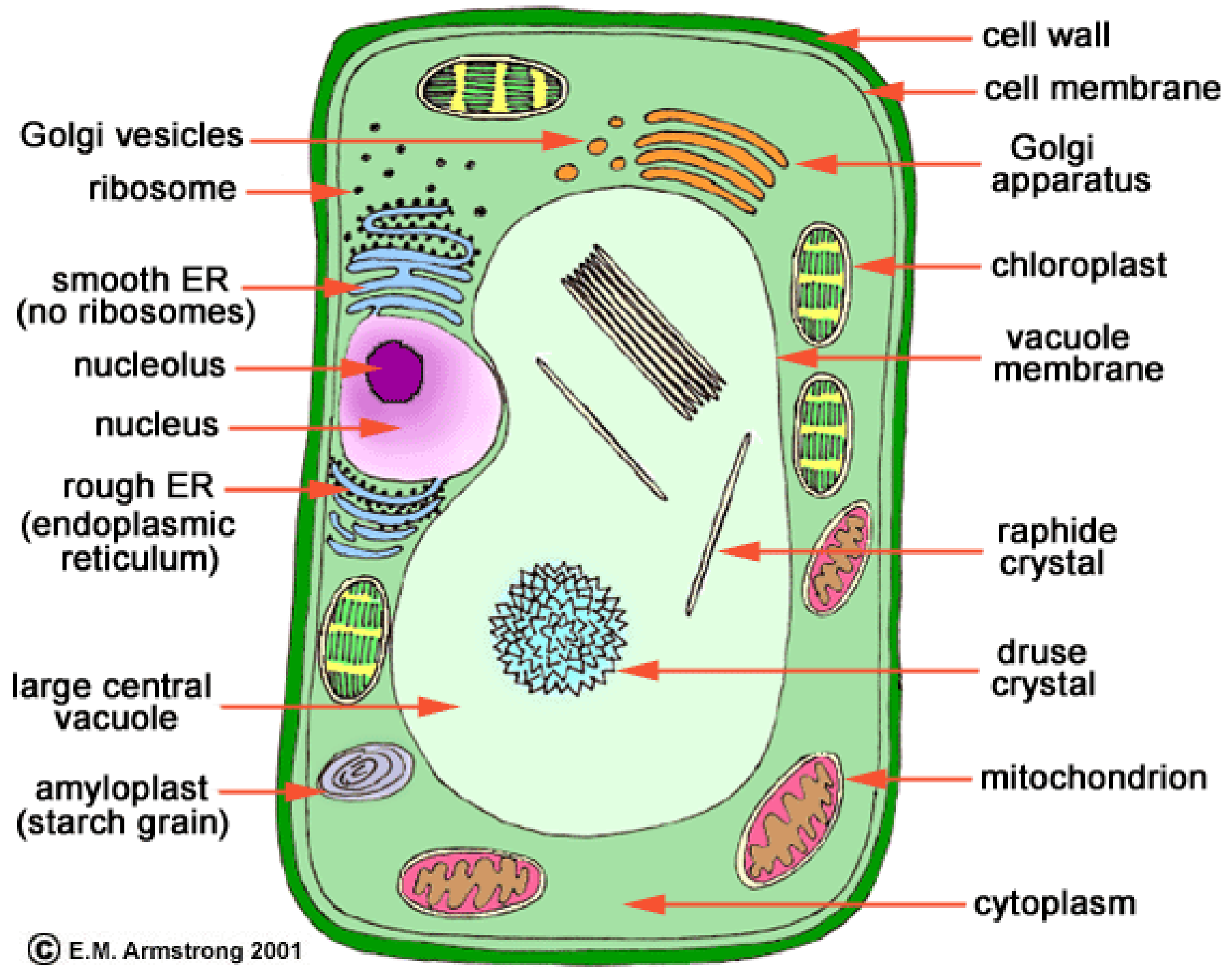
total analysis vs. available forms

Acquisition of element by plants X
(Nutrients uptake)

Plant cell :

Fig.1 p.114 in principle of plant nutrition of Mingel & krikby

* The cell wall structure is made up of pectic substance and cell ouse . Cellouse substance tends to aggregate to form chain like structures known as micro fibrils. Intermicrofibrils spaces allow the entry of water, air, and solute particles into cell wall.
* The plasma membrane (plasmalemma) is the membrane between the cytoplasm and the cell wall.


cell wall
cell membrane
Golgi vesicles
Golgi apparatus
ribosome
chloroplast
smooth ER (no ribosomes)
vacuole membrane
nucleolus
nucleus
rough ER (endoplasmic reticulum)
raphide crystal
druse crystal
large central vacuole
mitochondrion
amyloplast (starch grain)
cytoplasm
© E.M. Armstrong 2001

serves as a storage pool, e.g. for sugars, nitrate, and phosphate.

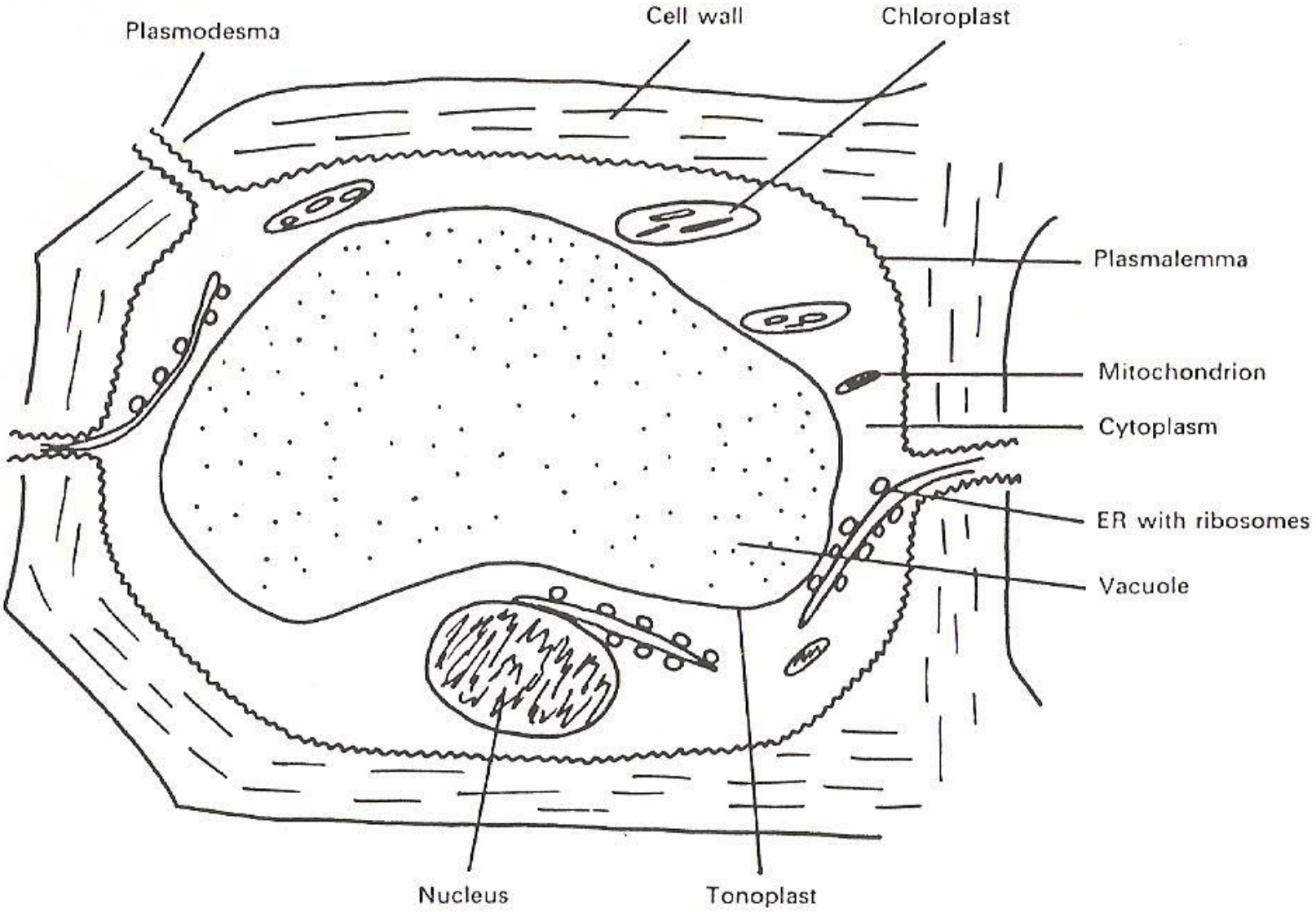


Fig. 3.1 Simplified representation of a mesophyll cell (not to scale).

The tonoplast is the membrane separates the cytoplasm from the vacuole.

Chloroplast → P.S.

Mitochondria → TCA cycle, respiration, and fatty acid metabolism

Ribosome → synthesis of polpeptide from a. a

ER → membranous channels permeating the cytoplasm and often leading from one cell to another . Produce material used in the synthesis plasma membrane

Vacuole → storage of inorganic ions and low M.W. organic substances.

* The size of living cells varies considerably for different tissues and plant species

-mesohpyll cells and cells of roots cortex tissue are about 20-100 micron in length.

- the diameter of chloroplast and plastids is in range of 8 micro and that of mitochondria is about 1 micron and of ribosome is about 23 micron

* The diameter of :- sucrose molecule =1nm.
glucose molecule = 0.6 nm
inorganic ions in their hydrated form in order of 0.5 – 1.0 nm.

* minute size of the inorganic ions in comparison with various cell organelles.

Cell membrane (plasmslema)

* biological membrane consist of protein and lipid molecules in approximately equal proportion and about 7 to 10 nm thick.
* cell membrane structure :

according to Singer(1972) biological membrane consist of amphiphilic molecules, which means presence of

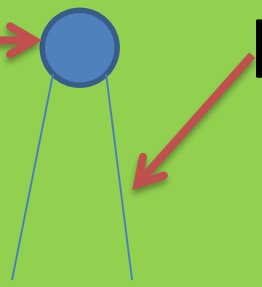
-hydrophilic group as OH groups, NH_2 groups, phosphate groups, carboxylic group.

- hydrophobic groups (hydrocarbon chain)

* lipids and protein may thus be bound by electro-static bonds, H bonds, and by hydrophobic bonds.

* biological membrane consists mainly of a lipidic double layer of amphiphilic lipids, a typical molecule unit of which consist of :

hydrophilic head (phosphate amino complex) carries +or – charge under physiological PH condition



lipidic tails(hydro-carbon chains)

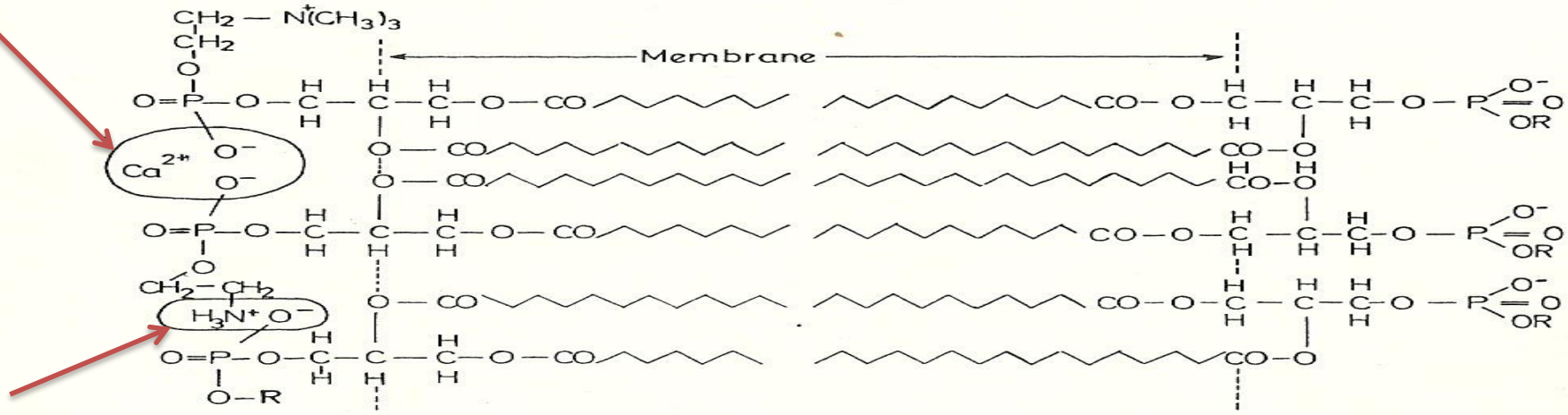


Fig. 3.2 Schematic representation of a membrane bilayer.

- The negatively charged phosphate group may bind cat ions, which probably influence the lipid conformation and membrane permeability
- the Ca is of particular importance for maintain of membrane stability as it may bridge two negative charge phosphate groups(Fig.3.2)

- in the double layer the tails are orientated toward each other(fig.3.2).

- the bilayer is not symmetrical so that different types of lipids occur in the upper and lower layer.

(structural and transport enzyme proteins) 40% lipids and 5% carbohydrates.

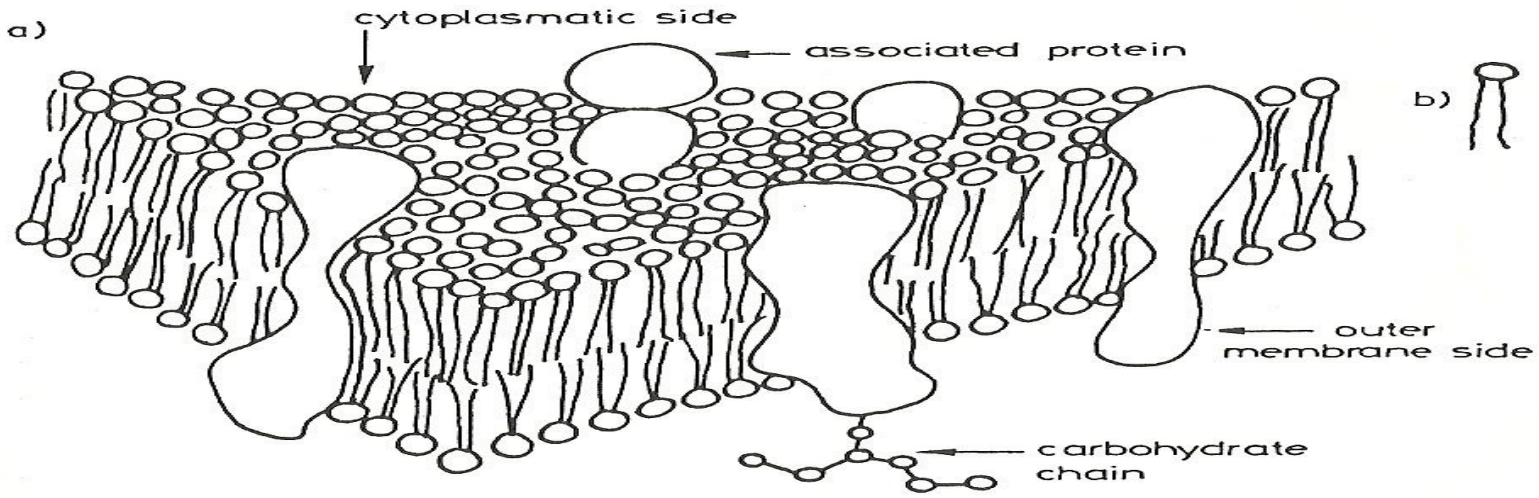


Fig. 3.3 a) Membrane section
b) Symbol for a membrane lipid molecule

- proteins are embedded within the bilayer and these generally protrude from both sides of the membrane. Protein within membrane is of hydrophobic nature, whereas the protein moieties which project out of membrane are hydropholic.
- protein orientated into cytoplasm generally bind additional protein(associated protein)and protein projected out of the cell are generally associated with carbohydrates (fig.3.3).

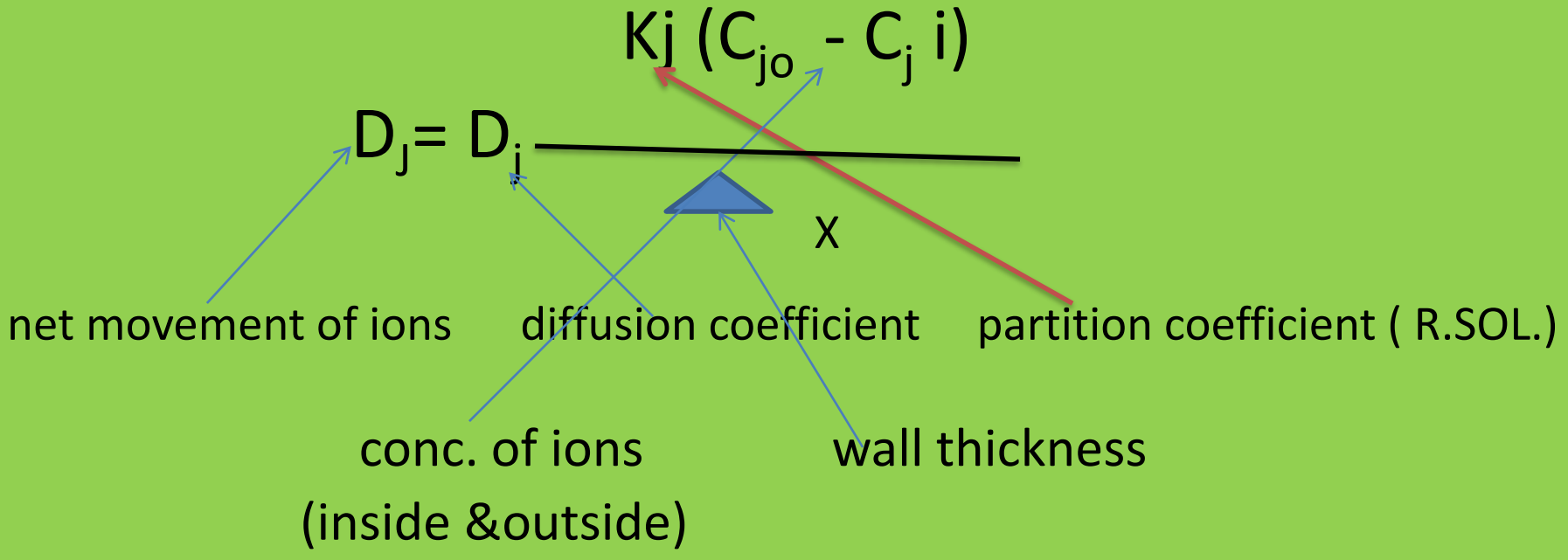
* composition of membrane:-
    - about 55% protein(structural& transport enzyme proteins)
    - about 40% lipids
    - about 5% carbohydrates.
* proteins which extend through membrane form "protein channels" from one side to another which hydrophilic molecules as water and inorganic ions pass through the membrane.
* the most important lipids of membranes are
    -phoshpolipids
    - steroids
    - glcolipid

* In acid medium Ca^{2+} is replaced by H^{+} and this bond is broken thus drastically increasing the permeability of the membrane.
* biological membranes are not completely impermeable. They may allow the diffusion of of hydrophilic ions and molecules. The degree of permeability depends on :
  - components which make up the membrane.
  - enzymes present in the membrane.

Membrane Permeability

How easily something can diffuse through the membrane?

* diffusion across the membrane fellows Ficks' law



$$J_j = p_j (C_j^O - C_j^I)$$

P= permeability coefficient

P_j ↑ ⟶ membrane is permeable

P_J ↓ ⟶ membrane is impermeable

pj depends on ions and nature of membranes

* Factors affect membrane permeability

conc. of Ca & H of the adjacent medium

a- H increases membrane permeability

b- Ca is required for maintaining membrane integrity : - bridges two phosphate groups in the membrane lipids.

- satisfies anionic sites of the membrane proteins.

- the influence of Ca is at the outer boundary between nutrient sol. and the plasm-alemma and not the metabolism of the cell.

-the Ca conc. of the nutrient solution needed for adequate normal permeability of cell membranes is rather low (about 10^{-4} M). This is considerably below the level of Ca^{+} in soil solution.

- Ca is necessary to for ions discrimination in roots. Ions compete with each other in absorption:

k^{+} vs. Rb^{+}

Ca^{+2} vs. Sr^{+2}

Cl^{-} vs. Br^{-}

$So_4^{=}$ vs. $SeO_4^{=}$

* Electrochemical potential

- passive movement of ions through membrane depends on the prevailing electrochemical gradient across the membrane and may take place in either direction.

