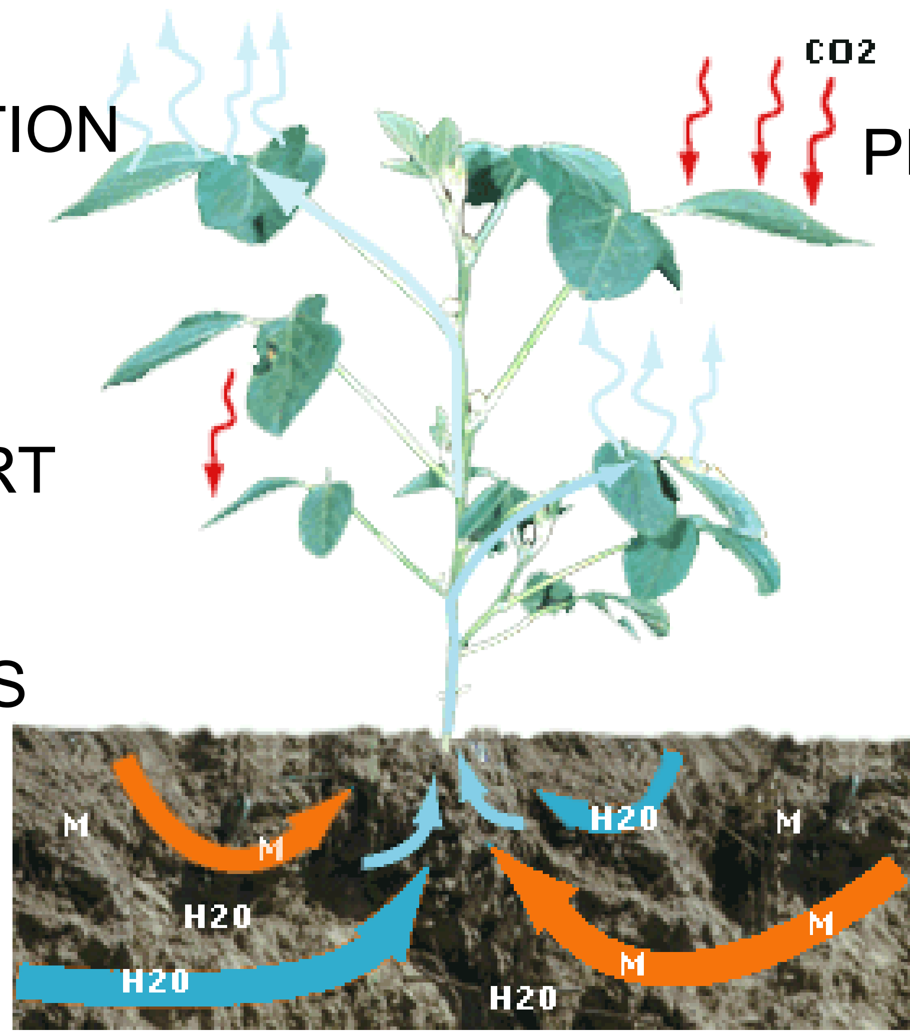
«Biologija nebiologiem»: plant physiology

- Plant mineral nutrition
- Photosynthesis
- Plant respiration
- Transpiration

Physiological processes in plants

TRANSPIRATION

PHOTOSYNTHESIS

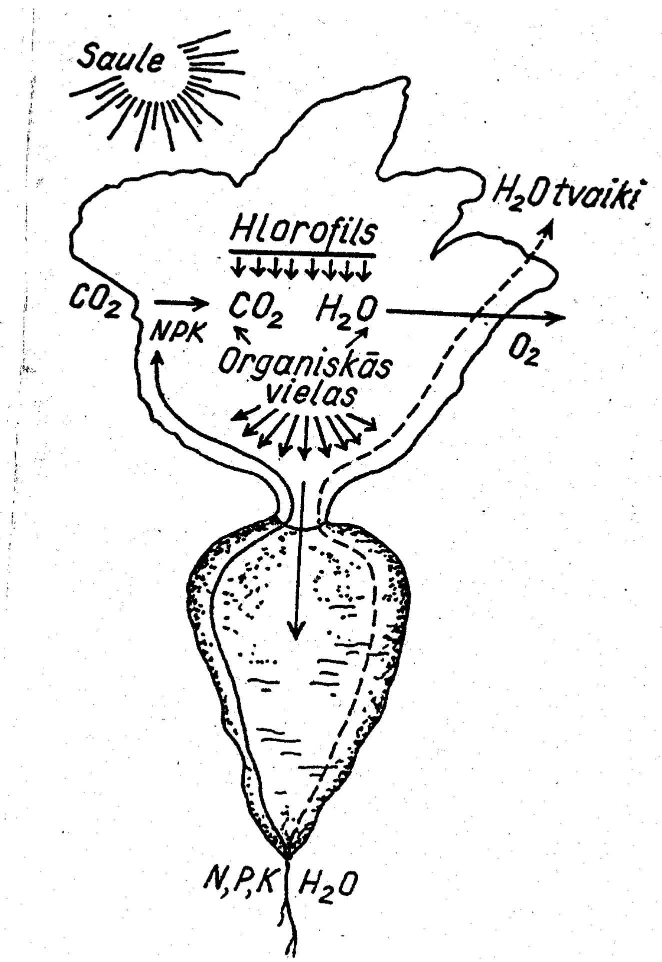


TRANSPORT OF WATER AND NUTRIENTS

NUTRIENT UPTAKE

WATER UPTAKE

Transport in a plant: different directions



Turnover of organic substances in plants
Vītols 1975

Distant transport:

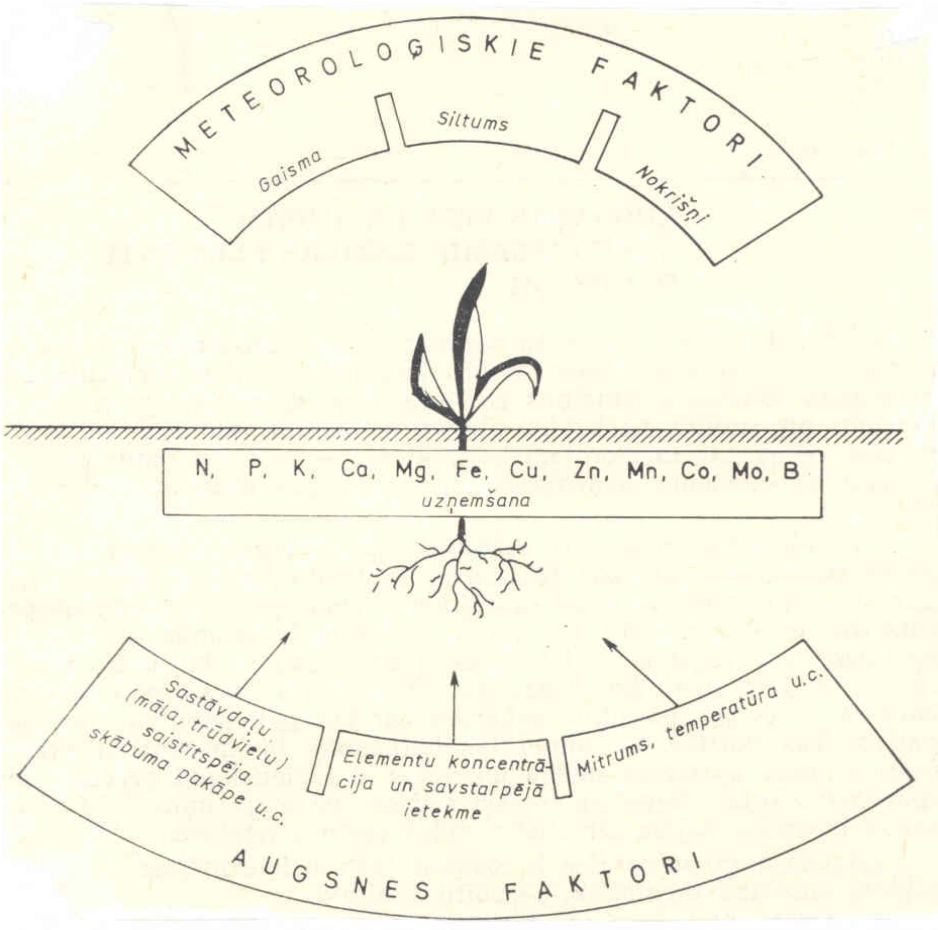
Organic substances, water solution

Nutrients in water solution

Phytohormones and growth regulators

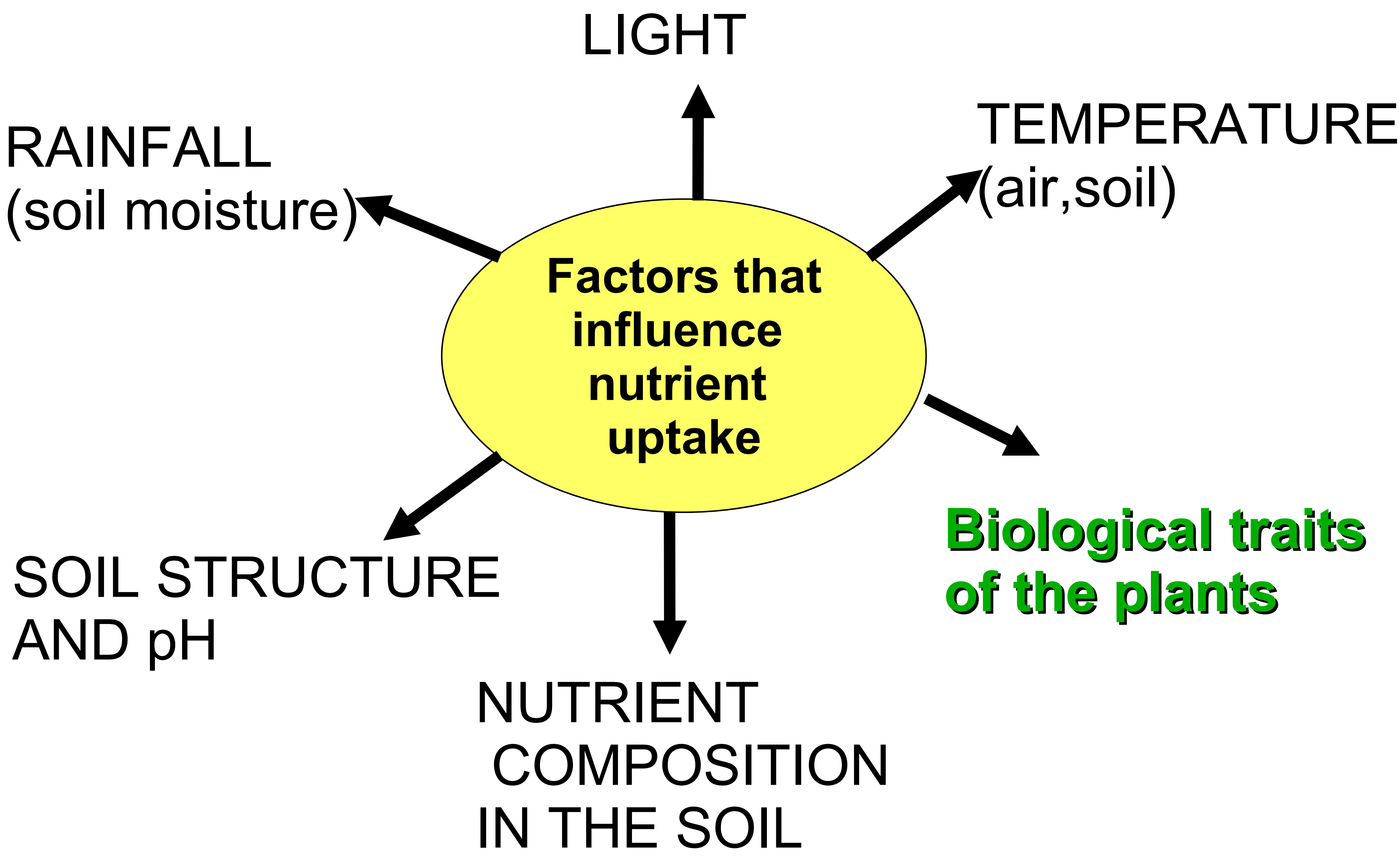
Aminoacids, organic acids

Close transport:
CO2, organic substances, growth regulators, signalling molecules