*development of electro potential

a- passive mechanisms

i- passive: unequal diffusion of ions cross the membrane (+vs.-ion)

(no ATPs needed)

E =-37mv

ii- passive (some metabolism related)

- Donon equilibrium can develop unequal ions distribution. It is developed when:
  - > the charges are bound to the inside the membrane.
  - > when protein molecules floating in cell solution and negative charges are not diffused through membrane (fixed charge on protein).

b- active mechanisms: direct mechanisms for using ATP to generate potential cross membrane.

It is generally accepted that in plant cells membrane bond ATPase and, especially the ATPase of the plasmalemma, is responsible for the negative charge of the cell. A hypothetical scheme showing the possible mechanism of an ATPase as follow

scheme showing the possible mechanism of an ATPase is shown in Figure 3.9.

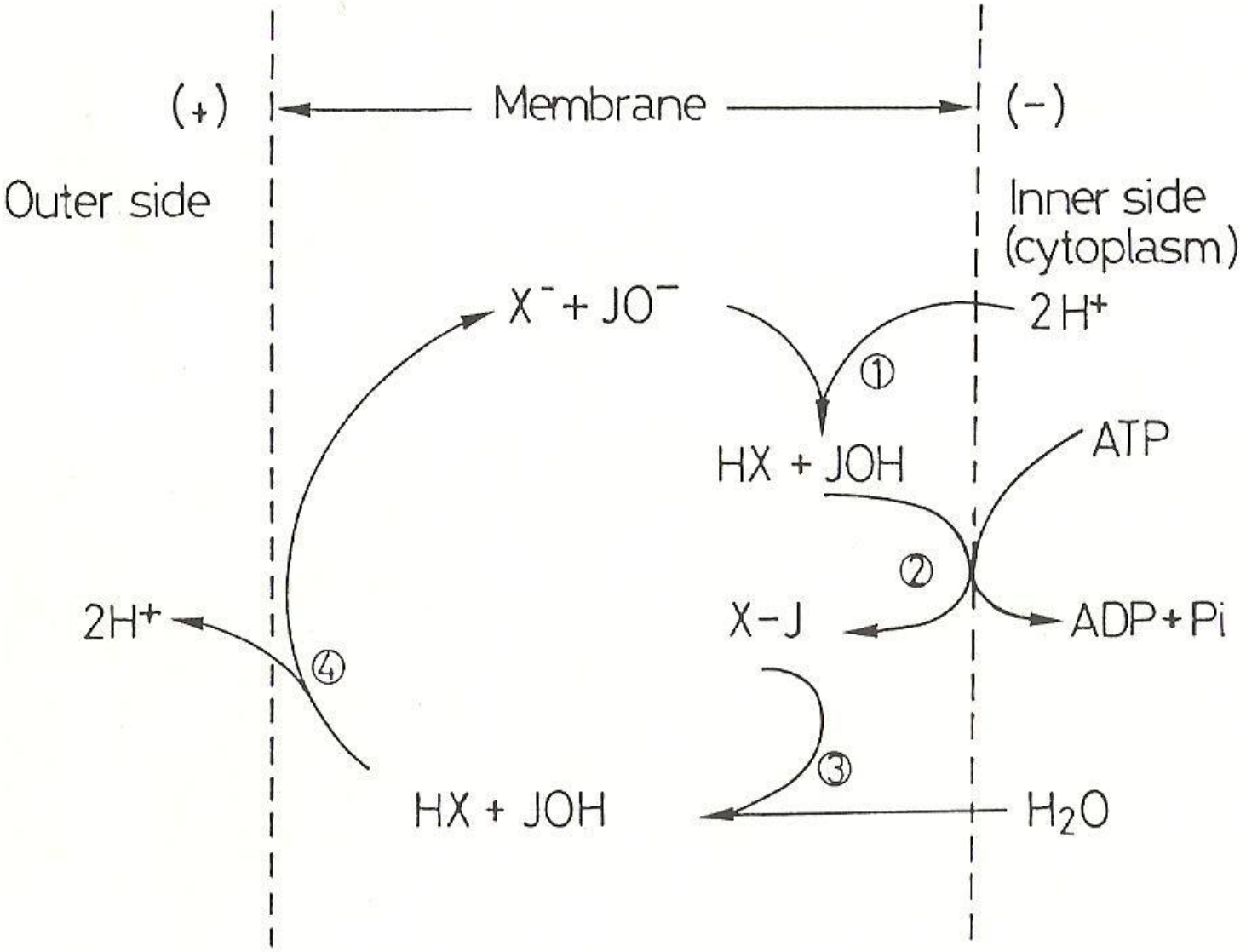


Fig. 3.9 Hypothetical scheme of an H^+ pump (ATPase) pumping $2H^+$ per 1 ATP out of the cell.

* Ion transport through membrane L5

ions in solution subject to :

chemical potential gradient

ions move from higher conc. to lower conc.

electrical potential gradient

ions attracted to opposite charge

so, ion movement depend on electrochemical potential

ions movement through membrane could be

a- passive

b- active

need ATP to generate potential cross membrane

need ATPs to genrate potential and ion transport cross the membrane

passive uptake (transport)

* movement of ions toward electrochemical pot.
* normally for cations (cytoplasm is negatively charged).
* cations move according to diffusion process, not simple diffusion but facilitated diffusion.
* net inwardly directed movement of cations terminates as soon as the equilibrium between the electrical and kinetic forces is attained between cytoplasm and outside(soil solution)

* equilibrium across membrane is described by Nernst equation. example:

if aqueous sol. of KCl is separated by membrane which permeable to both ion K^+ & Cl^- , state of equilibrium reached when

$$E = \frac{RT}{Z.F} \ln \frac{(K_o)}{(K_i)} = \frac{RT}{Z.F} \ln \frac{(Cl_i)}{(Cl_o)}$$

E=electrical pot.of cytoplasm – electrical pot of sol.

R ⟶ gas constant. T ⟶ absolute temp. Z ⟶ valence

F ⟶ faraday constant I ⟶ conc. of ion inside

o ⟶ conc. of ion out side (soil or nutrient solution)

* from the equation when:
  - E < o (the cell is negatively charge), the term $(K_o^+)/(K_i^o)$ must be <1(this means that under equilibrium conditions an accumulation of K in inner solution.) and the term $(Cl_i^-)/(Cl_o^-)$ must be <1 (Cl conc. out side higher than that of inner solution).

* from thermodynamic standpoint
  - active uptake = transport against an electrico-chemical gradient.
  - passive uptake = transport down or along electrochemical gradient

* in order to test, whether an ion has been moved actively or passively,

- the conc. of ion outer medium and in the cell must be measured, then calculate E value (E_{cal}) from Nernst eq.

$$E = \frac{RT}{Z.F} \log \frac{[k_o]}{[K_l]}$$

$$\frac{RT}{F} = (+,-)58$$

- electropotential between cell and outer media must be measured (E_m). Then

$$E_d = E_m - E_{cal}$$

for cations :

if E_d = negative value → passive uptake

positive value → active uptake

for anions

if E_d = negative value → active uptake

positive value → passive uptake

* in general :

anions → active uptake

cations → passive uptake

for K

at low conc. → active uptake

at high conc. → passive uptake

Relationship between uptake and ion conc. In the nutrient solution

* The rate at which an ion species is absorbed is dependent on its conc. In nutrient medium.
* the relation is not linear but follow an asymptotic curve (zero order Rx. & 1st order Rx.).

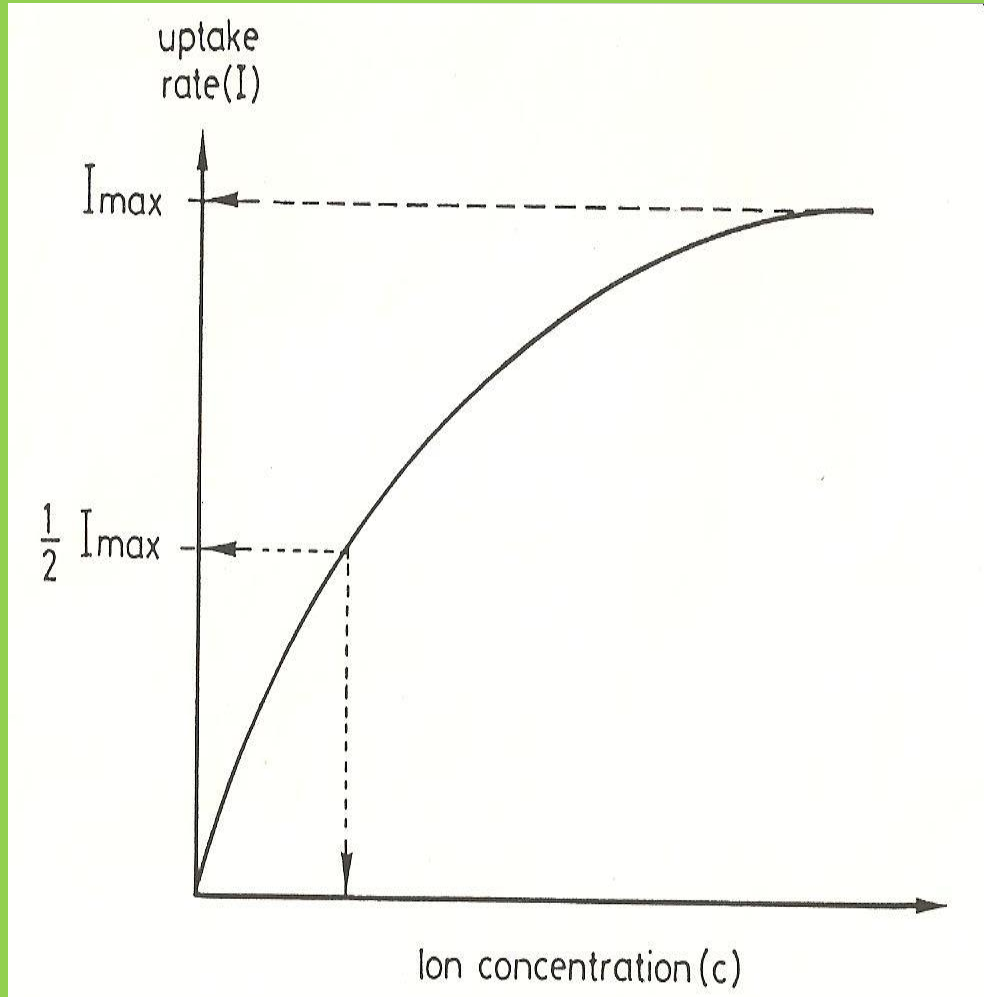
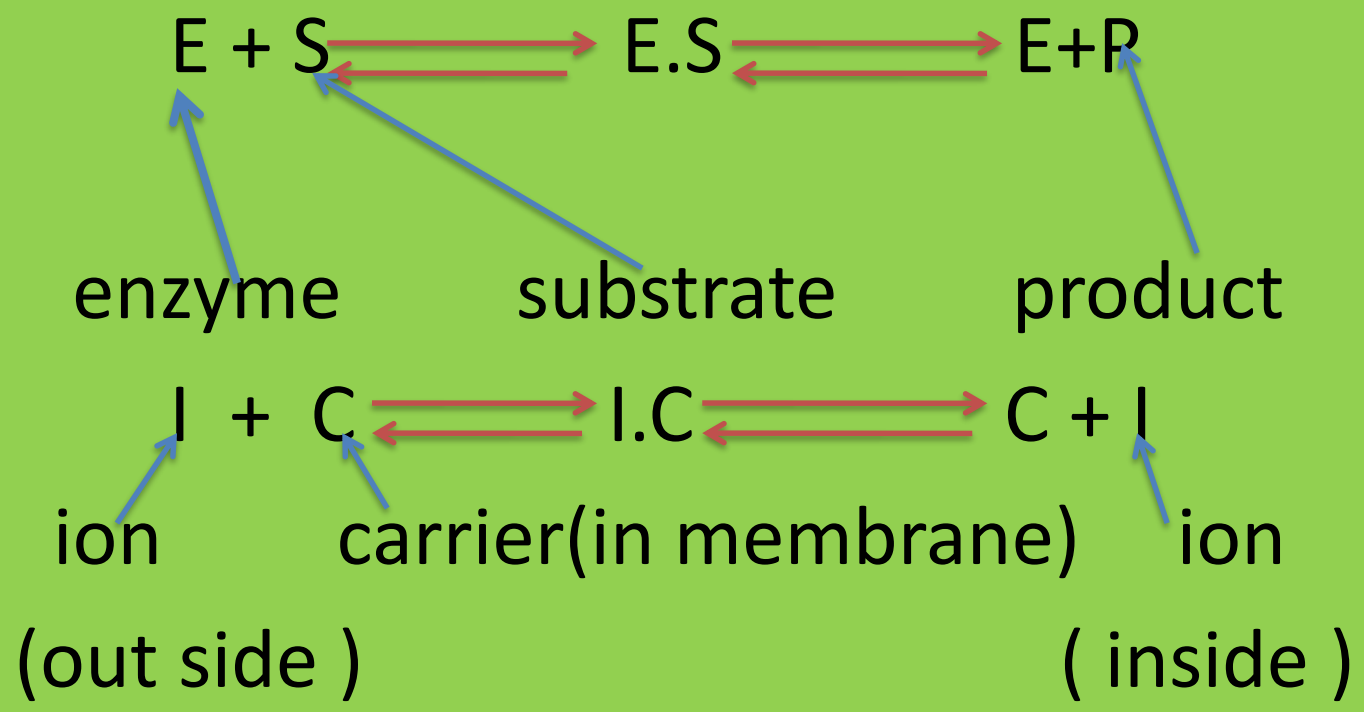


Fig. 3.15 Relationship between the ion concentration and the rate of uptake.

* Epstein and Hagen (1952) have linked the process of carrier mediated transport of an ion across a membrane to the enzyme catalysis of a substrate.

* Michaelis – Menten kinetic have therefore been applied to the ion uptake process.



mathematical model of nutrient uptake

$$I_n = \frac{I_{max} \cdot C}{K_M + C}$$

I_n: influx of ion

I_{max}: max. influx

C: conc. of ion at root surface

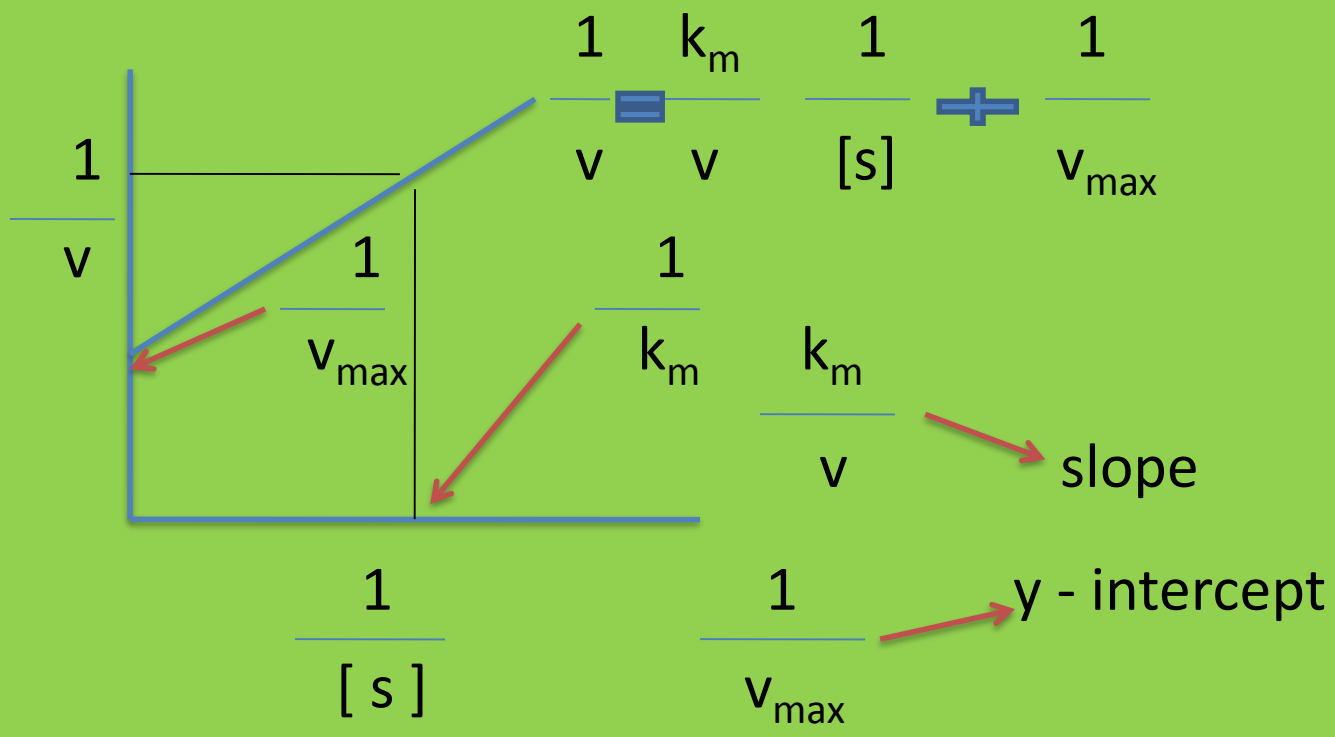
K_M: Michaelis constant = conc. at which up-take= ½ of max.

k_m ~~10~~ ⟶ 90% of max. uptake

k_m ~~10^{-1}~~ ⟶ 10% of max. uptake

Linear transformation of Michaelis- Menten equation

- lineweaver-Burk plot



Influx characteristics of intact 18 day old maize growing in solution culture

Nutrient	V_{max} pMol,cm^{-1} S^{-1}	K_M (Um)
NO_3^-	1.0	12
$H_2 PO_4^{--}$	0.4	3
K^+	17	2

The dual pattern of ion transport X

* ion uptake at low conc.
  follow Michaelis- Menten
  (all carrier sites are
  occupied , so no more
  ions can cross the cell
  membrane)
* at conc. up to 0.20 mM up
  take follows Mich-Men. ,
  at higher conc. the up take
  exceeds the theoretical max.
  predicted (dished line)
* soil sol., usually at range 1.

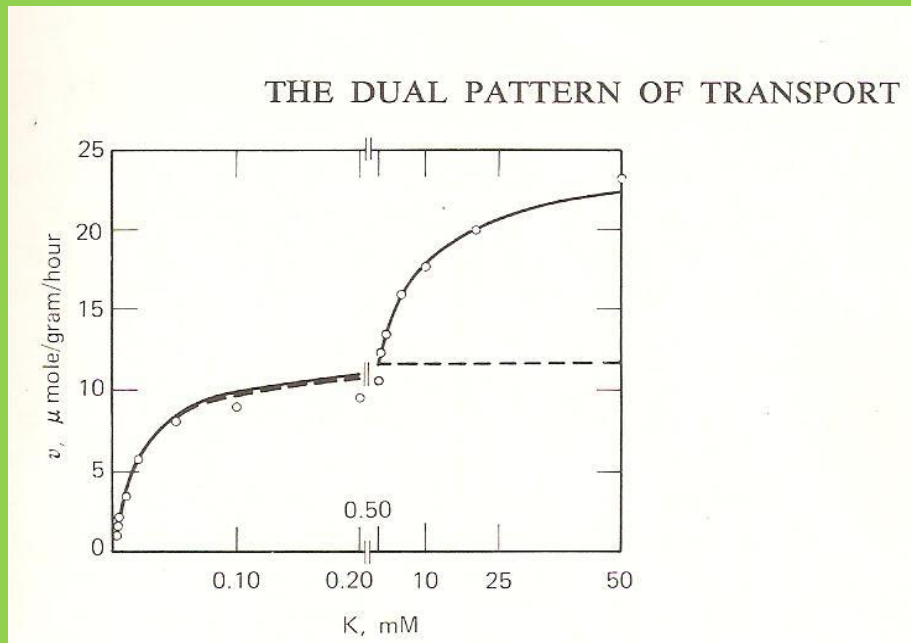


Figure 6-15. Rate, v, of absorption of potassium by barley roots as a function of the concentration of KCl in the solution. Concentration of $CaCl_2$, 0.5 mM. The horizontal (concentration) scale is broken between 0.20 and 0.50 mM. The solid line at the low concentrations, continued by the dashed line, is a plot of the Michaelis–Menten equation. K_m = 0.021 mM; V_{max} = 11.9 μmole/g fresh weight/hour. After Epstein *et al.* (1963).

* It is apparent, therefore, there is more than a single mechanisms of ion absorption.

there are two mechanisms of ion uptake:

- at low conc. mech.1 works, at high conc. mech. 2 works.
- mechanisms 2 has lower affinity for an ion that mech.1 with no selectivity for ions.
- locations of mechanisms
  - i- ranges 1 &2 on plasm-llema
  - ii- range 1 in the plasmalem-ma and range 2 is in tonplast

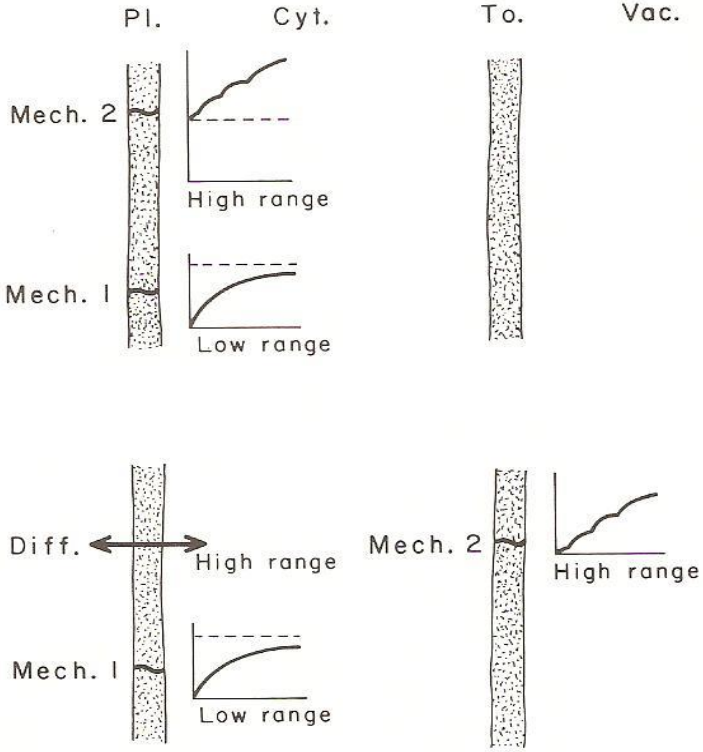


Figure 6-17. Diagrammatic representation of the parallel (top) and series (bottom) models of operation of the two types of ion transport mechanisms. The wavy lines in the membranes represent ion transport mechanisms. Pl., plasmalemma; Cyt., cytoplasm; To., tonoplast; Vac., vacuole; Diff., diffusion. According to the parallel model (top), rates of absorption from an external solution furnish no direct evidence concerning transport at the tonoplast.

How ions transport through membrane? I6

* Ionophores(facilited diffusion) and carriers(ATP_{ase})

- It is now generally accepted that biological membrane contains molecules called ionophores which play a crucial role in the transport of ions cross the membrane.
- organic molecules with M.W. in the range of 200-2000 which are capable of forming lipid soluble complex with polar cations.
-

well known naturally occurring ionophore :

a- Valinomycine:

- The ring is made up of three sequences each consisting of residual of lactate, valine, isohydroxy valeriate, and valine.
- The lipophilic groups are orientated to outer medium which makes the lipid soluble and mobile within the membrane.

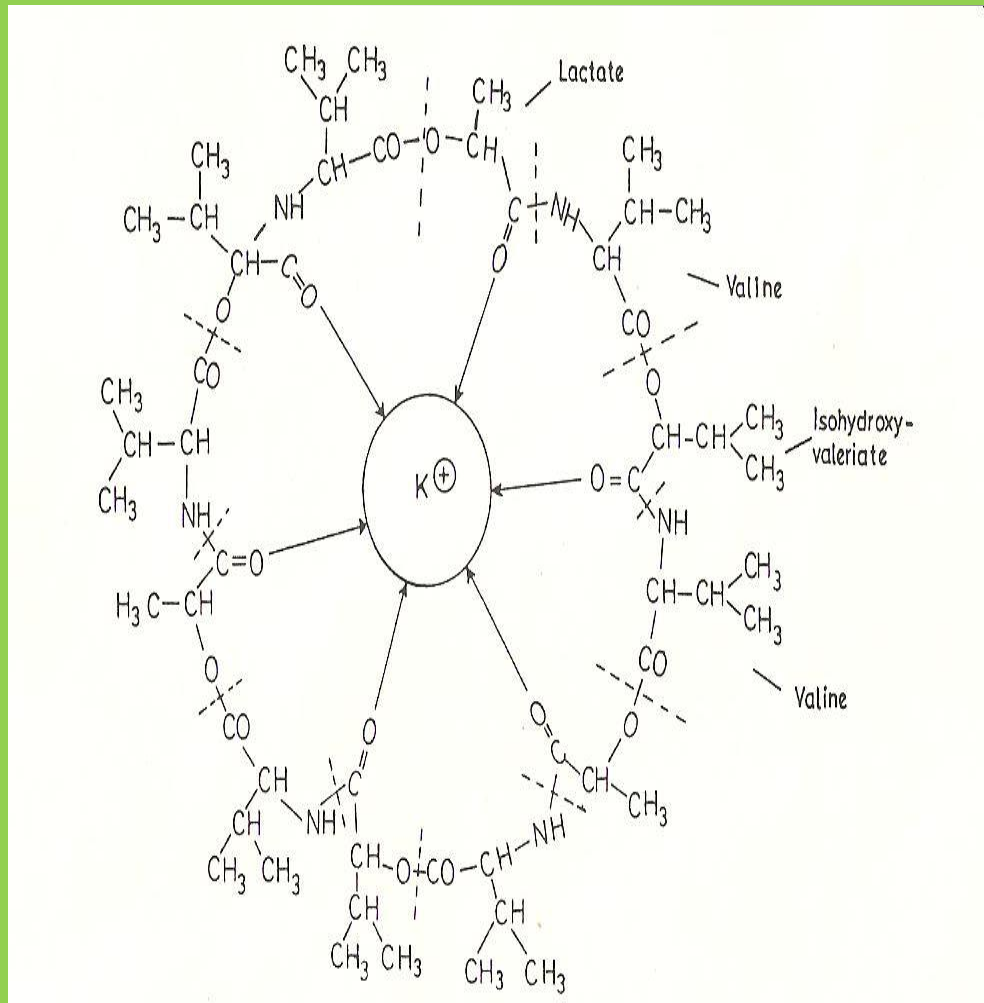


Fig. 3.4 Structure of the valinomycin K^+ complex. The molecule consisting of three sequences of lactate-valine-isohydroxyvaleriate and valine.

b- Nonactin

It is acyclic ester ,the nonatin- K^+ complex is described as a ball with a lipophilic exterior resulting from methyel group, the K^+ located at the center of the ball being surrounded by 8 oxygen atoms

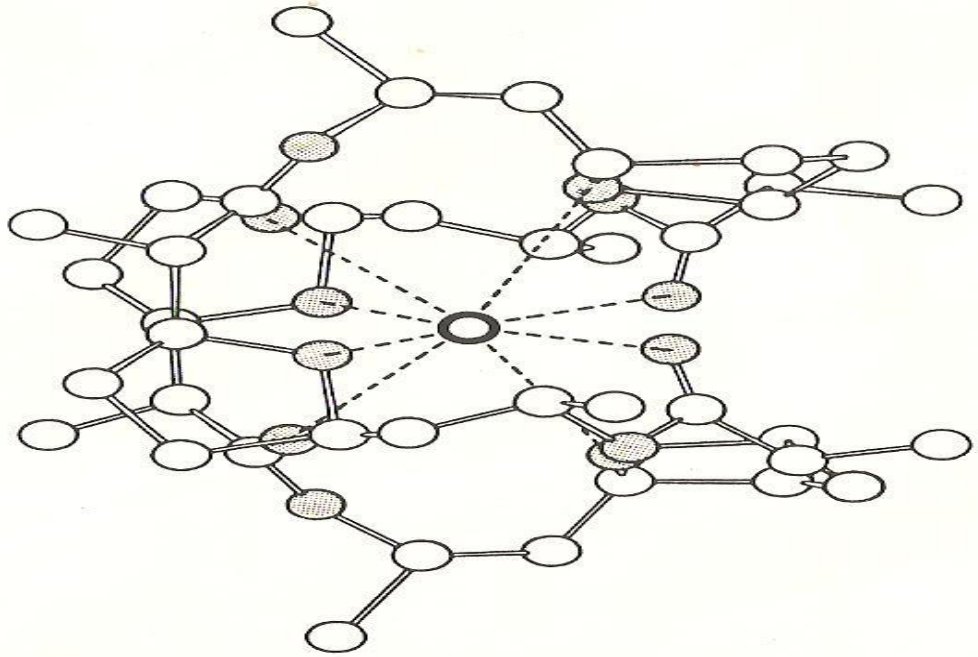


Fig. 3.5 The nonactin-K^+ complex. Carbon atoms are represented by open circles, oxygen by shaded circles and K^+ by the heavy circle (after KILBOURN *et al.* [1967]).

c- gramicidin A

It is a molecule which consist of 15 hydrophobic amino acids forming a spiral. Two gramicidin A molecules can form a tunnel of about 4 nm through the membrane allowing the selective passage of cation.

d- Enniatin

It is a K transporter. Two molecules of cyclic that are connected together with K in between.

* The tendency of cations to form complex with ionophore depends on hydration energy of the cations .

- as the hydration energy decrease , the tendency to form complex increase .
- crucial difference between K^+ and Na^+

Na has hydration energy of 400 kj mol^-

k has hydration energy of 315 kj mol^-

Hence, the selectivity of valinomycine for k is about 10,000 times greater than for Na.

Table 3.1 Ionophores and their important characteristics (after PRESSMAN [1976]).

	Mol. Weight	Selectivity	K/Na selectivity
Valinomycin	1110	$K^+ > NH_4^+ > Na^+$	17000
Enniatin	639	$K^+ > Na^+ > Ca^{2+} > Mg^{2+}$	2.8
Nonactin	736	$NH_4^+ > K^+ > Na^+$	16
Nigericin	724	$K^+ > Na^+$	45
X 537 A	590	$K^+ > Na^+ > Ca^{2+} > Mg^{2+}$	3.0
Gramicidin A	1700	$H^+ > NH_4^+ > K^+ > Na^+$	

Ionophores such as valinomycine and enniatin may function as carrier in transporting cations across membrane.

- ionophores are very specific for particular cation.
- the direction of transport follows the electrochemical gradient.

p. 130) so that efflux as well as influx can be mediated by carrier

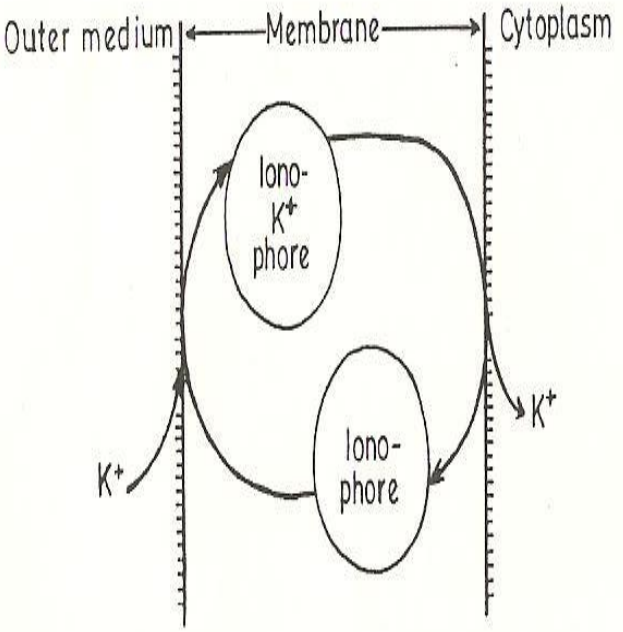


Fig. 3.6 Carrier transport of K^+ across a membrane mediated by a ionophore.

*Anions uptake :

anions uptake cannot be explained as downhill process, for in this case a negative charge move toward negative charged cell

Hodges(1973) has proposed a hypothetical model to account for both cations & anions uptake

- ATP_{ase} renders the cytoplasm more alkaline, and the cytoplasmic OH^- drives the anion carrier.

pletely clear (POOLE [1978]).

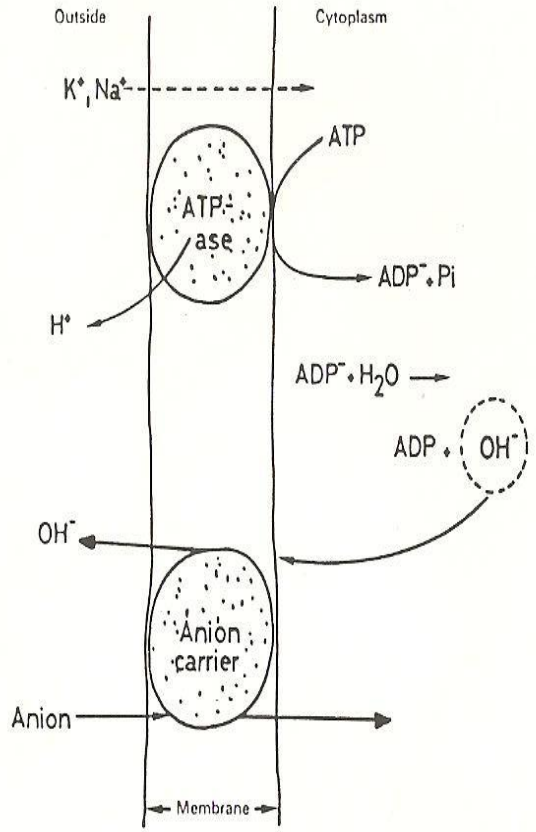


Fig. 3.10 Model of an ATPase driven cation pump coupled with an anion carrier (modified after HODGES [1973]).

* Phloem loading with sucrose

The phloem mechanism proposed by Giaqinta (1977) :

- the H^+ pump(ATP_{ase}) provides an acid medium in the apoplast .
- protonation of a sucrose carrier, which in protonated form cross the plasmallema into the cell.

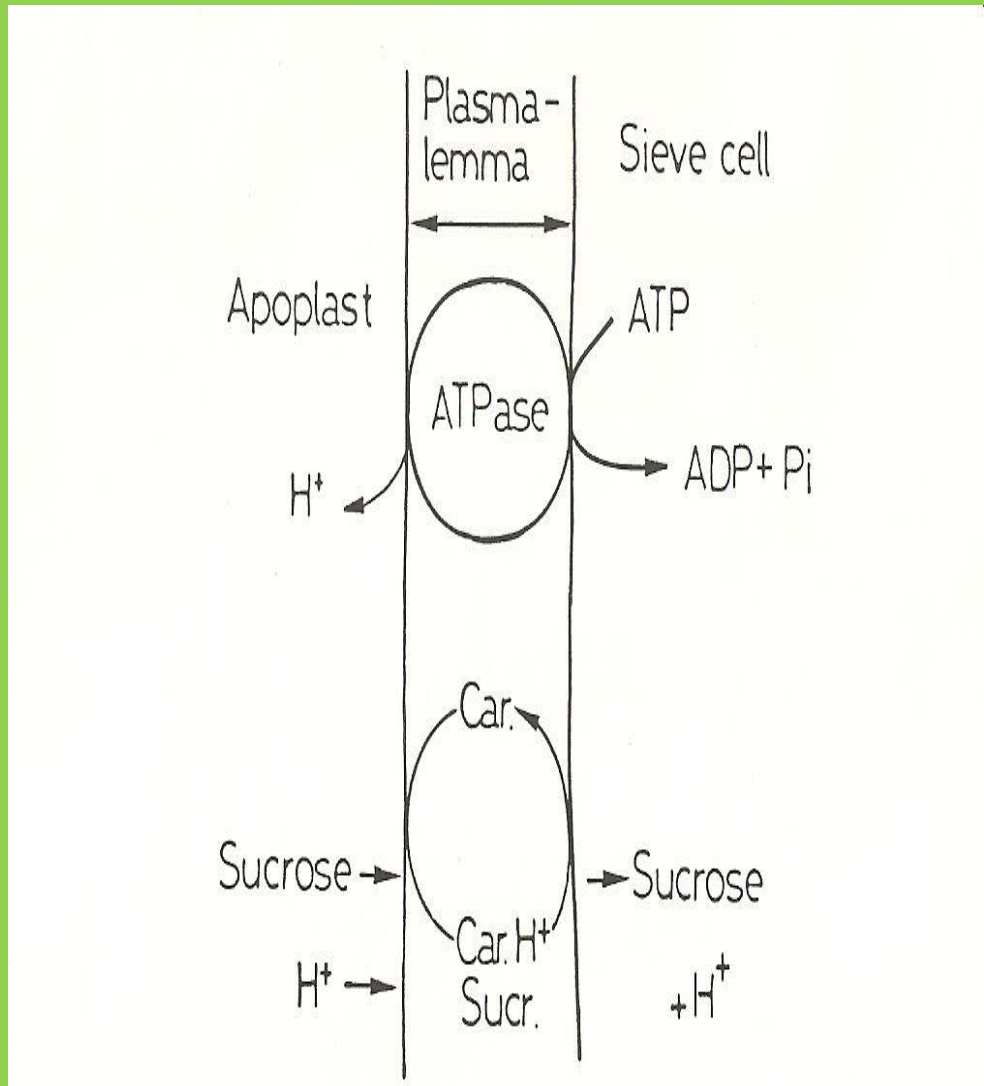


Fig. 3.11 Scheme of proton-sucrose cotransport driven by ATPase.

Movement of ions from external medium into xylem vessels

apoplast pathway :

movement of ion throug cell wall spaces (do not cross the plasmlemma).

symplamic pathway :

ion movement through cells, cytoplasm.

and others such as potassium may decrease in acidic soils.