Plant mineral nutrition

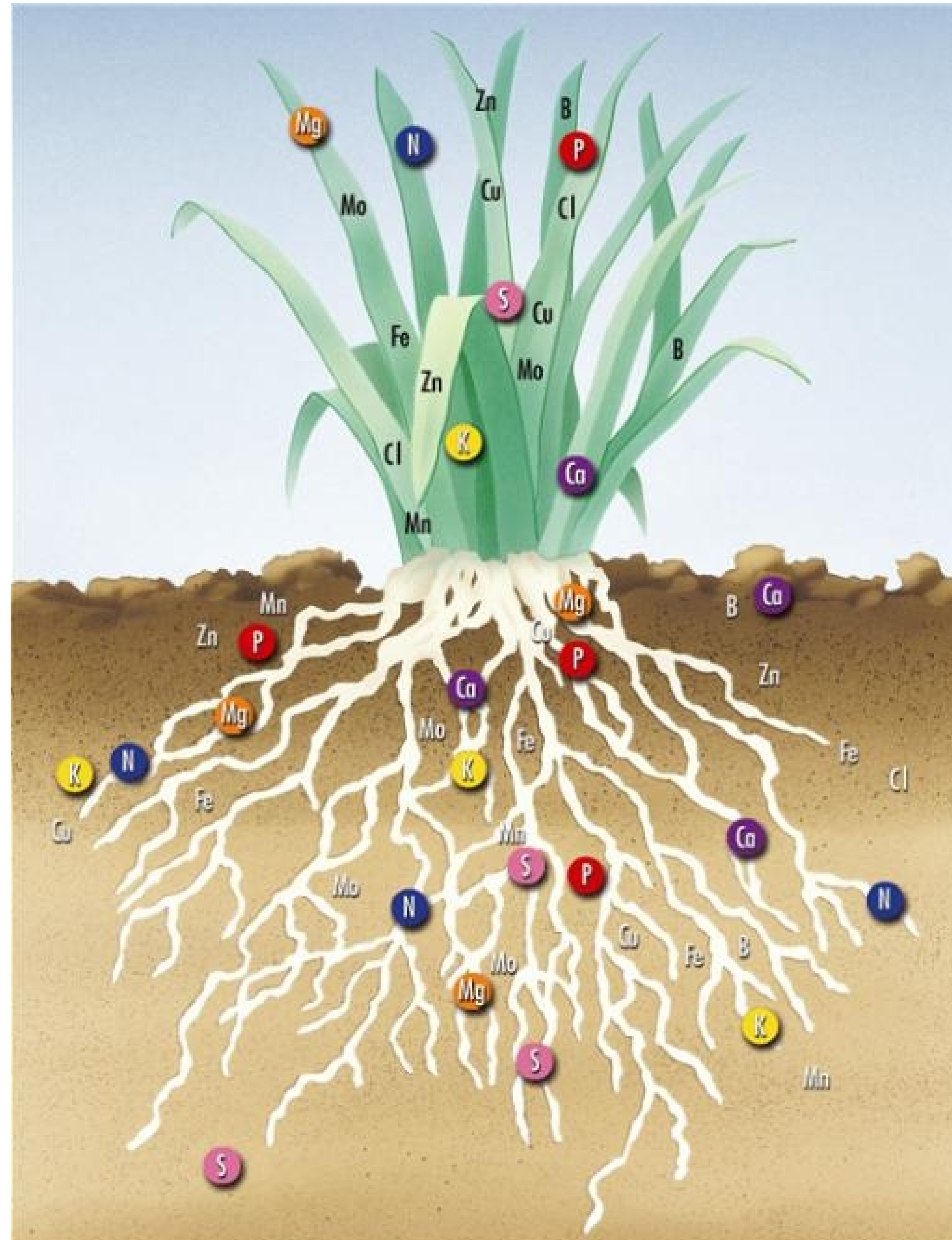
Riņķis, Ramane, 1989


LIGHT
RAINFALL
(soil moisture)
TEMPERATURE
(air,soil)
Factors that influence nutrient uptake
SOIL STRUCTURE
AND pH
NUTRIENT
COMPOSITION
IN THE SOIL
Biological traits
of the plants

Chemical composition of plants

Macronutrients	Micronutrients
(10^{1}-10^{-2})	(10^{-3}-10^{-5})
C – 45%	**Mn**
H – 6,5%	**Cu***
O – 42%	**Zn**
N – 1,5%	**Mo***
P – 0,05-0,3%	**B***
S – 0,2-1%	**Cl**
K – 0,5-1,2%	**Na**
Ca – 0,2-3,5%	**Si**
Mg – 0,02-3,1%	**Co**
Fe – 0,01-0,015%	**Al**
	Ni
	Li
	Se