Roots enrich the soil with organic matter. Some plants transport as much as 60% of the sugar not used by

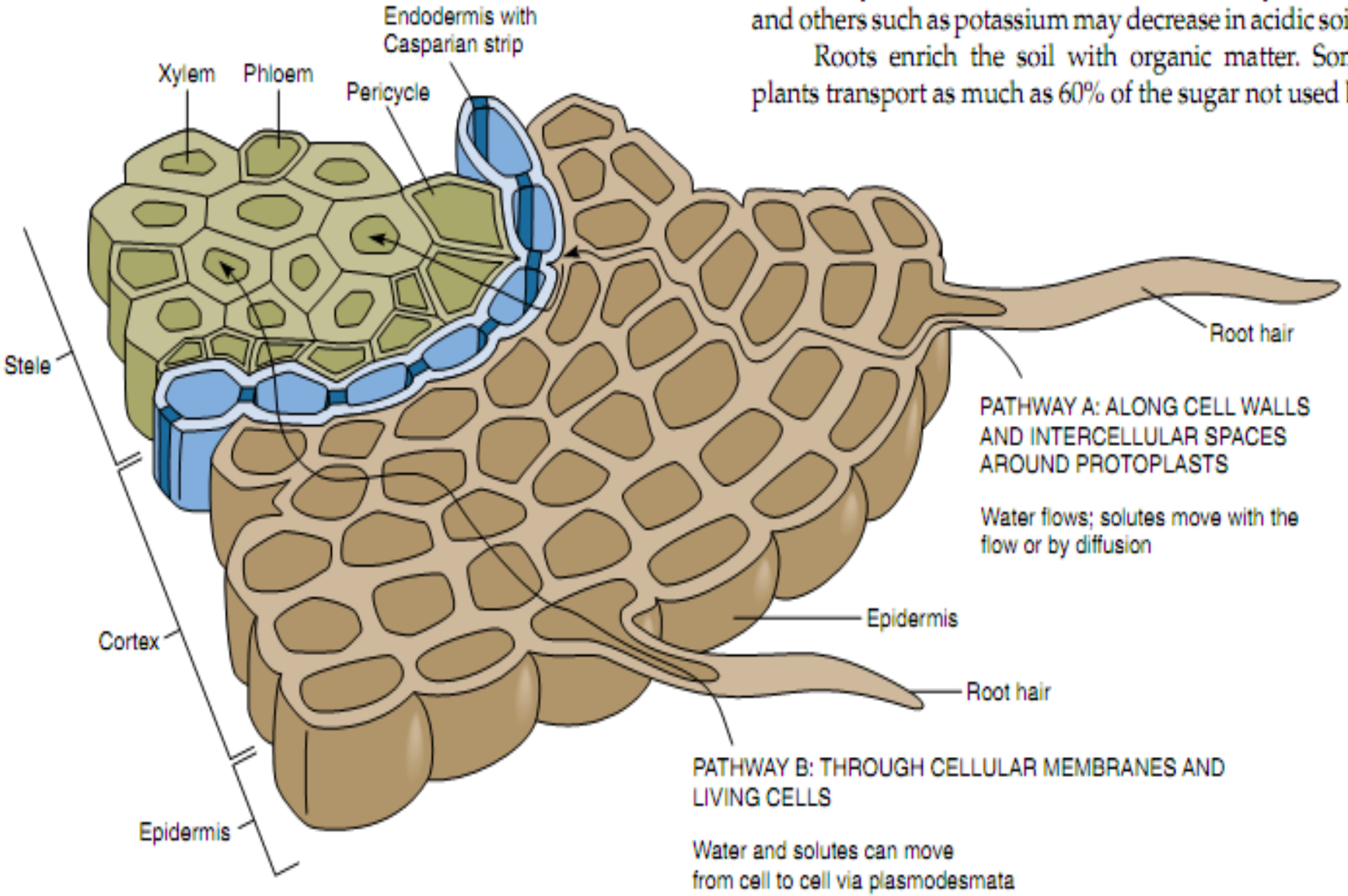
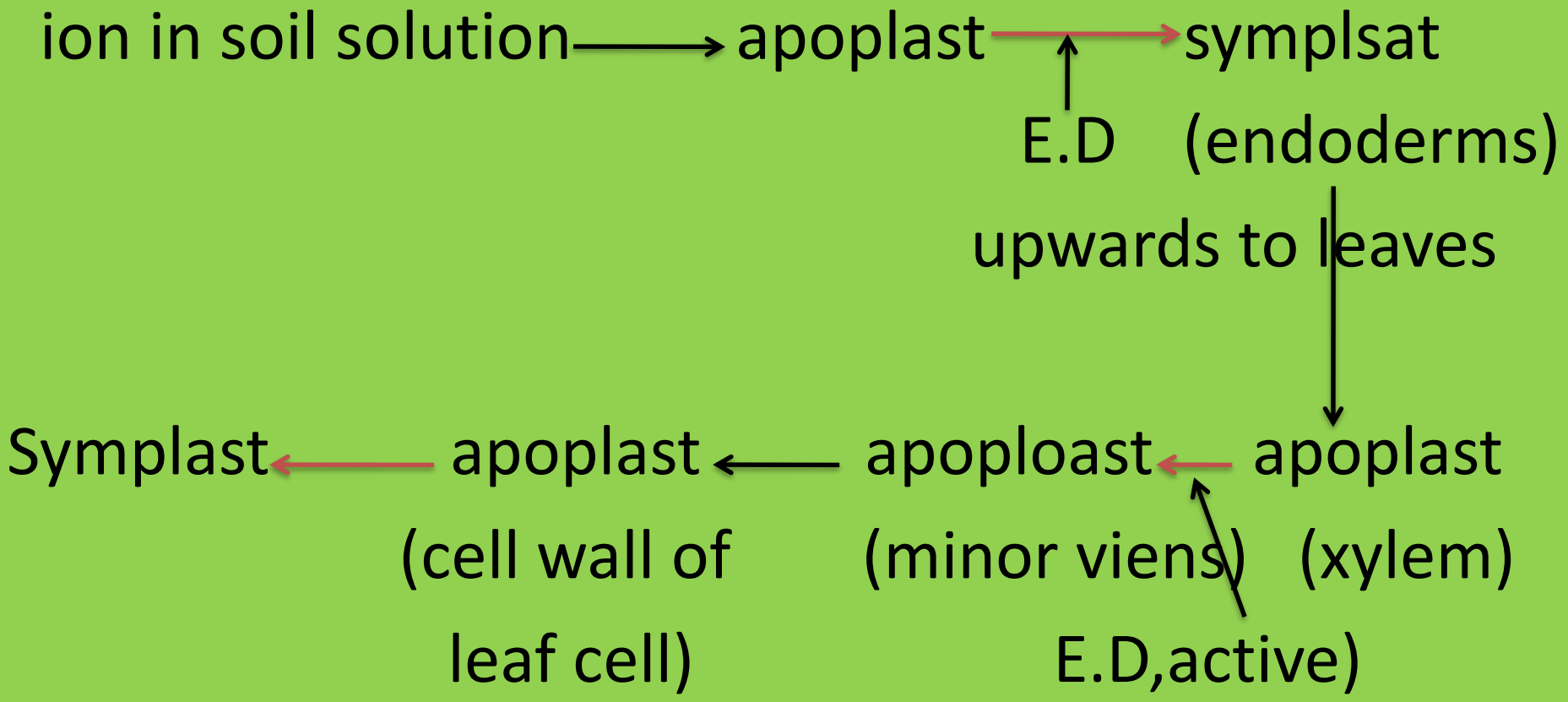


FIGURE 7.10

Pathways show routes water may take as it moves from the soil, through the root, into the stele. Casparian strips in cell walls of the endodermis block off the stele of the root. As a result, water and dissolved minerals enter the stele through the cell membranes of endodermis cells (×100).



* ion movement upward

- root pressure → quttation liquid
- transpiration pull

FIGURE 7.1
Taproot system of dandelion (*Taraxacum*), consisting of a prominent taproot and smaller branch roots.

FIGURE 7.2
Fibrous root system of a grass. Fibrous root systems consist of many similarly sized roots that form extensive networks in the soil.

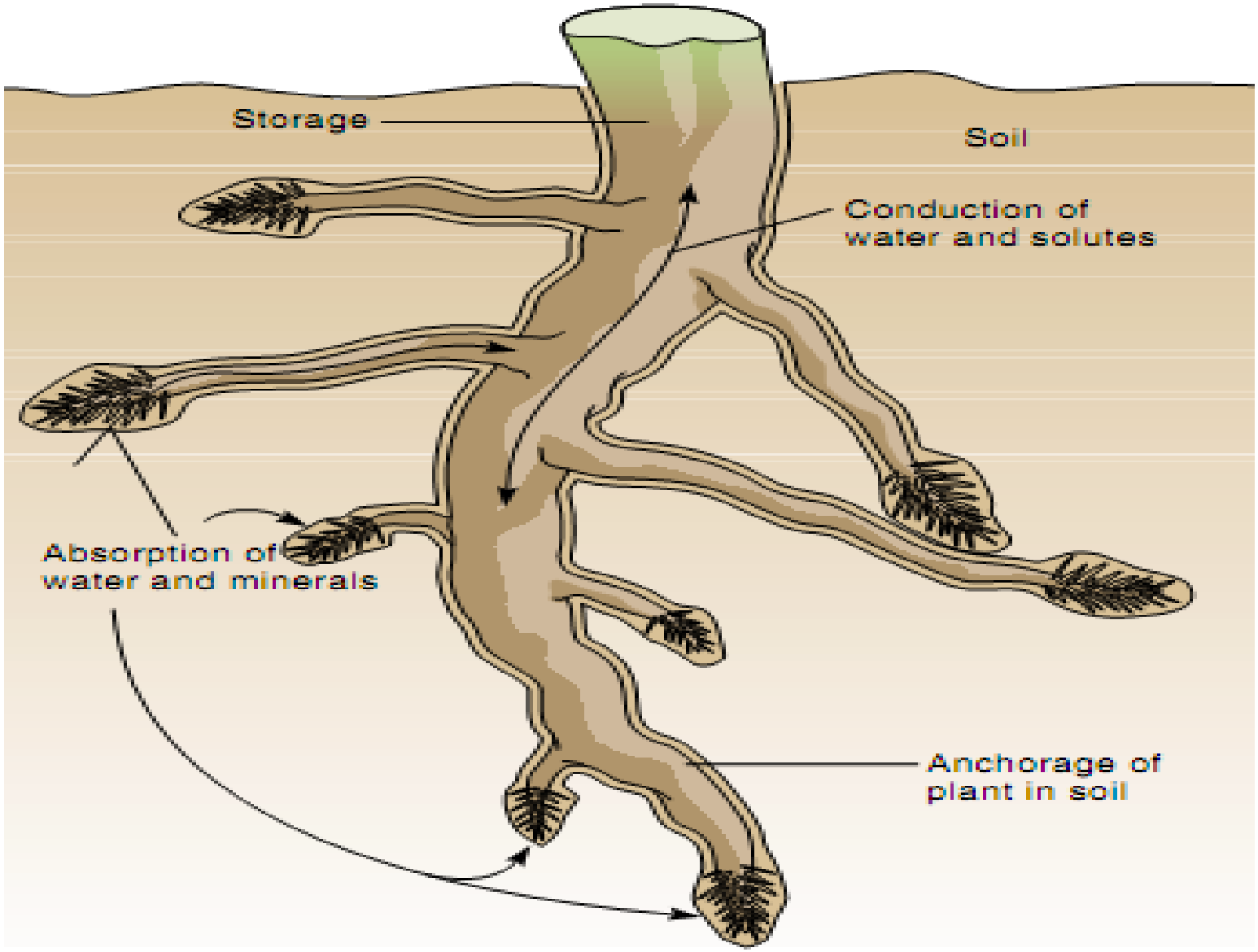


FIGURE 7.13
Diagram summarizing the major functions of roots. The rhizosphere is the narrow zone surrounding the entire root.

and others such as potassium may decrease in acidic soils.

Roots enrich the soil with organic matter. Some plants transport as much as 60% of the sugar not used by

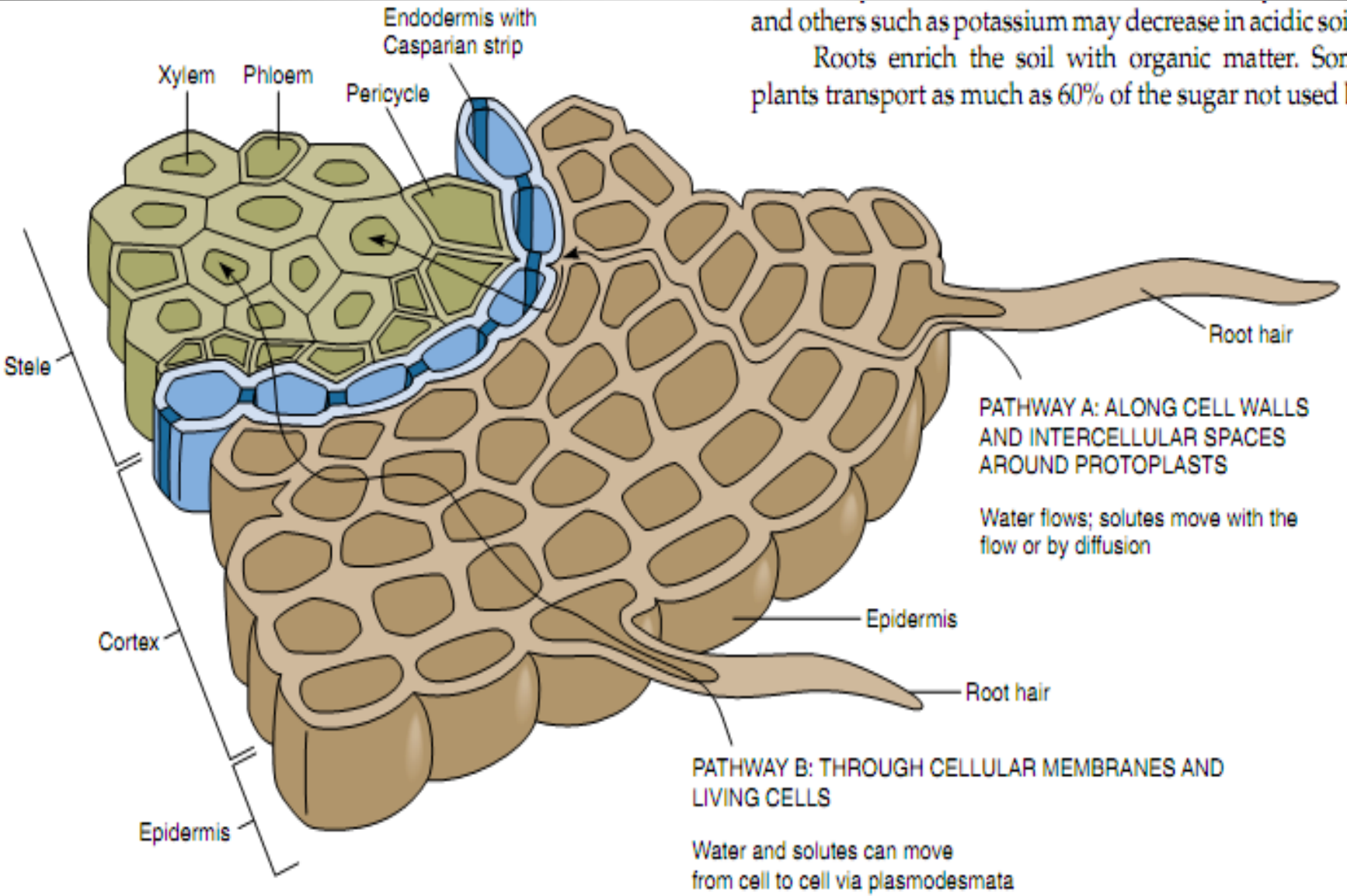


FIGURE 7.10

Pathways show routes water may take as it moves from the soil, through the root, into the stele. Casparian strips in cell walls of the endodermis block off the stele of the root. As a result, water and dissolved minerals enter the stele through the cell membranes of endodermis cells (×100).

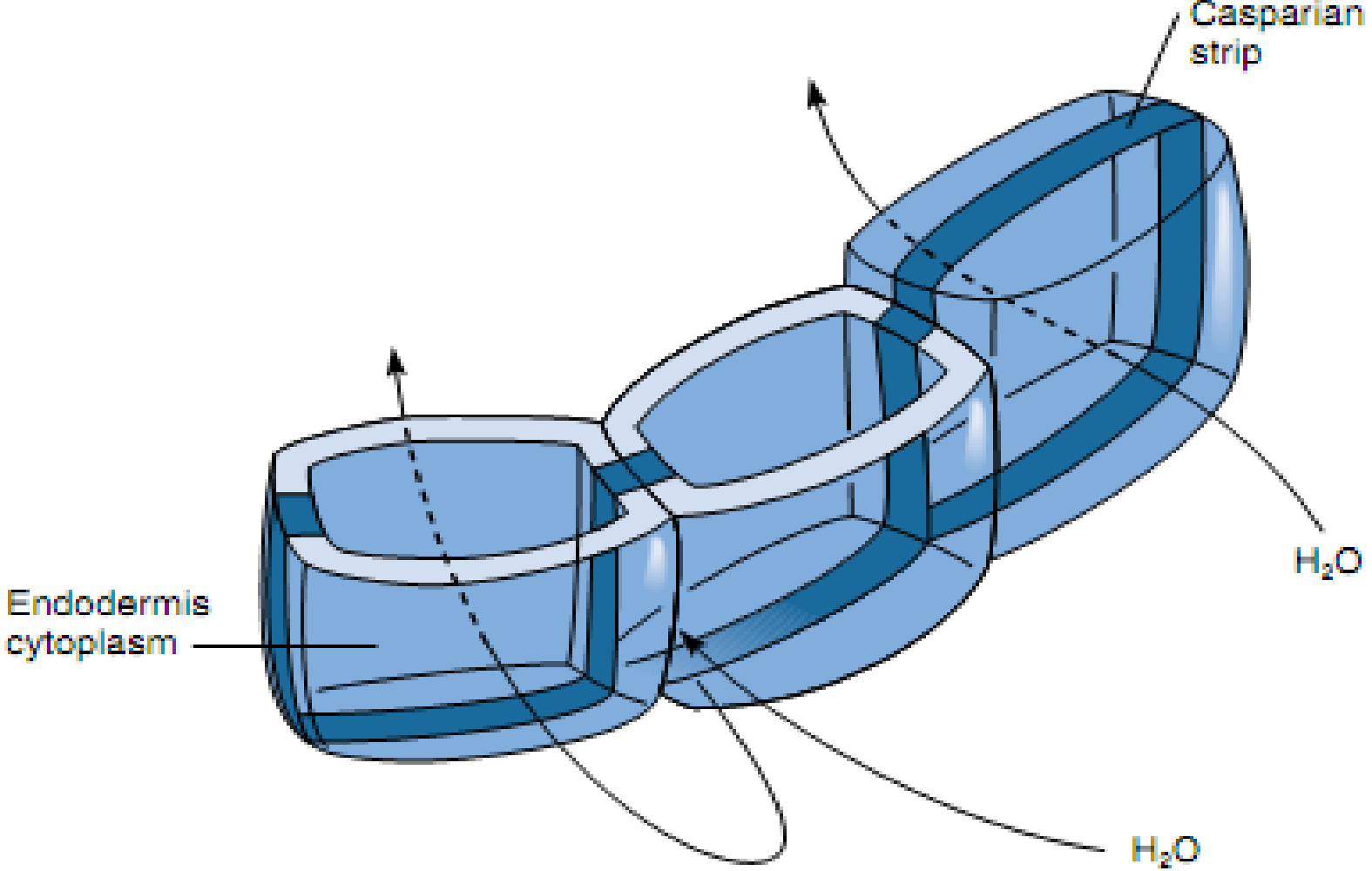
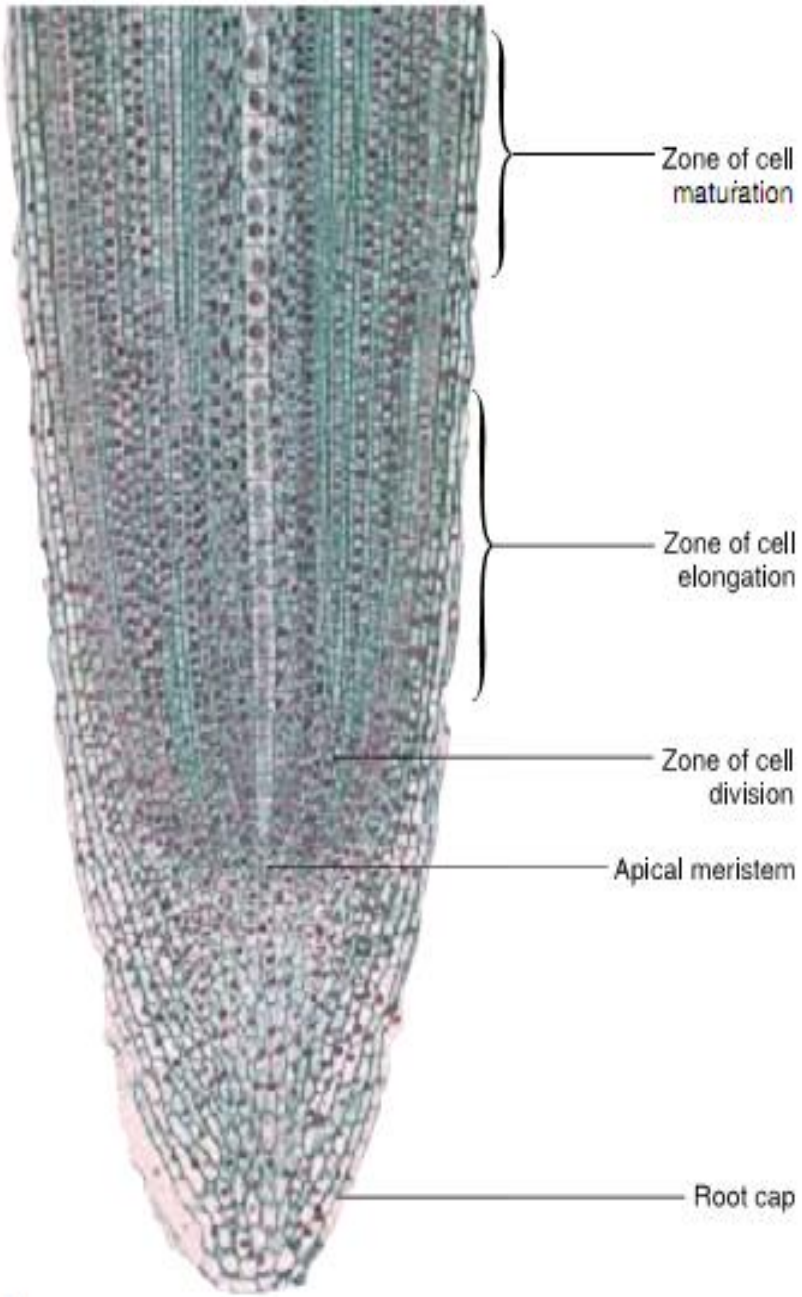
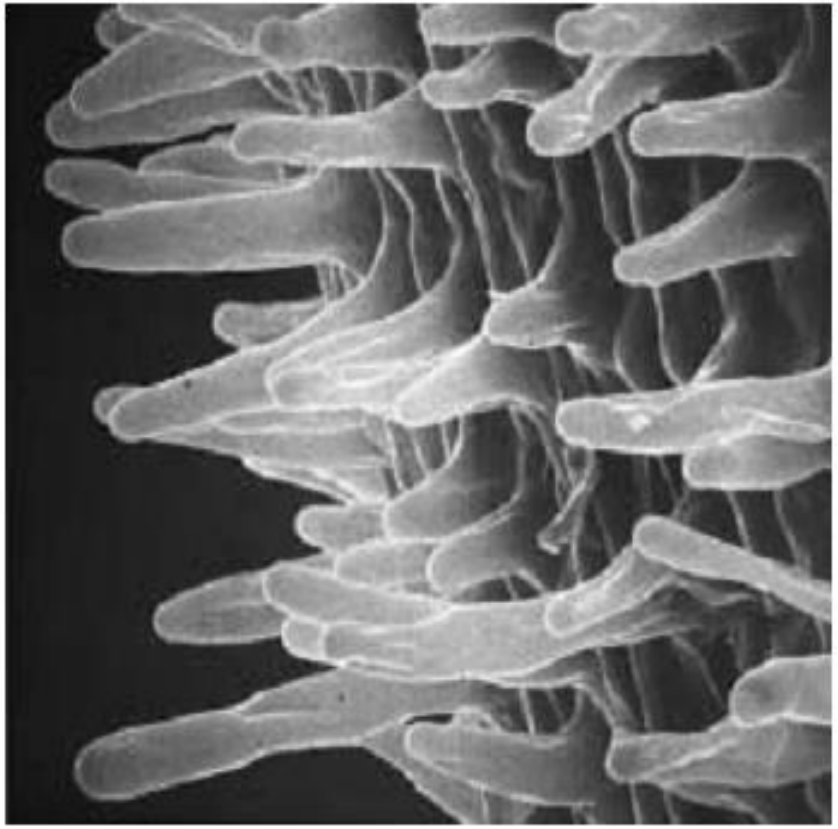


FIGURE 7.9

The Casparian strip of the endodermis blocks the movement of water and dissolved minerals in the cell walls and between cells. As a result, water and dissolved minerals are directed through the cell membrane and protoplast of endodermal cells, where subsequent use and movement are more controlled.