* - nutrients, deficient n Latvian soils

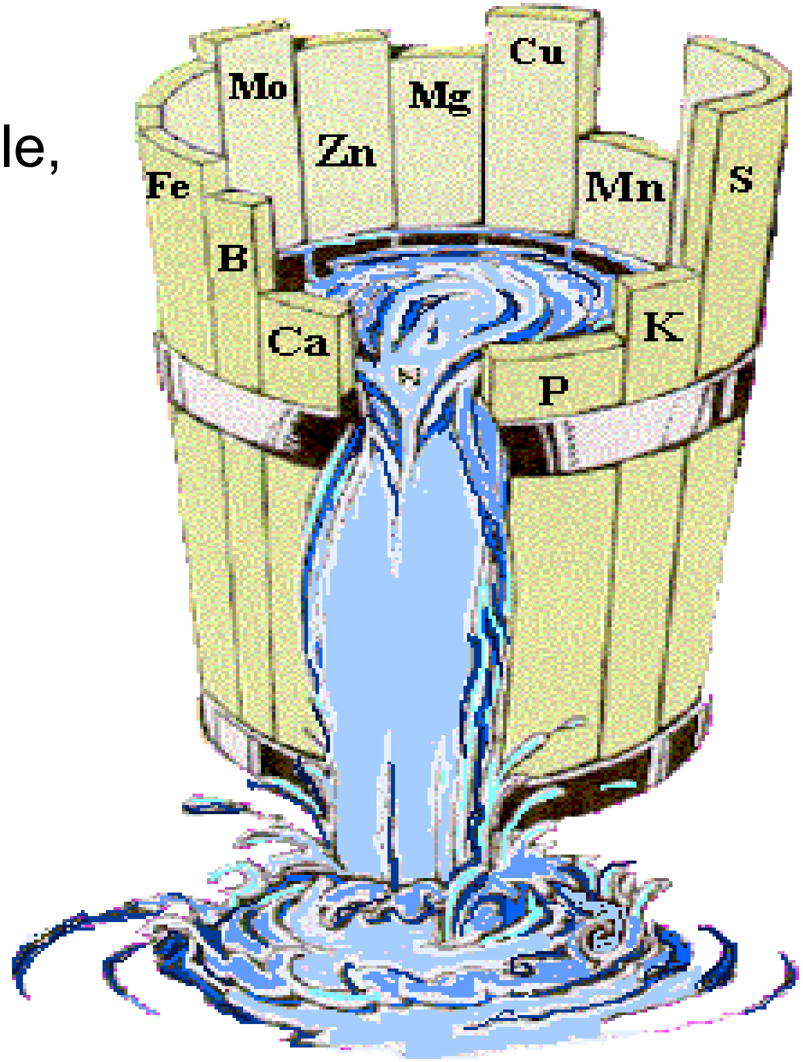


Liebig's law or the law of the minimum

«Growth is controlled not by
the total amount of resources available,
 but by the scarcest resource
(limiting factor)»

Carl Sprengel,
Justus fon Liebig


Justus von Liebig



«Liebig's barrel»

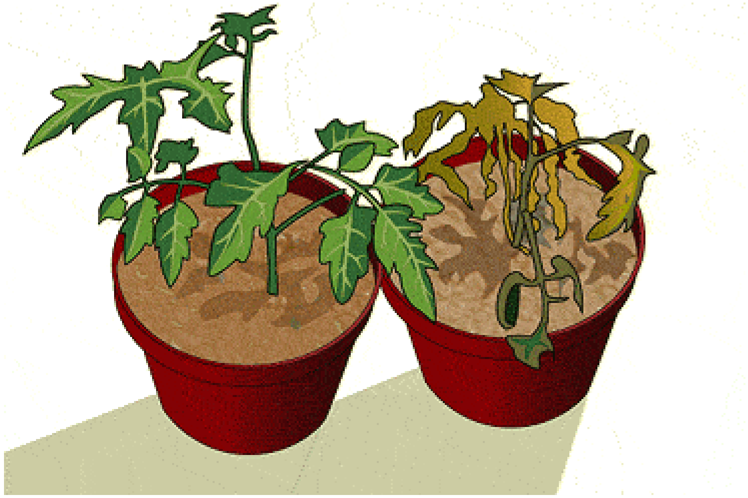
Nutrient deficiency symptoms in plants

Deficiency symptoms are explained by the role of each nutrient:

MACROELEMENTS are the structural elements
that make up the plant cells and its structures, as well as enzymes

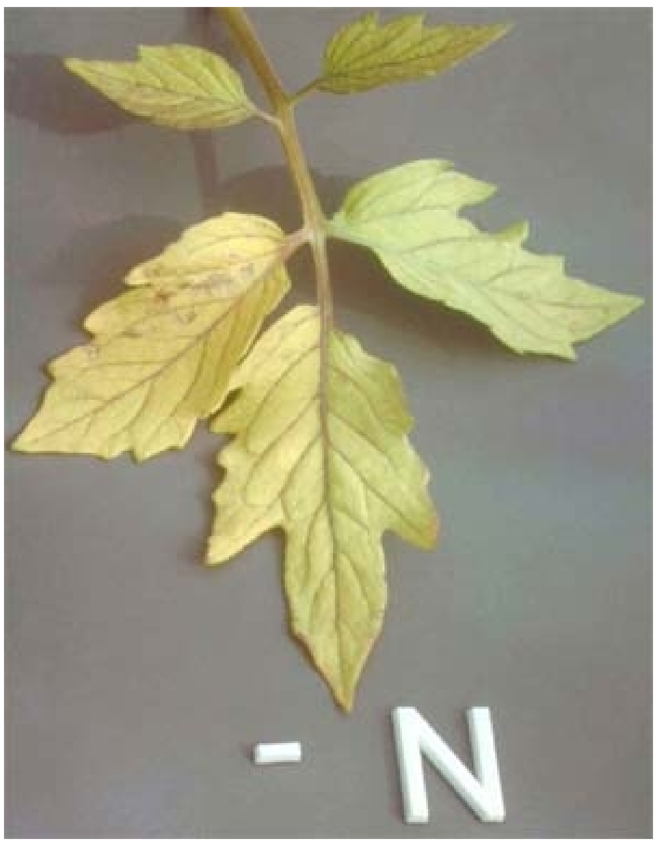
MICROELEMENTS are regulatory elements, often enzyme cofactors

Exceptions -K and Si

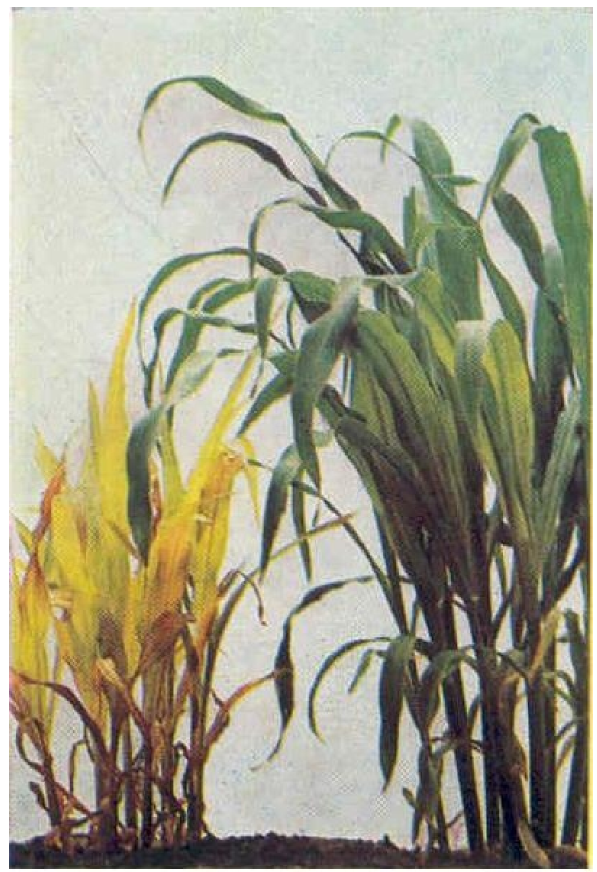


Nitrogen deficiency

Yellowing leaves, first in **older** leaves (N is reutilized), decreased size (slower growth)



Epstein and Bloom 2004
http://4e.plantphys.net Topic 5.1



Bergmann 1986

N is necessary for
the synthesis
or proteins,
nucleic acids,
chlorophyll,
phytohormones
and other substances

Phosphorus deficiency

Slow growth, decreased plant size (plants look more juvenile), leaves roll in, reddening of leaves, purple or reddish stripes or spots (P can be reutilized)

Lyle Cowell of Saskatchewan, Canada 2007 Crop Nutrient Deficiency Photo Contest
http://www.ipni.net/

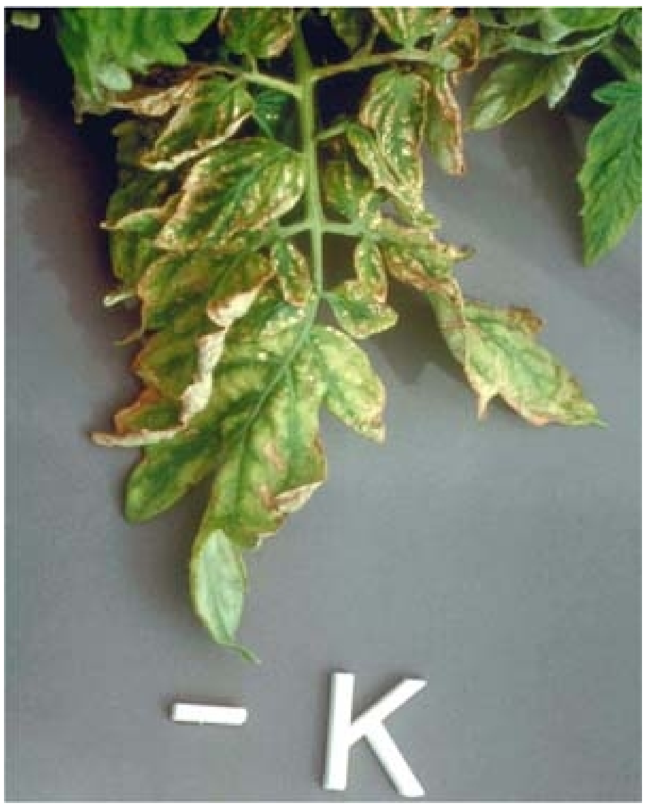
Bergmann 1986

P is necessary for synthesis of proteins, ATP, phospholipids;

P deficiency alters the balance of sugar and phospholipid synthesis

Potassium deficiency

Yellowing at the edges of leaf blades, first in older leaves (K can be reutilized); brownish spots at the edges and tips of the leaves, later between the veins



Epstein and Bloom 2004

Bergmann 1986

K regulates the opening of stomata, sugar metabolism, permeability of plasma membranes, cell osmotic potential and other processes in the plant cells

Calcium deficiency

Young meristematic tissues fail to develop (apex, root tips), mucous cell walls; first symptoms appear in actively growing plant parts

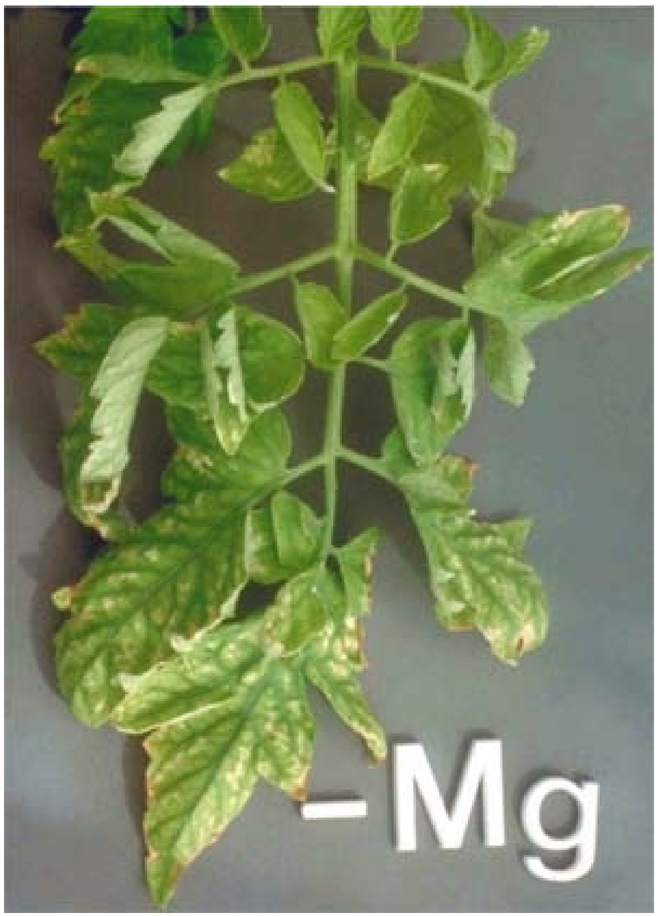
-Ca Sugar beet; 2007 Crop Nutrient Deficiency Photo Contest