(a)



(b)

FIGURE 7.7

(*a*) The subapical region of roots includes the zone of cell division, zone of cell elongation, and zone of cell maturation. (*b*) Scanning electron micrograph of root hairs in the zone of maturation on a primary root of a radish (*Raphanus sativus*) (×25). Root hairs, which are extensions of epidermal cells, greatly increase the absorptive surface area of the root.

Nitrogen

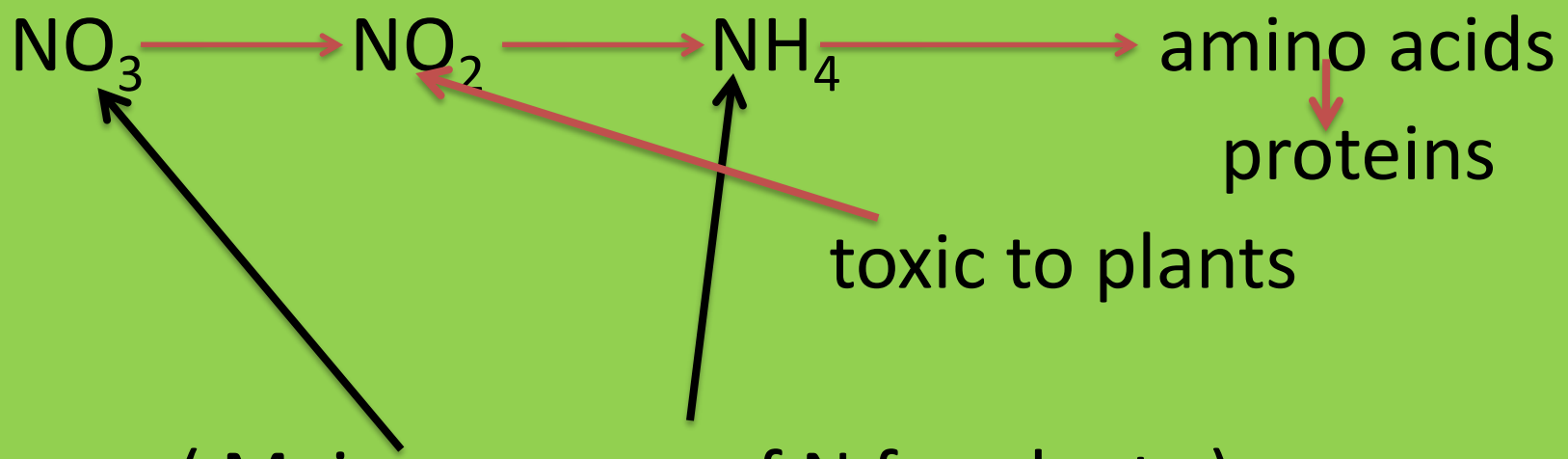
* determination of essentiality

  p.22 in Handbook of plant nutrition

* nitrogen metabolism and nitrogenous compounds in plants

  - some plants compounds have oxidation - reduction state of +7 as in pernitic acid.
  - plant metabolites have oxidation – reduction ranging from +5 to -3
  - biologically important organic molecules in plants include proteins, nucleic acids, purine, pyrimdines, and coenzymes(vitamins) among many other compounds.

*Nitrogen assimilation



(Major sources of N for plants)

- requires large input of energy
- form toxic intermediates
- mediated by specialized enzymes that are closely regulated
- does not have to start at the beginning

* Nitrate reduction (NO_3^- ⟶ NO_2^-)

$$NO_3^- + NAD(P)H + H + 2e \xrightarrow{N.R} 2NO_2^- + NAD(P)^+ + H_2O$$

$$+ \; H_2O \longrightarrow HNO_2^- + OH^-$$

from p.s.

- enzyme nitrate reeducates
- cytoplasmic reaction
- form highly toxic nitrite
- N.R. required Mo as a cofactor
- HNO_2^- moves to chloroplast

* Nitrate reductase (N.R)

$$NADH \xrightarrow{2e} FAD \longrightarrow Heme(Fe) \longrightarrow MoCo$$

$$NADH \xrightarrow{2e} FAD \longrightarrow Heme\ (\ Fe) \longrightarrow MoCo$$

- Homodimer(two identical subunits)
- principle Mo – containing protein
- enzyme activated by light, carbohydrate, and other environmental factors
- inducible enzyme
- favored high PH condition
- high NH_4 & a.a decrease N.R. activity

* Nitrite reduction L7

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

- chloroplastic Rx.
- requires more e^- and reducing power
- form toxic ammonium
- mediated by nitrite reductase
- energy for producing the reducing potential is provided by glycolysis and respiration

green tissue

non green tissue

* the assimilation of nitrate is an energy – counsm - process, it needs 15 mole of ATP for each mol. of nitrate reduced. The assimilation of NH_4 required an additional 5 ATP per mole.
* factors effect nitrate reduction :

- ↓ Mo ⟶ ↑ NO_3 accumlation ⟶ ↓ a.a

- ↓ Mn ⟶ ↓ in p.s.1 ⟶ ↓ In e flow ⟶ ↓ NO_3 reduction

* site of nitrate reduction

- roots and shoots are capable of nitrate metabolism, and the proportion of nitrate reduced in roots or shoots depends on plant species and age, nitrogen supply, temp., and environmental factors.
- in tomato : 80-90 % of N in xylem sap is form of NO_3 . Hence, NO_3^- reduction must take place in leaves.
- most plants , are able to reduce NO_3 in roots and upper plant parts.

* ammonia assimilation (NH_4^+ ⟶ amino acids) X

- metabolizes the toxic ammonia produced by nitrogen assimilation and photorespiration
- utilized a number of different pathways that allow for :

i- metabolic flexibility

ii- interaction with carbon metabolism

- occurs in the chloroplast or mitochondria

Ammonia assimilation pathways : a-via GS-GOGAT (major route)

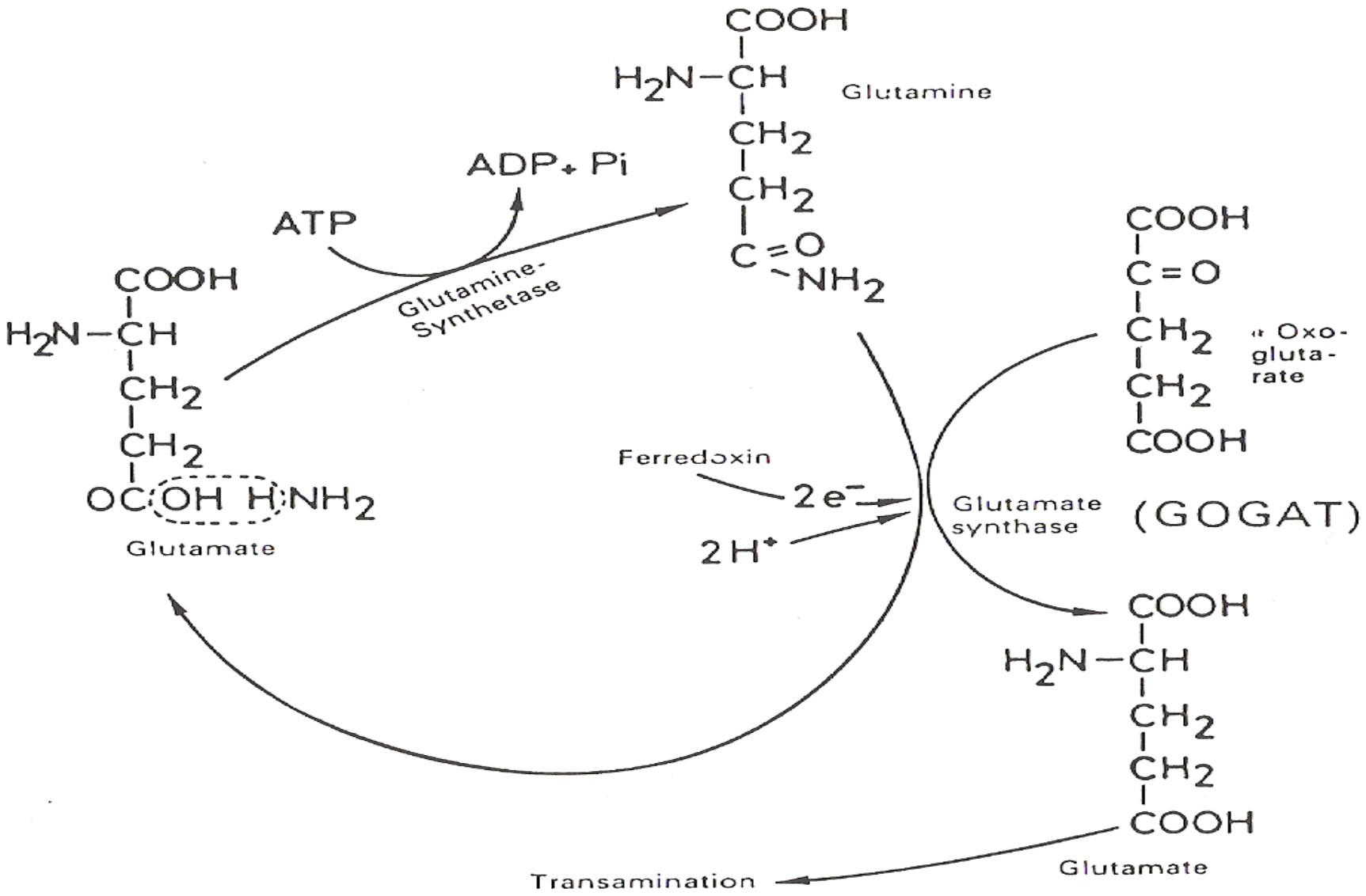
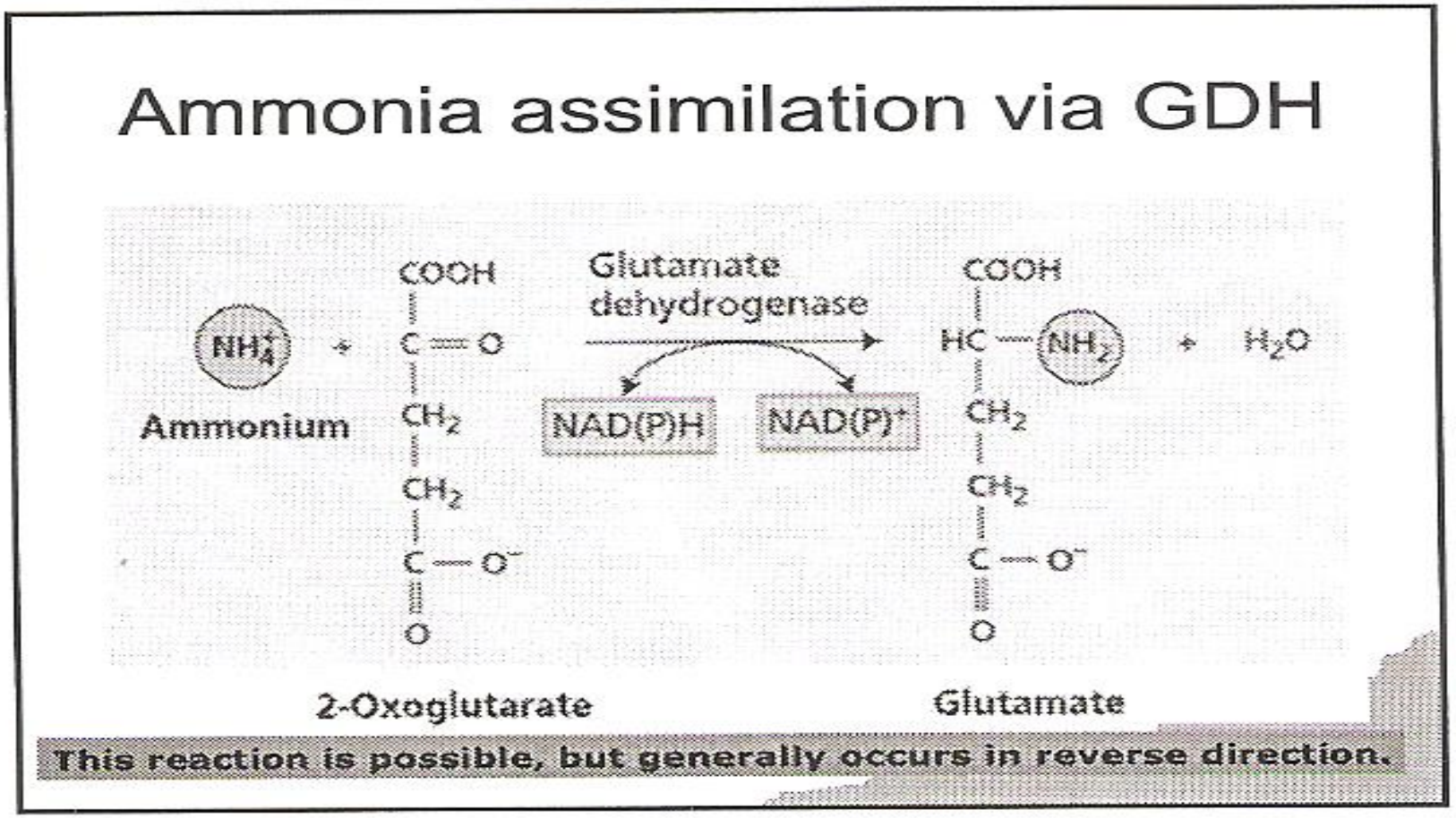


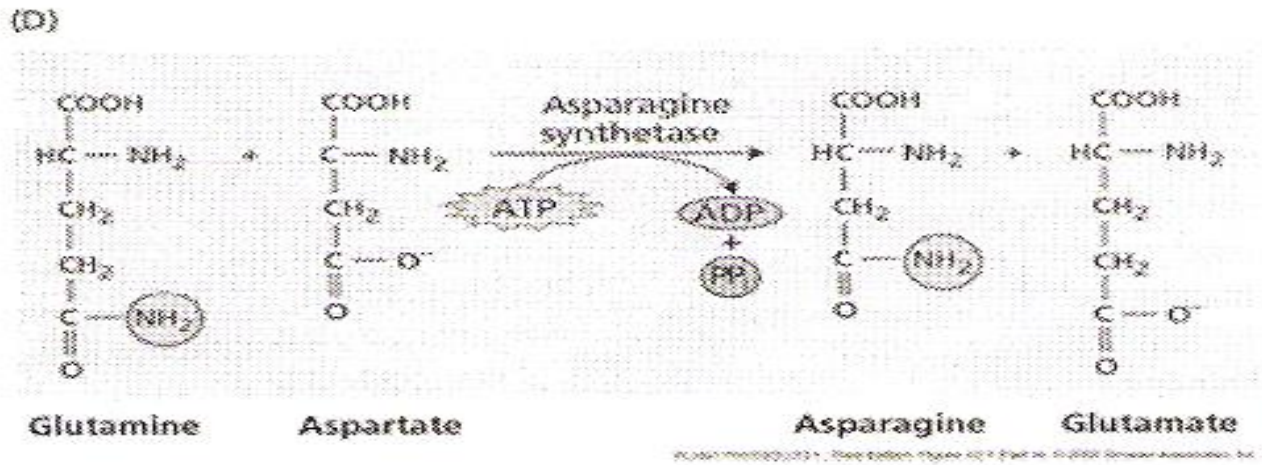
Fig. 3.32 Reaction schemes of glutamine synthetase and glutamate synthase.

b- via GDH


Ammonia assimilation via GDH
Glutamate dehydrogenase
NAD(P)H
NAD(P)+
Ammonium
2-Oxoglutarate
Glutamate
This reaction is possible, but generally occurs in reverse direction.

c- Asparagins synthesis via AS

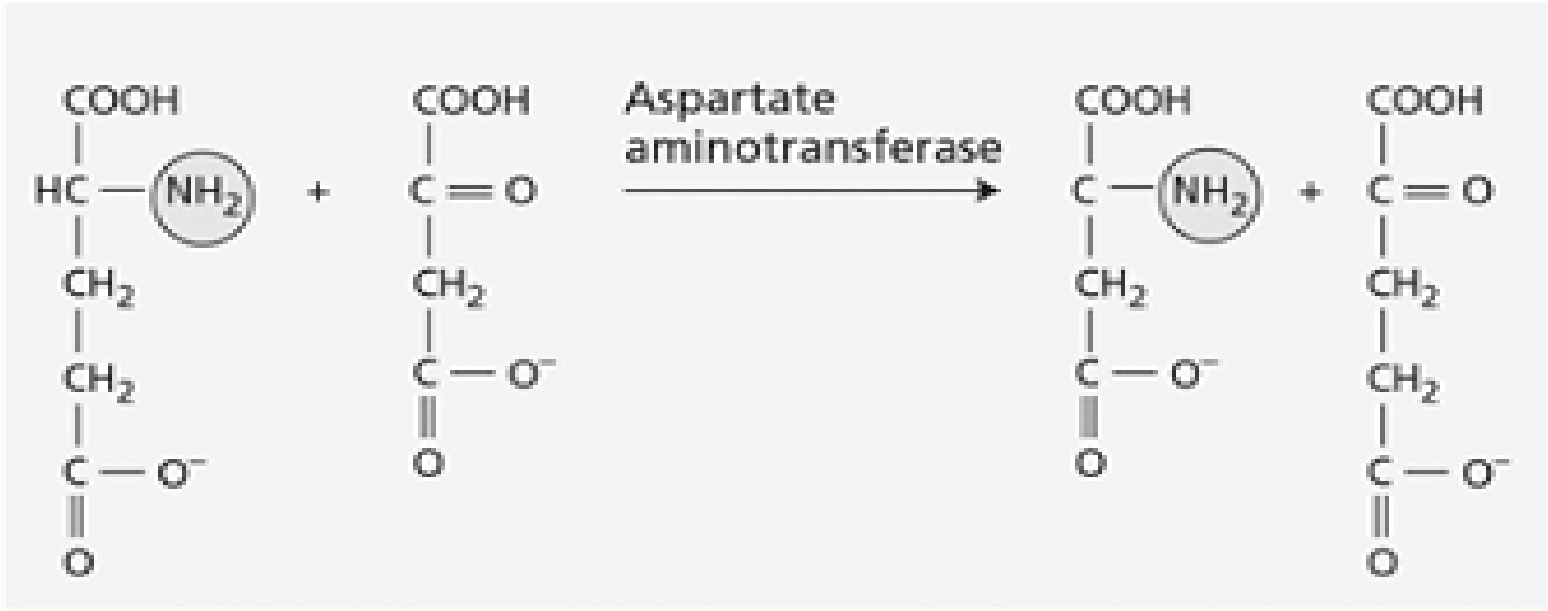
Asparagine synthesis via AS



- Forms important link between C and N metabolism
- High light and CHO's favor GS-GOGAT activity
- Low light and CHO's favor AS activity