Ca is necessary for the synthesis of cell walls, (Ca pectates)

Ca^{2+} ions are part of signal transduction mechanism

Magnesium deficiency

Leaf chlorosis (deficiency of the green pigment) between the veins in older leaves (Mg can be reutilized); variegate leaves



Epstein and Bloom 2004


Bergmann 1986

Mg is necessary for the synthesis of chlorophyll

Sulphur deficiency

Yellowing or pale leaves, first in the **young** leaves, but mainly in the whole plant (S can be reutilized, but it does not compensate deficiency). Brittle leaves.

Epstein and Bloom 2004

S ir necessary for the synthesis of aminoacids, coenzymes, vitamins

Iron deficiency

Chlorosis in young leaves (Fe cannot be reutilized); first appears between the veins, later throughout the leaf blades

Fe is required for synthesis of chlorophyll; it is also a co-factor of various enzymes

http://www.ipm.iastate.edu/ipm/info/plant-diseases/nutrientsoil-ph-imbalances

-Fe Banana; 2007 Crop Nutrient Deficiency Photo Contest

Zink deficiency

Rosette-shaped leaves, necrosis between the veins

Epstein and Bloom 2004

-Zn Corn; 2007 Crop Nutrient Deficiency Photo Contest

Zn is required for synthesis of tryptophan (aminoacid) ans is a co-factor of more than 200 enzymes

Boron deficiency

Poorly deveoped growth tips (apices) and vessels; wilting of leaves, necrosis.

Bergmann 1986

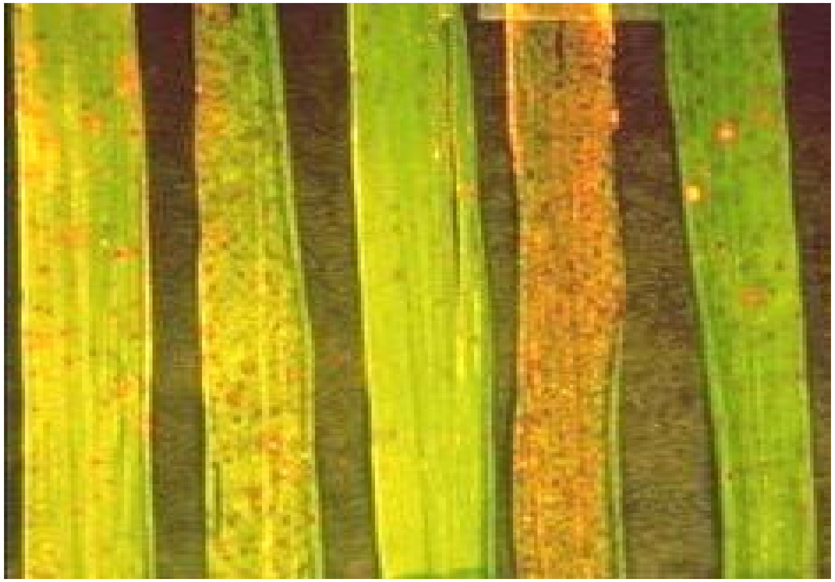
www.bitkisagligi.net

B is rewuired for sugar transport (makes complexes with sugar molecules)