Transamination reactions (e.g., AAT)

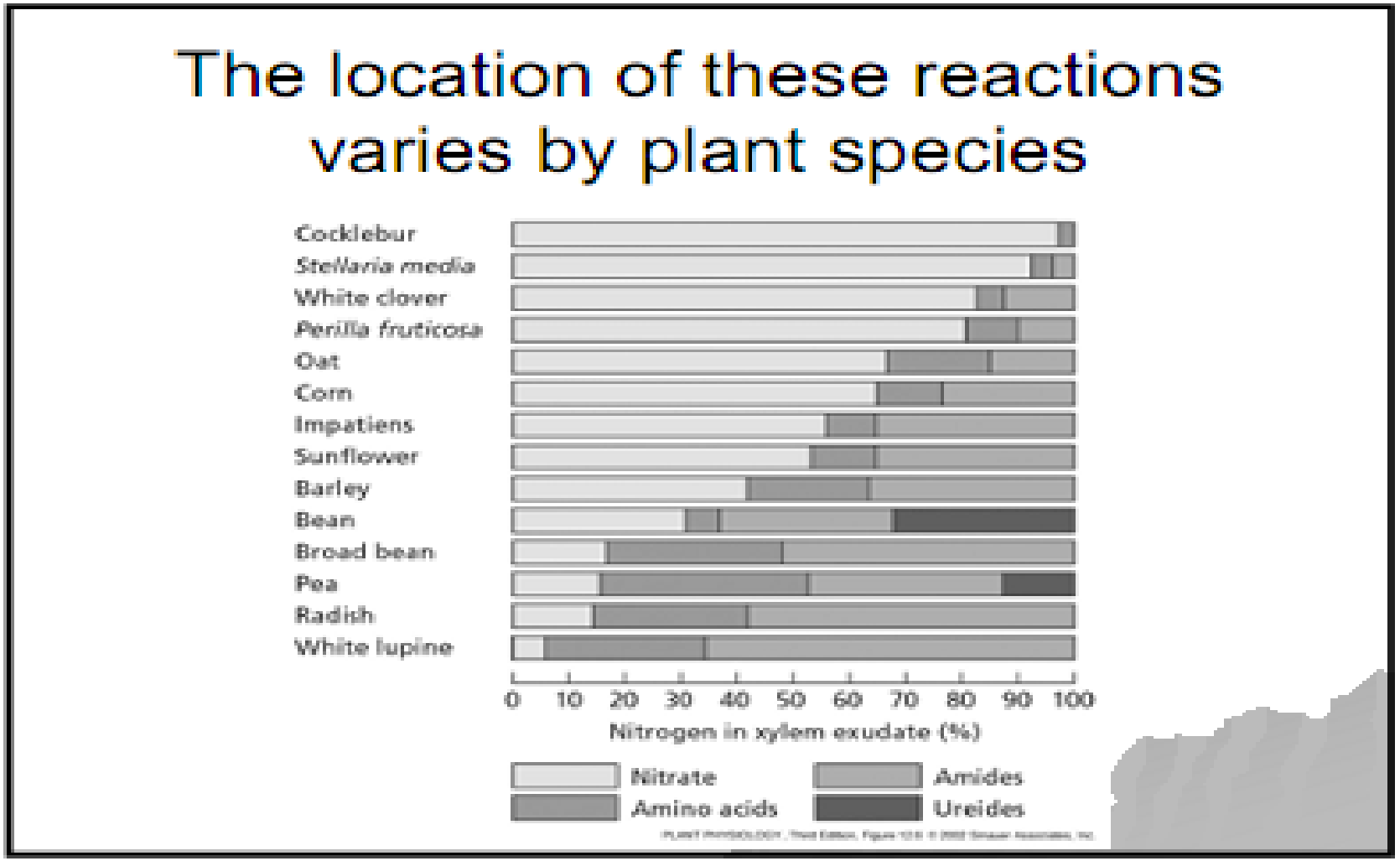
Transamination reactions (e.g., AAT)



* The most important NH_2 accepters(oxo acids) of the transamination process and their corresponding a.a.

Oxo acid	*Amino acid*
α-oxoglutarate	glutamate
oxaloacetate	aspartate
glyoxylate	glycine
pyruvate	alanine
hydroxy pyruvate	serine
glutamate γ-semialdehyde	ornithine
succinate semialdehyde	γ-amino-butyrate
α-keto β-hydroxy-butyrate	threonine

The location of N- assimilation varies by plant species



Protein and other nitrogenous compounds

- Unlike animals plants do not eliminate nitrogen from their bodies but reuse N from the cycling of proteins and other nitrogenous constituents.
- Nitrogen losses from plants occur mainly by leaching of foliage by rain or mist and by leaf drop .
- Nitrogen in plants is recycled as ammonium.
- Nitrogen rich compounds as (amides, arginine , and others) accumulate as reserves of nitrogen at the oxidation – reduction level of ammonium. These compounds are formed from the catabolism of proteins.

L7

Amino acids are assimilated into proteins or other polypeptides (28). Although plants contain more than 100 amino acids (1,29), only about 20 enter into proteins (Table 2.1). Hydroxyproline may be formed after incorporation of proline into proteins. Cystine is the dimer of cysteine and is formed after incorporation of cysteine into protein. Animal proteins occasionally contain amino acids other than those listed in Table 2.1.

TABLE 2.1
Amino Acids Occurring Regularly in Plant Proteins

Alanine	Glutamic acid	Leucine	Serine
Arginine	Glutamine	Lysine	Threonine
Asparagine	Glycine	Methionine	Tryptophan
Aspartic acid	Histidine	Phenylalanine	Tyrosine
Cysteine	Isoleucine	Proline	Valine

Source: From McKee, H.S., *Nitrogen Metabolism in Plants*, Oxford University Press, London, 1962, pp. 1–18 and Steward, F.C. and Durzan, D.J., in *Plant Physiology: A Treatise. Vol IVA: Metabolism: Organic Nutrition and Nitrogen Metabolism*, Academic Press, New York, 1965, pp. 379–686.

TABLE 2.2

Approximate Fractions and Common Ranges of Concentrations of Nitrogen-Containing Compounds in Plants

Compound	Fraction of Total Nitrogen (%)	Concentration (µg/g Dry Weight)
Proteins	85	10,000 to 40,000
Nucleic acids	5	1000 to 3000
Soluble organic	<5	1000 to 3000
Nitrate	<1	10 to 5000
Ammonium	<0.1	1 to 40

The major portion of nitrogen in plants is in proteins, which contain about 85% of the total nitrogen in plants (Table 2.2). Nucleic acids (DNA, RNA) contain about 5% of the total nitrogen, and 5 to 10% of the total nitrogen is in low-molecular-weight, water-soluble, organic compounds of various kinds (36).

Low molecular weight , water –soluble organic nitrogen compounds

- Are intermediates in the metabolism of nitrogen .
- Some have specific roles in processes of other than intermediary metabolism .
- Amides and amino acids have roles in transport and storage of nitrogen in addition to their occurrence in protein.
- Ureides are prominent in xylem sap and transport nitrogen fixed in root nodules of legumes.
- Amines and polyamines have been assigned roles or have putative roles in the lipid fraction of membranes and involved in plant growth and development.

- Putrescine accumulation in plants may be a physiological response to stress such as the form of nitrogen supplied and the nutrient status of plants.
- Simple nitrogen bases , such as choline, are related to alkaloid in plants and to lipids .
- Analogs of purines and pyrimidines have functions in growth regulation.
- Various amino acids other than those in protein exist in plants :-

  -related to those occurring in protein

  - β- Alanine , homoserine, γ- aminobutric acid are common examples of these a.a.

- Accumulation of a.a . Such as ornithine and citrulline is generally rare in plants , but they may the major soluble nitrogenous constituents of some species.

- Non protein amino acids may be natural products or metabolites, but their functions are generally unclear.

Concentrations of Nitrogen in plants

* Generally the conc. of N in plants reflect the supply of nitrogen in the root medium, and yields increase as internal conc. in plant tissue increases (up to certain extent) .
* Various models have been developed to described the response of plants to nutrient supply and accumulation .

Fig. 2.2 p.28 in handbook of plant nutrition

- zones of concentrations :

C.L. , Deficient , Transition , and Adequate

* concentrations of total N in plant parts

table 2.3 p.29 } in handbook of plant nutrition

table 2.4 p.30 }

Diagnostic and recommendation integrated system (DRIS)

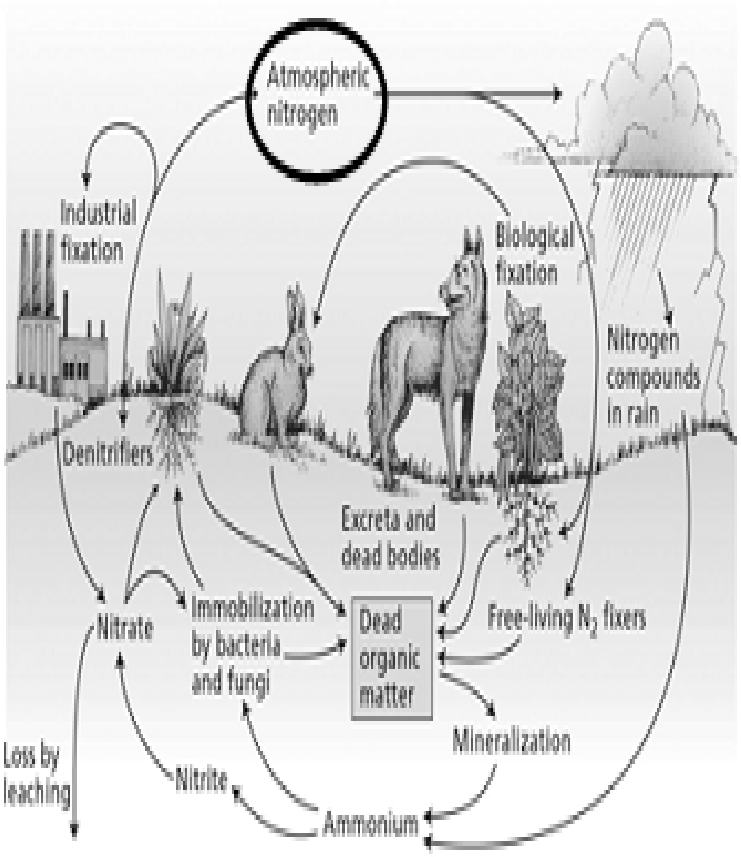
- evaluates nutrient relationship that involve ratios between Paris of nutrient s and evaluates the adequacy of a nutrient in relation to others
- optimum range for DRIS is -15 to +15

< 15 → the element is deficient

>15 → the element is excess

Nitrogen cycle

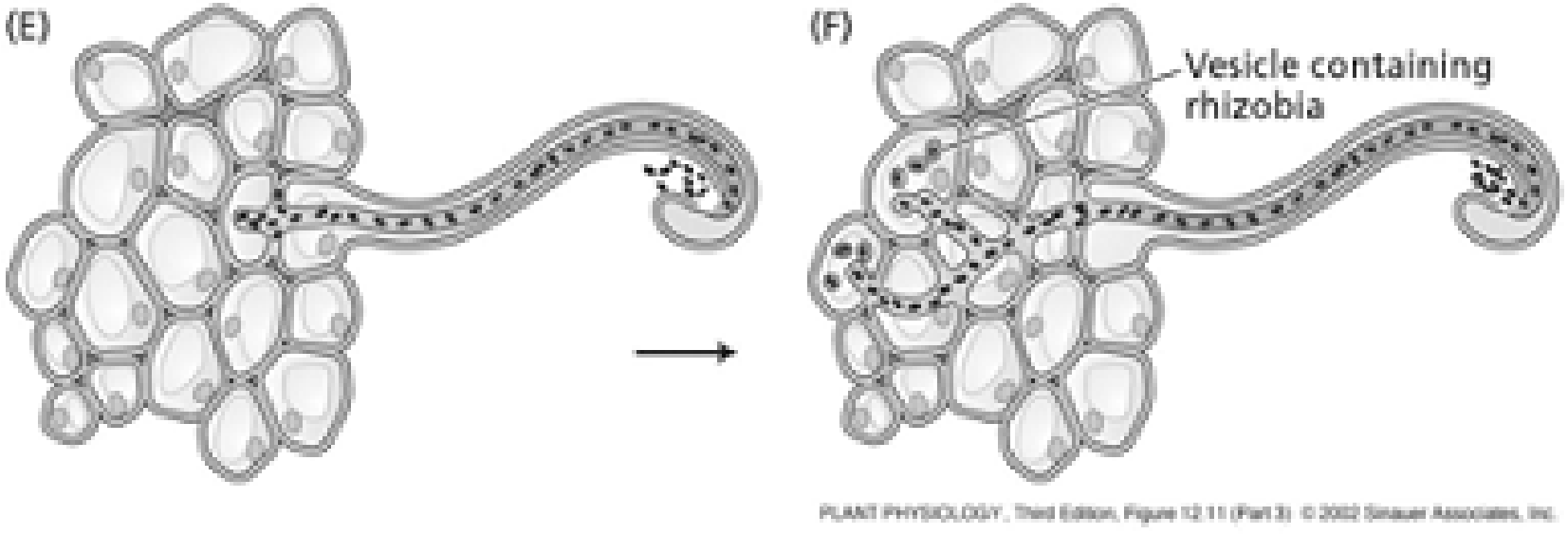
Which of these is the largest pool of nitrogen?



Nitrogen fixation

- Plants cannot directly use the atmospheric nitrogen
- Some microbes can use atmospheric nitrogen in their metabolism
- Symbiotic relationships have developed that allow some plants to tap this vast reservoir

Symbiotic N-fixing organisms seek each other out



PLANT PHYSIOLOGY, Third Edition, Figure 12.11 (Part 3) © 2002 Sinauer Associates, Inc.

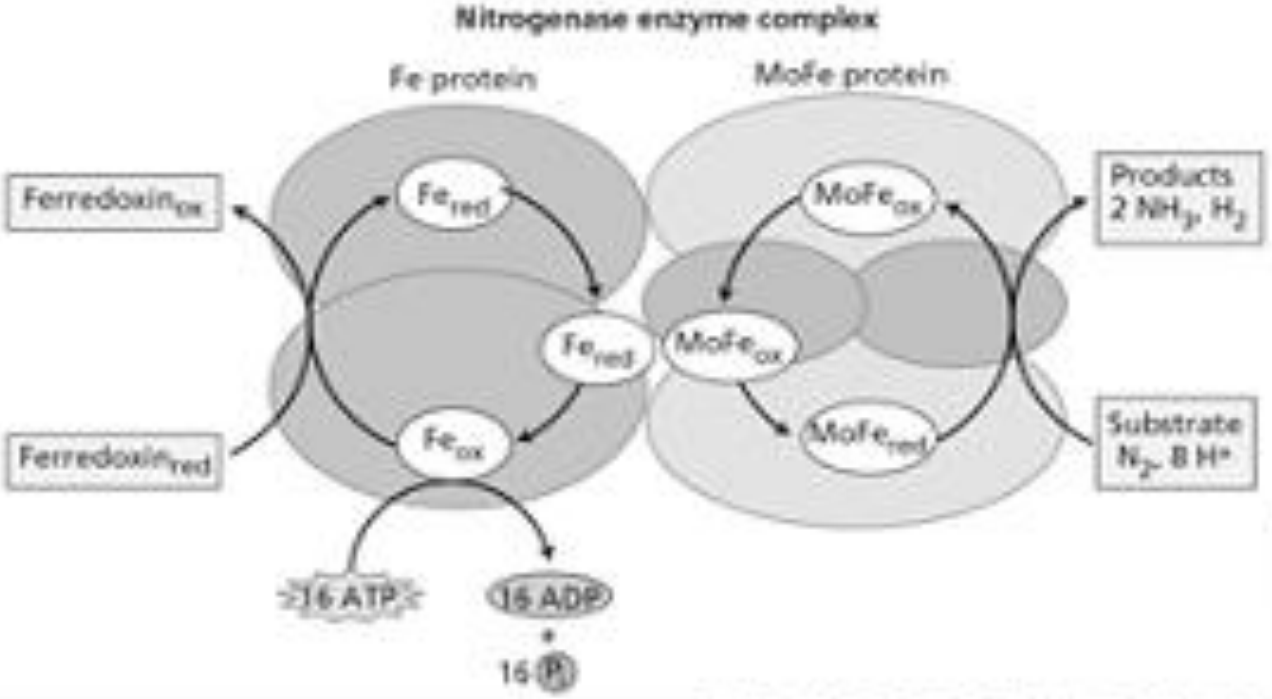
Nitrogen fixation and plants

- Plant provides
  - Structural safety in nodules
  - Microclimate
  - Controlled O_2 levels via leghemoglobin
  - Sugars to support the microbes

Nitrogen fixation occurs via nitrogenase

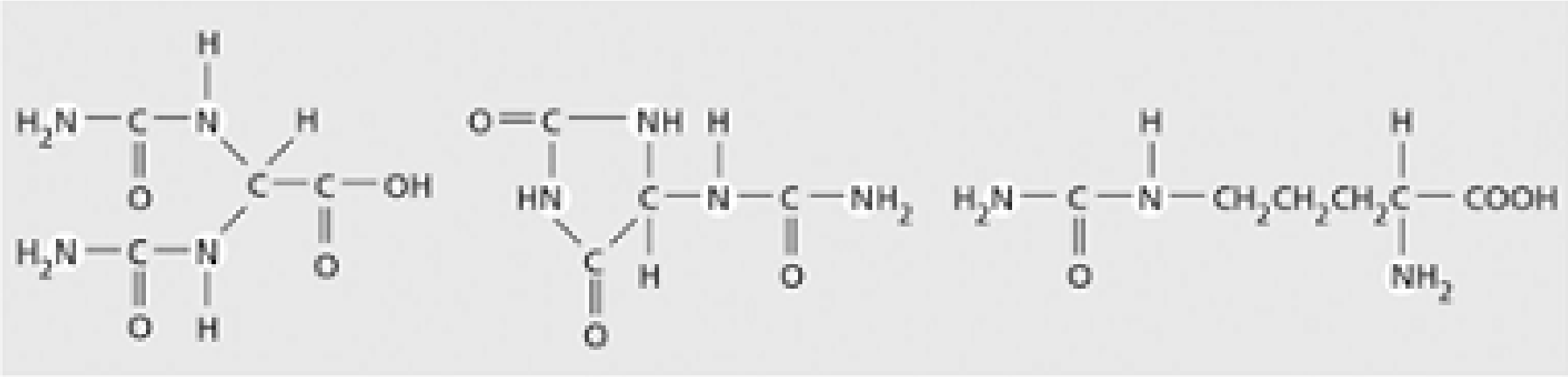
$N_2 + 8\ e^- + 16\ ATP$

$\rightarrow 2\ NH_3 + H_2 + 16\ ADP + 16\ P_i$



Nitrogen fixation and plants

- Plant receives
  - Ammonia, which is converted to ureides for transport to leaves



Allantoic acid

Allantoin

Citrulline

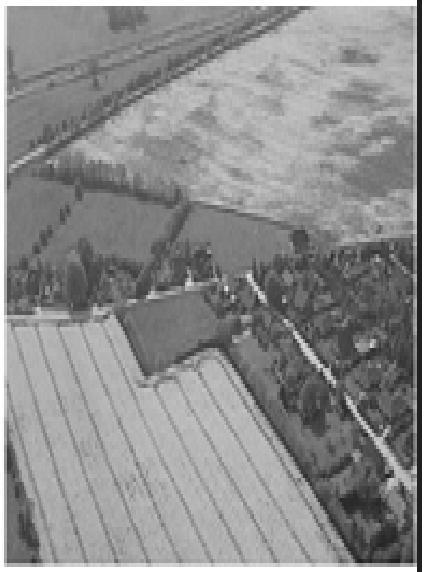
PLANT PHYSIOLOGY, Third Edition, Figure 12.13 © 2002 Sinauer Associates, Inc.