and is required for lignin synthesis

Silicium deficiency

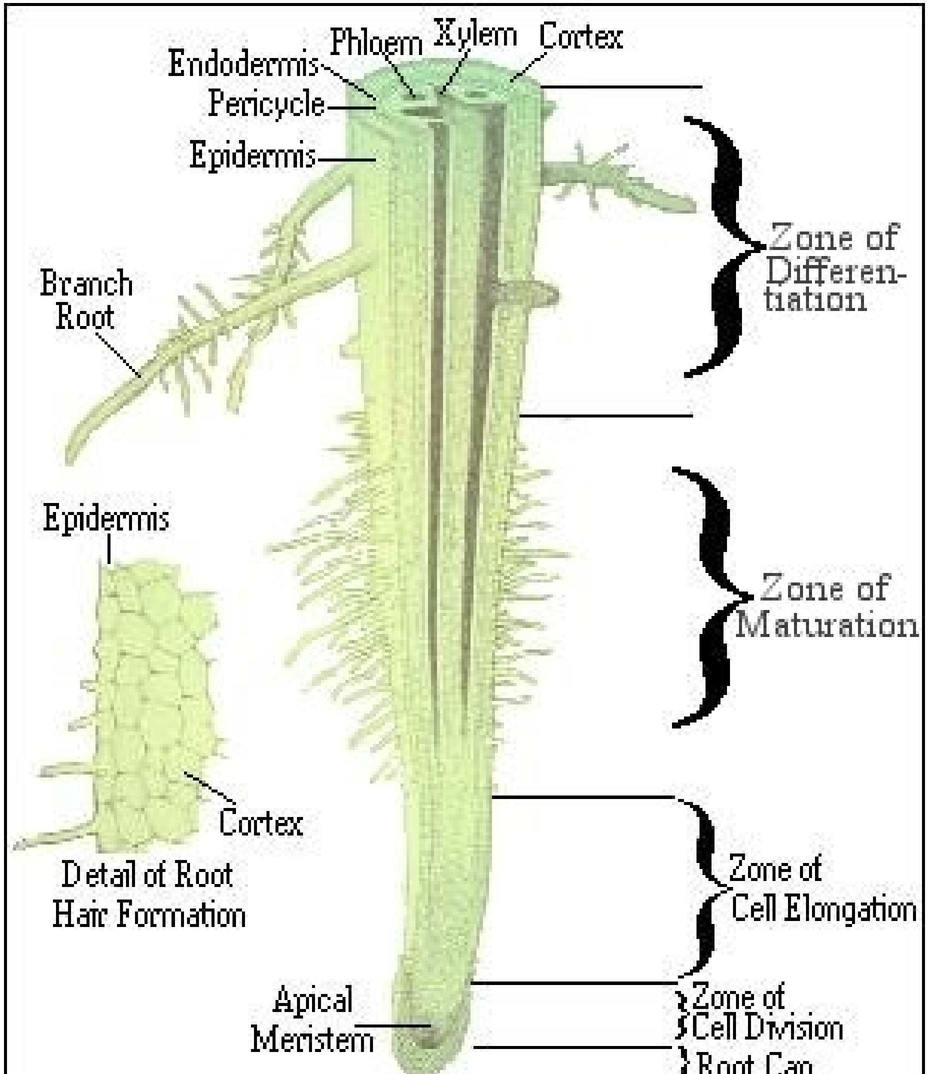
Altered plant shape, wilting



www.knowledgebank.irri.org

Si is incorporated in the cell walls and adds to its mechanical strength, especially in cereals. Meristems of cereals contain specializes Si-accumulating cells

Nutrient uptake



Taiz, Zeiger, 2006

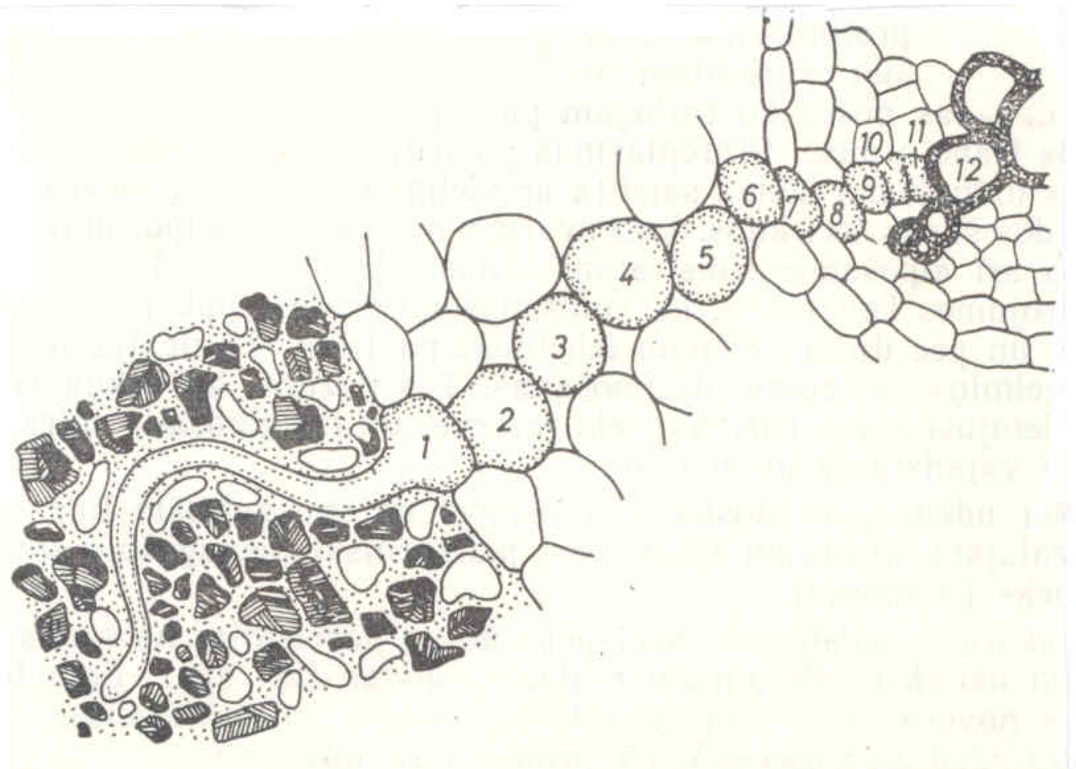
Root hairs — outgrowths of the root epidermis cells

Zone of maturation - most of the root hairs

Zone of cell elongation

Zone of cell division (contains root apical meristem)