Sulfur Assimilation

Another link to C and N metabolism

Sulfur

- Several important functional roles
  - Amino acids (cysteine and methionine)
  - Plant hormones
  - Secondary compounds
  - Glutathione
- Important interface with C and N metabolism



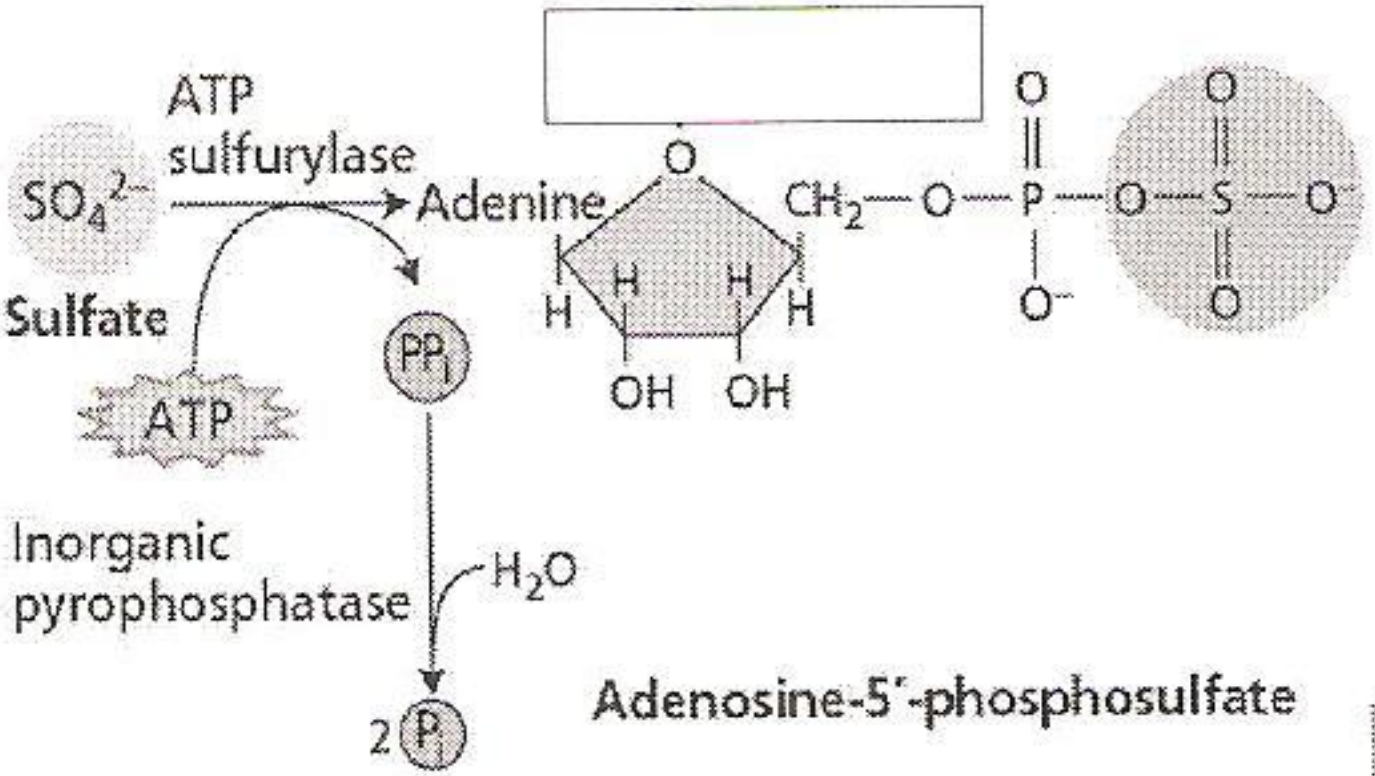
Sulfur assimilation

- Energy intensive (nearly double that of C and N assimilation)
- Typically utilizes soil sulfate, but may also extend to SO_2 and H_2S
- Occurs primarily in leaves to link with the energetics of photosynthesis

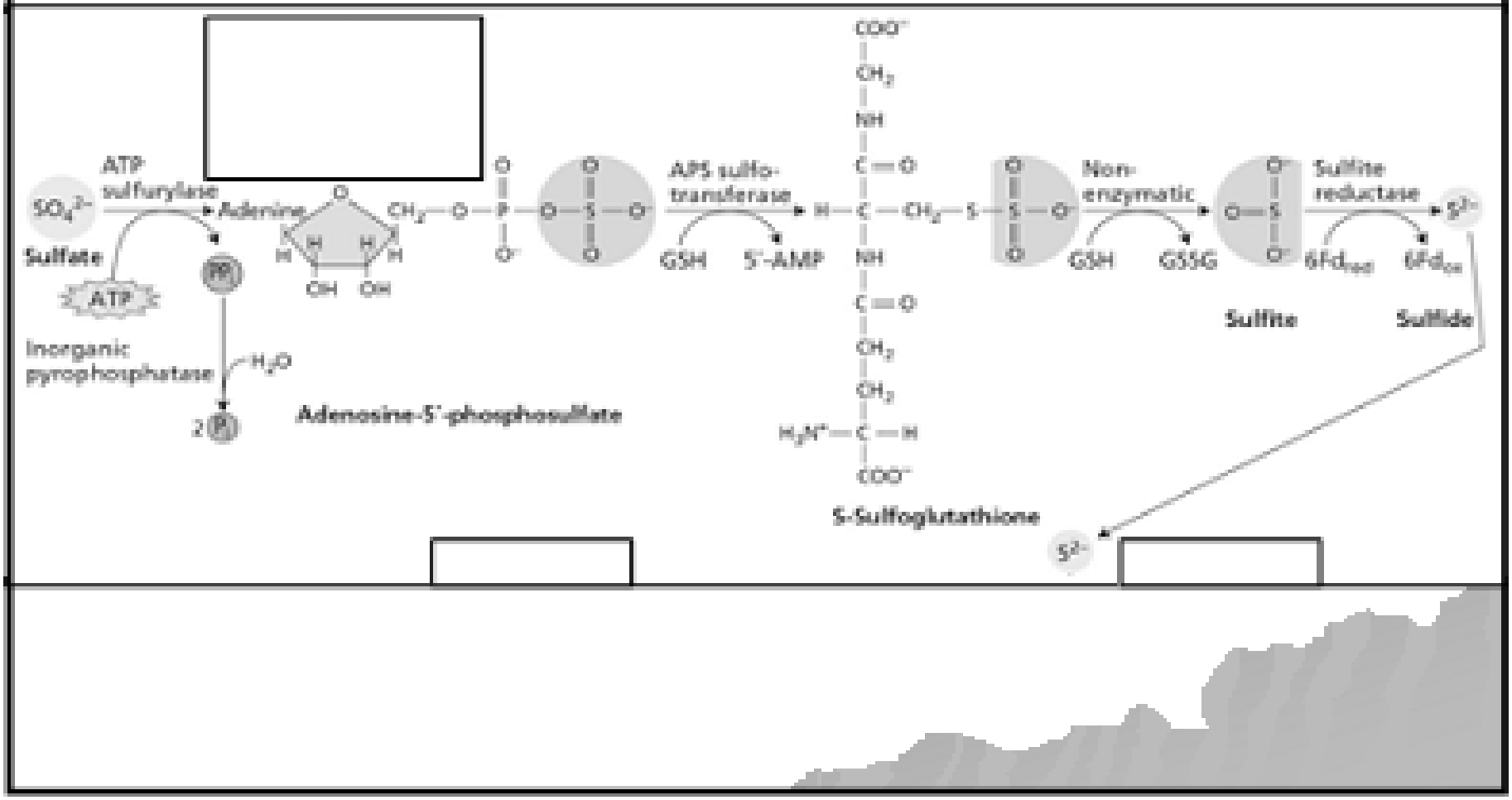
Reductive sulfur pathway stages

- Activation
- Reduction to sulfide
- Incorporation of sulfide to form cysteine

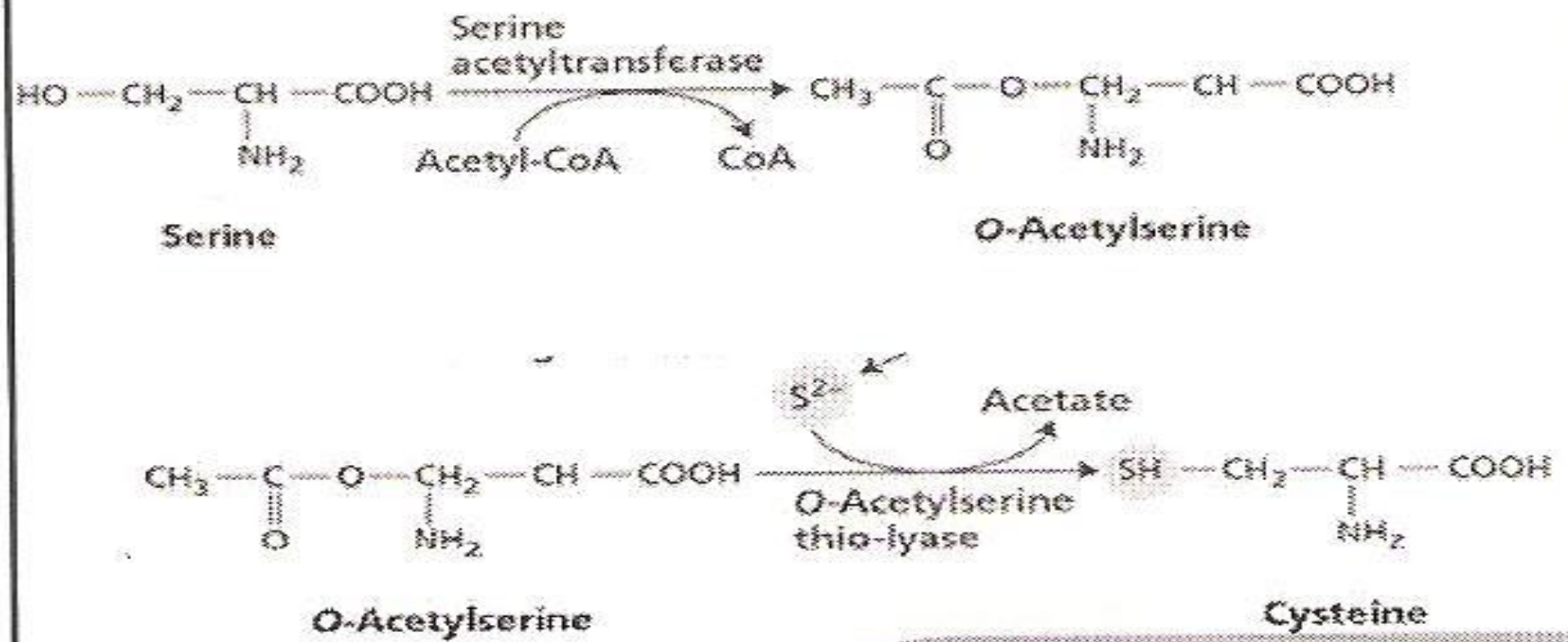
Activation of sulfate



Reduction to sulfide



Incorporation of sulfide to form cysteine



Sulfur metabolism

- Despite its importance, is poorly understood compared to nitrogen
- Has been used as a basis for the study of selenium assimilation in plants

Plant Water Relationship L8

* Water may consider as plant nutrient(H atom).
  - essential for P.S.
  - the quantity required for p.s. is only about 0.01 of total quantity of water required by plants.
* water is a solvent for many substances such as inorganic salts, sugars, and organic anions.
* it is a medium in which all biochemical R_X . take place.
* water molecules are absorbed at the surfaces of particles forming hydration shells, which influence chemical and physical reactions

* water in liquid form allow diffusion and mass flow of solutes, and for this reason is essential for the translocation of distribution of nutrients and metabolites throughout the entire plant.
* maintain the rigidity of leaves , roots and other plant organs.

water potential v.s. water content

change more dramatically with water stress than water content , so it is better indicator

Water potential :

The difference in chemical pot. Per unit volume between a given water sample and pure water at the same temp. and pressure.

chemical pot. of water

chemical pot. of pure water

$$\Psi_w = \frac{\mu_w - \mu^o_w}{V_w}$$

V_w ← partial vol. of water

$$\mu_w - \mu^o_w = \Delta w \text{ (chemical pot.)}$$

* standard international unit of water pot. is Pascal (Pa) . Pascal is very small unit so bar used in stead .

$1 \text{ bar} = 10^5 \text{ pa}$

water pot. of pure water = 0

* factor effect water pot.
  - temp.
  - pressure
  - solute

since temp. & press. have influence

$\mu_w - \mu^o_w$ could be put in some other expression

$\mu - \mu^o = R\ T\ \text{Lin}\ a_w$ water activity

gas constant absolute temp.

$a_w = \emptyset\ N_w$

activity coefficient molar fraction

$\mu - \mu^o = RT\ \text{Lin}\ \emptyset\ N_w$

`

the chemical pot. can also expressed as :

$$\mu - \mu = R\,T\,\text{Lin}\,\frac{P}{Po}$$

P ← partial pressure

Po ← partial pressure in pure water

$$\Psi_w = \frac{\mu_w - \mu^o}{V_w} = \frac{RT\text{Lin}\,a_w}{V_w}$$

$V_w = 18 cm^3 / mole$

water potential may expose to :

- hydrostatic pressure (+)
- suction pressure (-)
- osmotic pressure (-)

solute dissolved in water

then water pot. can be expressed as

$$\Psi = \Psi_p + \Psi_s + \Psi_m$$

(+) (-) (-)

Ψ_p = hydrostatic pressure

Ψ_m = suction pot. = matric pot.

play major role in seeds.

* in normal plant cell :

- the vacuole is originally the organelle that contributes the most to the over all solute potential (osmotic pot.)
- matric pot. Plays minor role in plant water potential. So water pot. in plants could be expressed as

$$\Psi_w = \Psi_p + \Psi_s$$

* things that decrease water pot.

solute , matrix force, tension , increase in temp.

* things that increase water pot.

  pressure , decrease in temp.

* water pot. In plant between -0.1 to -1.5 MP_a

  (-1— -15 bar)

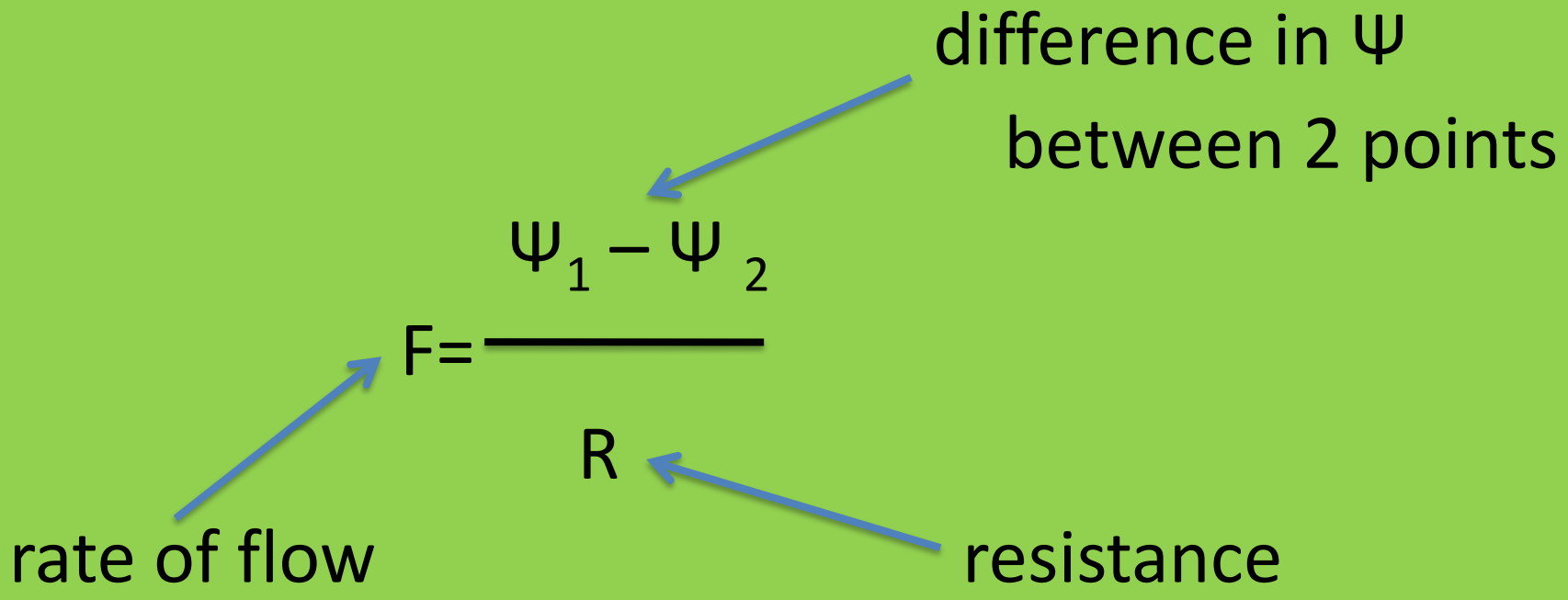
* different plant tissues tend to have different water pot.

$$\Psi_{soil} > \Psi_{root} > \Psi_{leaf} > \Psi_{atmosphere}$$

* water movement in cells, tissues, and whole plant take place from a higher to lower water pot.

* hypothesis of Van Honert :-

water movement between two points depends on the difference in water pot. and the resistance to flow



* water release into xylem :-

- not yet completely understood.
- it is controlled by osmosis and therefore clearly linked to ion transport. How?
- inorganic ions are actively or passively leak into the xylem vessel is not clear.

Water movement in long distance

a- Root pressure

- the secretion of ions into the vessel causes decrease in water potential into the vessel and cause water inflow into xylem.
- xylem show no restriction to absorb water as absorbed water can move in an upward direction.

- above mechanism is responsible for phenomenon called root pressure.
- in young plants root pressure contributed to the up ward translocation of soluble organic and inorganic material, particularly under conditions of low transpiration
- far too weak to transport water through xylem vessel to upper plant parts.
- in seedling can often cause quttation . Water is pumped through the entire plant and released as droplets at the leaf tips.

b- Transpiration (most important)

- At opt. temp.

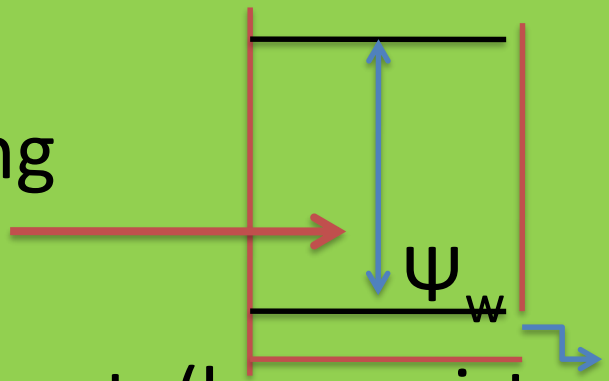
rate 1-2 g H_2O /dm^2 /hr

- a maple tree can transmit into the atmosphere via transpiration 50 gallon of H_2O / day.
- a single Needle plant transpires 25 gallon of H_2O /day.
- if 1 part of water is symplastically transported, 50 parts are apoplastically transported.

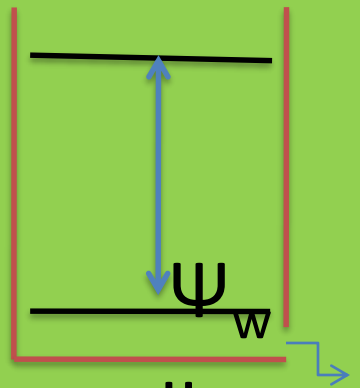
* Transpiration pull :- X

- at R.H. 50% $\Psi_{atmo.}$ = -900 bar , this is a big driving force for water from leaves to atmos.
- water transport according to $\Delta\Psi$ between two points.

driving force



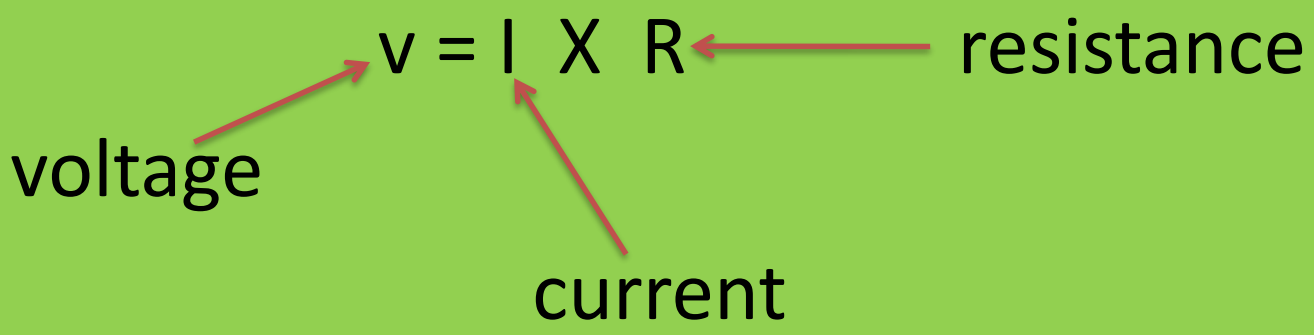
faster rate(less resistance)



smaller rate

(more resistance)

* in both cases driving force is same and direction of flow is same , but rate of flow differ because of different resistances. So, times needed to reach equilibrium are different
* Oum law could be used to describe water movement in plants



for water relations in plants

driving force

$\Delta \Psi_w = J_w \times R$

flow of water

resistance

$\Delta \Psi_w$ change in water pot.

$J_w = \frac{\Delta \Psi_w}{R}$

R resistance (variable factor can be changed)

* to apply oum law for water relation in plants :

J = rate of transpiration

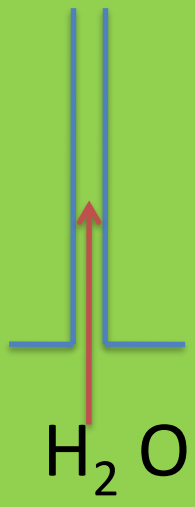
$\Delta \Psi_w$ = change in water pot.

R = opening and closing of stomata

* Capillary rise

water has surface tension of 72.8 dyn/cm.

so, has ability to rise in capillary tubes



capillary movement of water in capillary tube

* Wettability and Adhesion :

is the attraction between the inner surface of the capillary tube and the water molecules.

* Cohesion

affinity of water molecules to other through H bonds.

so, two forces affect water movement in capillary tubes :

adhesion

cohesion

if

cohesion = adhesion

attraction between molecules to them selves= attraction of molecules to surface , then

α between water molecules and inner surface of capillary tube is very small , then water Colum in tube (h) is > o which means water move up in plants. However , if

adhesion = ½ cohesion

α ≈ 90 ⟶ surface will be straight and

h = 0

* The forces in the capillary :

3.141 surface tension

up ward force = $2 \pi r \sigma \cos \alpha$

in capillary

radius of capillary

down ward force = $\pi r^2 h \rho g$

in capillary

density

gravitational acceleration

at equilibrium , both forces should be equal

$$h = \frac{2\pi r \sigma \cos\alpha}{\pi r^2 \rho g} = \frac{2\sigma \cos\alpha}{r \rho g}$$

the variable is r

the over all high is going to be $= \frac{0.149\ (cm^2)}{r\ (cm)}$

for water so if you know r, you can find h

* plants need micro capillaries in the top to provide high pull, and large cells in the bottom to provide a large quantity.

* xylem contribute very little to puling capacity , however, it supplies most of the volume. The pulling power is contributed by the capillary pores.
* lifting force of water is the transpiration, which occur due to differences in Ψ_w between plants & atmosphere.

Considerations:-

- water continuity : cohesion due to hydrogen bonding.
- ability of water to withstand stress, water is pulled in the system not pushed .

* other ideas

- there is hydrophilic material in xylem and this cause Ψ_m develop , so water movement up by Ψ_m gradient through xylem (no much evidence).
- presence of pumps in xylem, pump water up ward.

* plant controls water lost through stomata opening and closing .

R- values

closed stomata	open stomata
100 -150 sec/cm	2 sec/ cm

The development of water stress in plant

* the direction of flow is clearly indicated by the water pot. in the atmosphere and that of soil.
* in most plants water losses is more than water uptake, so stress will develop.
* plant can employ some mechanisms to tolerate water stress:
    - as water stress develops, there is a decrease in Ψ_p of plant cells, and water potential become negative.
    - there is change in the thermodynamic parameter rather than in water content .
* plant never subject to continuous stress, so there are much fluctuation in stress.

sensitivity of processes to water stress in plant :

Ψ_w (bar)

0 -1 -2

cell enlargement -4 -8 -10

ABA formation

stomata closed -16

chloroplast

function & p.s

-25

CH_2O &

protein hydrolysis

Relationship between soil water and water potential of soya bean leaves

Soil water potential, kp_a	leaf water potentia,MP_a
0 to – 10	- 0.2
0 to -20	- 0.4
0 to -40	- 1.2
0 to -100	- 1.9

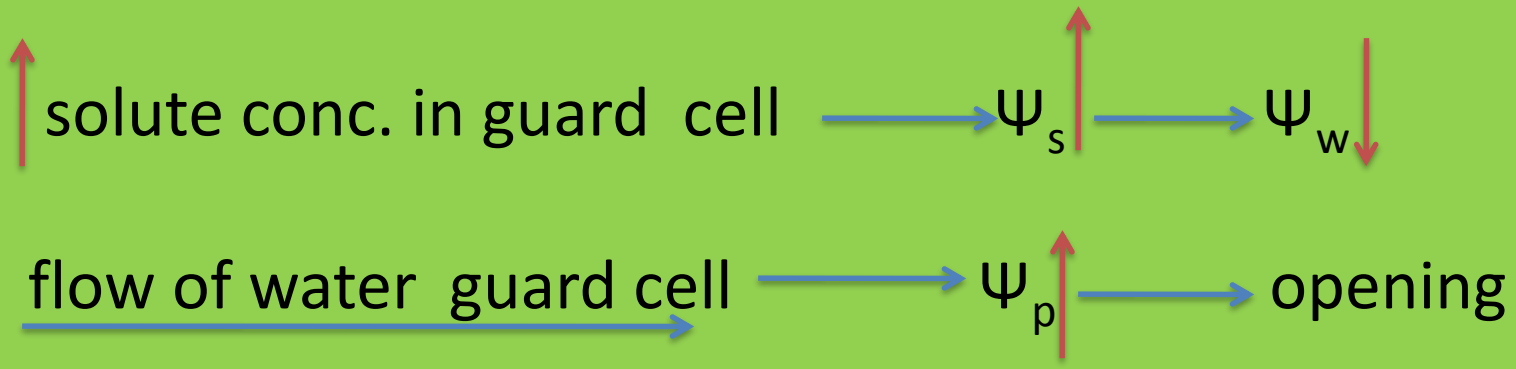
Stomatal opening and closure L9

* largest amount of water transpired by crop plants is released through the stomatal pores .
* stomata are mainly located on the undersides of of leaves and enable gaseous exchange between leaf and atmosphere .
* in some cells there are cells associated with gard cells: subsidiary cells which may derived from the leaf epidermis, and they are enlargement to guard cells.

* guard cell have radial ribs encircle the entire guard cell and work as sort of radial supporting

mechanism . Play important role in stomatal opening . Find how ?

opening mechanisms :-



Factors influencing stomatal activity

* environmental factors

1- CO_2

- most important factor

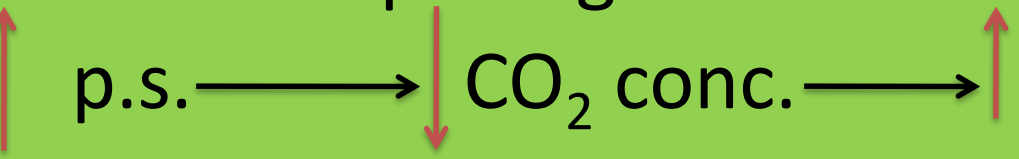
low CO_2 ⟶ opening

high CO_2 ⟶ closing

- normal air has 0.03% CO_2 . The max. opening occurs at 0.01% CO_2 in many species.
- CO_2 conc. inside influenced by
  - i- external conc.
  - ii- photosynthesis
  - iii- rate of respiration

2- light effect

- most important light effect is via P.S. which effect CO_2 conc.
- light induced opening of stomata



3- water stress

- no effect as the Ψ_w goes from 0 to – 10 bar
  (relatively insensitive region)
- some where between Ψ_w –8 to – 15 bar
  there is a threshold closure of stomata

tomato	– 7 to –9 bar
beans	– 10 to – 12 bar
grape	– 12 to – 16 bar
corn	– 8 to – 10 bar also sorghum

hypothesis :

as moisture stress develops, there is increase in ABA both in xylem and synthesis in leaves . The levels of the acids generated is enough to cause stomatal closure

* Internal factors

1- K uptake

- K- up take is related to guard cell movement . Related to Ψ_p and depend on metabolic activity(active K uptake)

- source of k in guard cell

i- partially provided by the vacuoles of subsidiary cell

ii- partially provided by the epidermal cells.

- no differences were found between any of the cells of the leaf epidermis , regardless of the state of stomata.

- k transport through plasmadismata connection rather than a cross cell membrane.

- companying k uptake would also be anion uptake (Cl).

2- Starch degradation

starch ⟶ sugar ⟶ ↑ solute potential

starch it self is poor as an osmotic agent

(rejected idea, play secondary role)

3- Organic acid metabolism

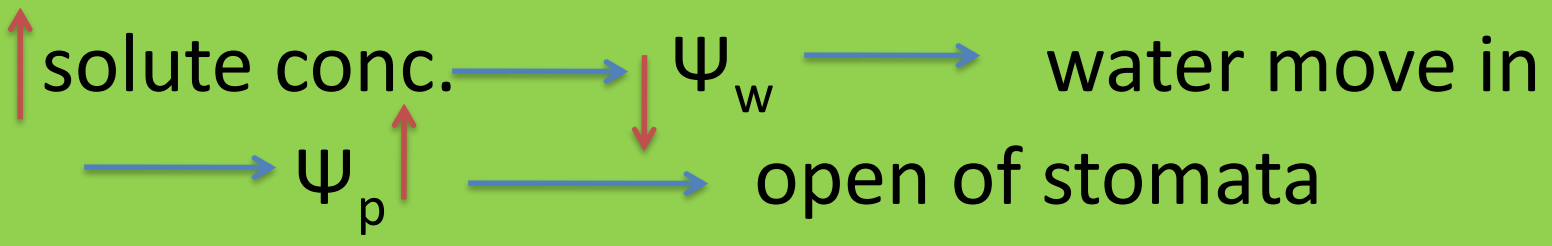
- malic acid is the principle agent.

high conc. → stomata opened

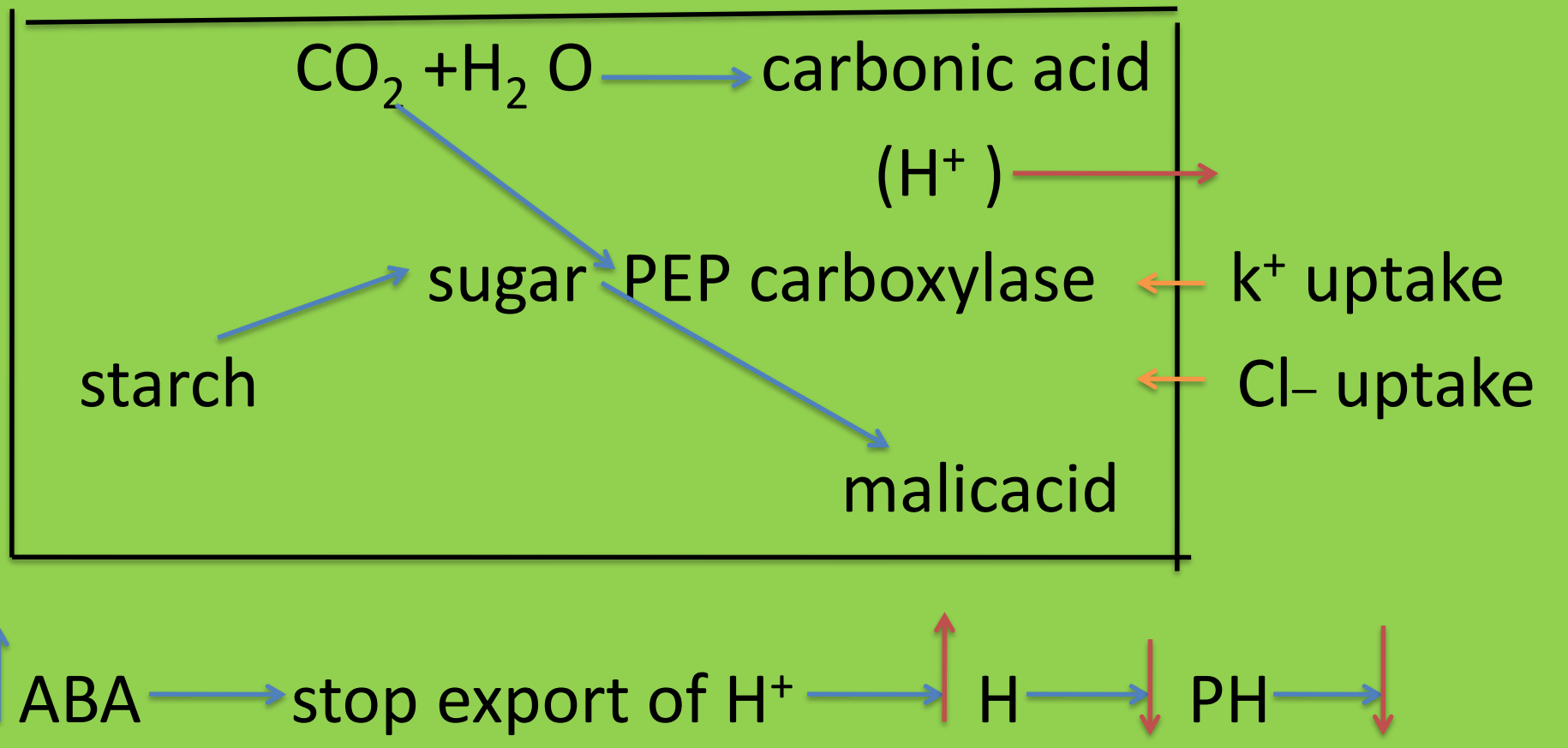
low conc. → stomata closed

- CO_2 + PEP → malic acid
- CO_2 fixation occur even at night

4- Photosynthesis : direct effect



* model to connect environmental response to internal factors



malic acid synthesis

* factors contributing to the opening of stomata
  - malic acid
  - K^+
  - Cl^-
* acidity influence the Rx. of malate generation.
  Exporting H^+ from cell increase the rate of Rx. generating malate
  - induce flow of K^+ from outside to inside by Δ of electrochemical potential.
  - malic acid , Cl^- , K^+ contributing to Ψ_s
  - PEP carboxylase mediate malic acid synthesis ability in guard cells.

Solute translocation in phloem X

* phloem component :

- sieve cell (sieve element)

most important part of the phloem

two things lacking :

i- nucleus- at maturity

ii- vacuoles

- companion cell

i- play important role in phloem loading

ii- combine to sieve element by plasmadesmata with sieve element forming functional unit (sieve - element companion complex)

- parenchyma cell

* continuity from one cell to other is through sieve plate.
* in upper plant parts phloem located in cortex , the petioles ,and in the major veins& minor veins of leaves

sieve cell VS sieve element

i- still developing and so highly specialized as sieve element.

ii- contain more mitochondria than sieve element .

iii- have smaller diameter

vi- located in the minor veins system of leaves.

* Materials transported :

most common things to find in phloem are

1- carbohydrates (80-90 % of total) mostly non reducing sugar (sucrose),fructose & glucose could also be found (result of sucrose degradation) ,raffinose and sugar alcohol are there too.

apple and apricot :

sorbitol is the main form of CH_2O when arrived to fruit → sucrose

sugar alcohols are the predominate translocated sugar.

Soybean :

- insitol is the major form. It is a polyhydroxy compound that has a methyl group.
- stem exudates of 6 – week soybean plant the following distribution of sugars are noticed

form	%
o-methyl insitol	42
glucose	16
fructose	9
sucrose	22
other	11

2- organic nitrogen

a.a and amides at conc. of 0.03 to 0.4

% increase in autum when leaves are aging and about to fall.

3- inorganic materials

K^+, $H_2 PO_4^-$,Ca^{+2} (is limited) , NO_3^-, Na^+, Mg^{+2} and other ions.

4- Hormones

auxin, GA, cytoknin, ATP and other.

* Mechanism of phloem transport

1- cytoplasmic streaming (rejected)

cycling material through the sieve tube membrane or direct streaming

2- activated diffusion

sugar pump? Pumping system made of contractile proteins (not a lot of support)

3- electro osmosis

K is being loaded at one end of sieve element and unloaded at other, so get gradient and a bulk flow of water .

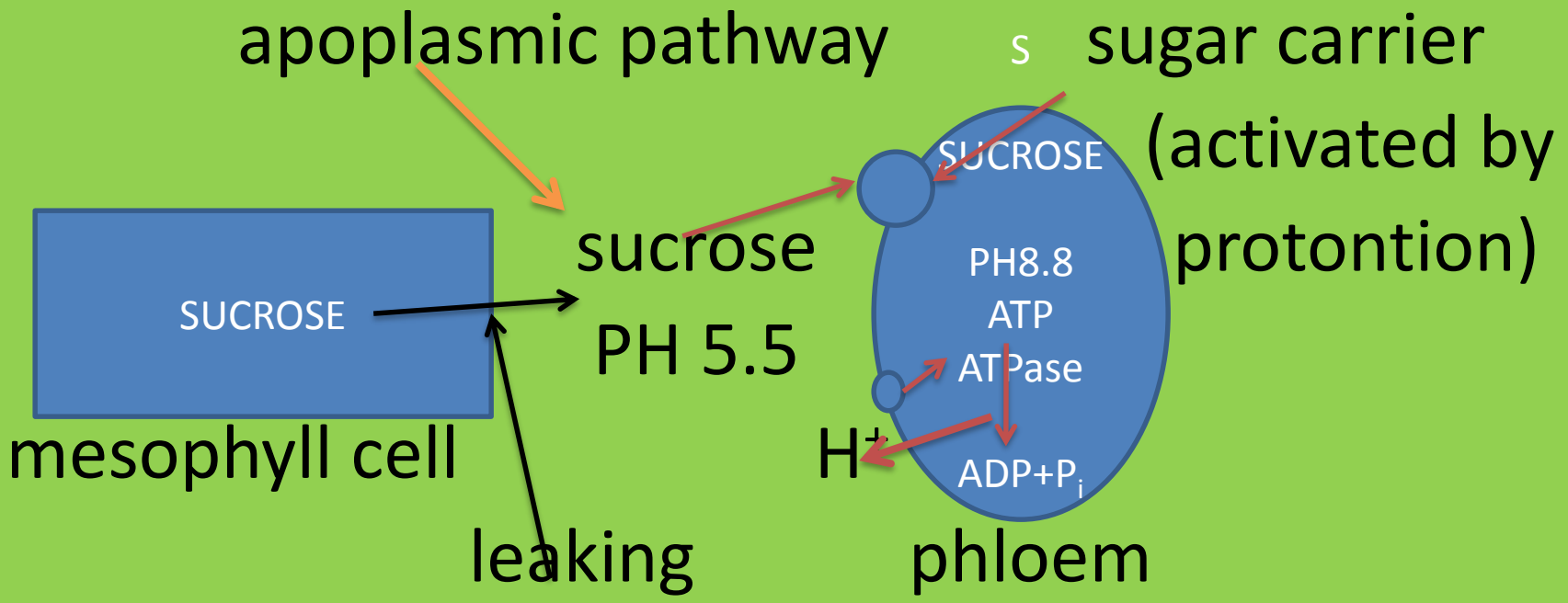
4- bulk flow or mass flow (dominate theory)

* How sugar moves from leaves to sieve tube ?

hand out p. 220 Mingle & kirkiby (fig. 4.9)

- organic solute transported in phloem & tissues are mainly produced in the chloroplast.
- chloroplast imports inorganic P ,CO_2, and HNO_2 and export Triosephate and a. a
- uptake of CO_2, HNO_2, probably take place by diffusion through the outer chloroplast membrane
- transport of both inorganic and organic p across membrane is brought about by a so called phosphate translocatoer which couple the uptake of inorganic p with export of triose-phosphate.

* transport of sucrose from mesophyll to phloem



- affinity of sugar carrier for sugar increased 100 times by protontion.
- a. a transport by a carrier driven by ATPase, but differs from sucrose carrier.

- translocation of sugar is an active process (ATPS)
  - translocation from low to high conc.

	sucrose conc. *M* 10^{-3}
mesophyll	*3 - 3.5*
minor veins	*20 - 25*
major veins	*50 - 70*
phloem	*200 - 300*
storage tissue of root	*400 – 600*

- phloem unloading in sink tissue is associated with invertase activity (enzyme in apoplast with high activity in acid medium) . As sucrose leak in to apoplast it splits by invertase and cannot therefore, reabsorbed by phloem.