Transport of water and nutrients in the root



1 — root hair

2-6 — root cortex cells

7 — endodermis cell

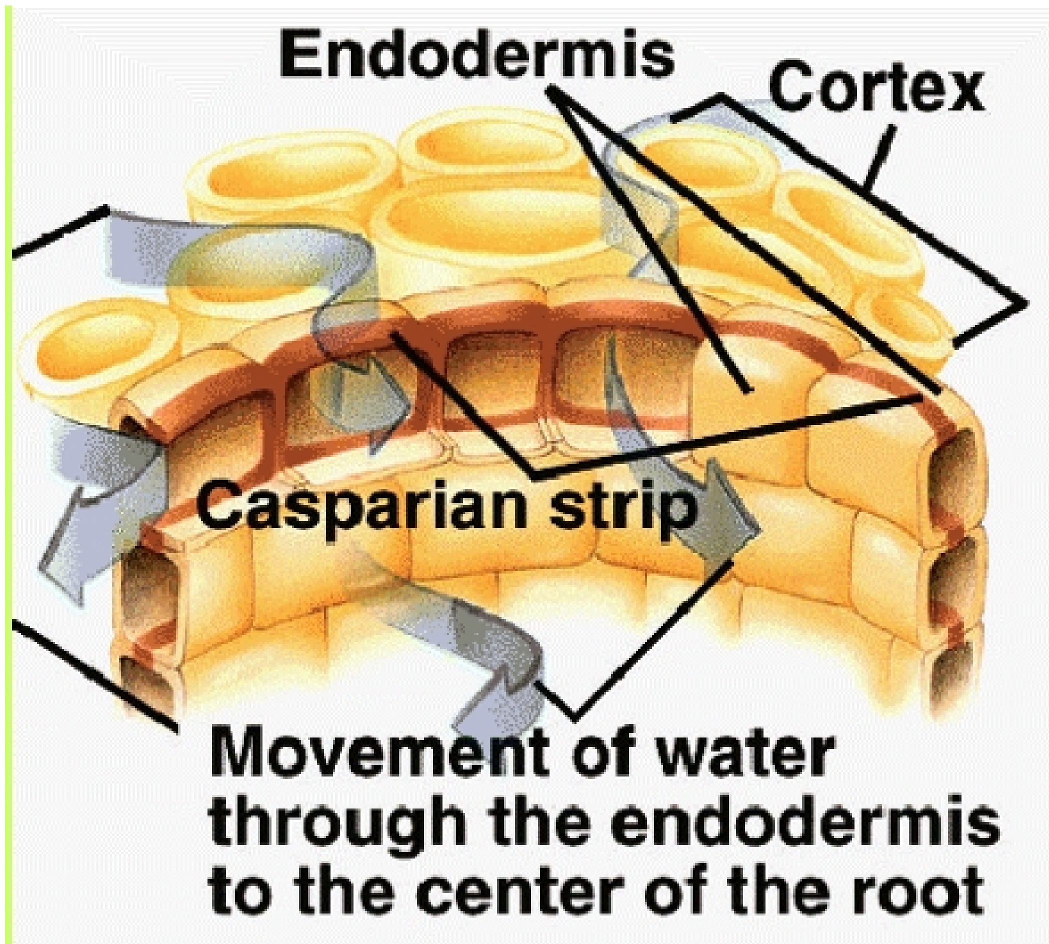
8 — pericycle cell

9-11 — central cylinder cells

12 — vessel element (trachea)

Mauriņa, 1987

Nutrient transport to the root central cylinder

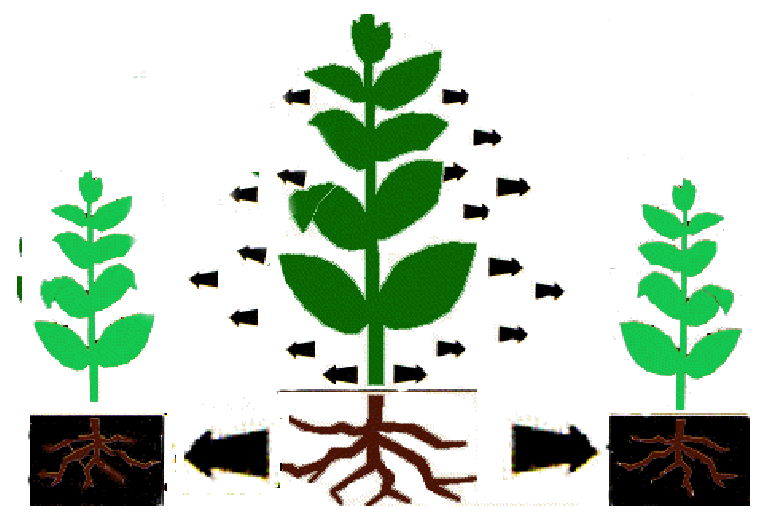


Root exudates, allelopathy

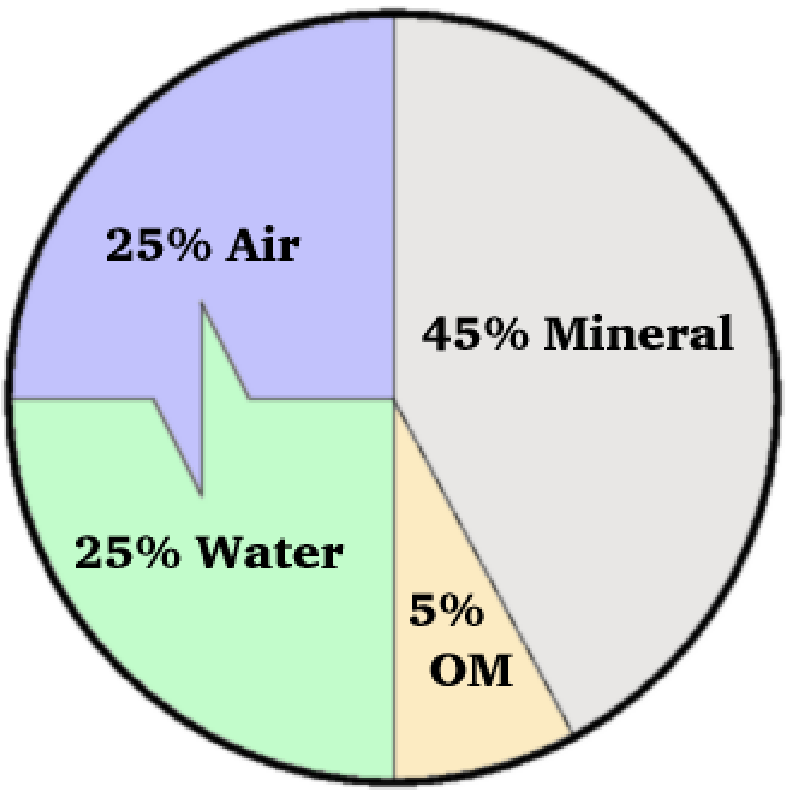
Plant roots can axudate into the soil:
- aminoacids
- acids
- nutrients (Ca, Na, K, Co)
- sugars
- DNA a.o. nucleic acids, phenols
- growth regulators

<u>Examples:</u>
beans (*Fabaceae*) — aminoacids
oil plants — phosphoric acid, nutrients
apple trees (*Malus*) — phenols
couch grass (*Elytrigia repens*) — benzoic acid, cynnamic acid that impede root growth in other plants (Baziramakenga et al. 1994); phenols

Allelopathy – influence of one species on other species by means of root exudates or volatiles



Soil composition



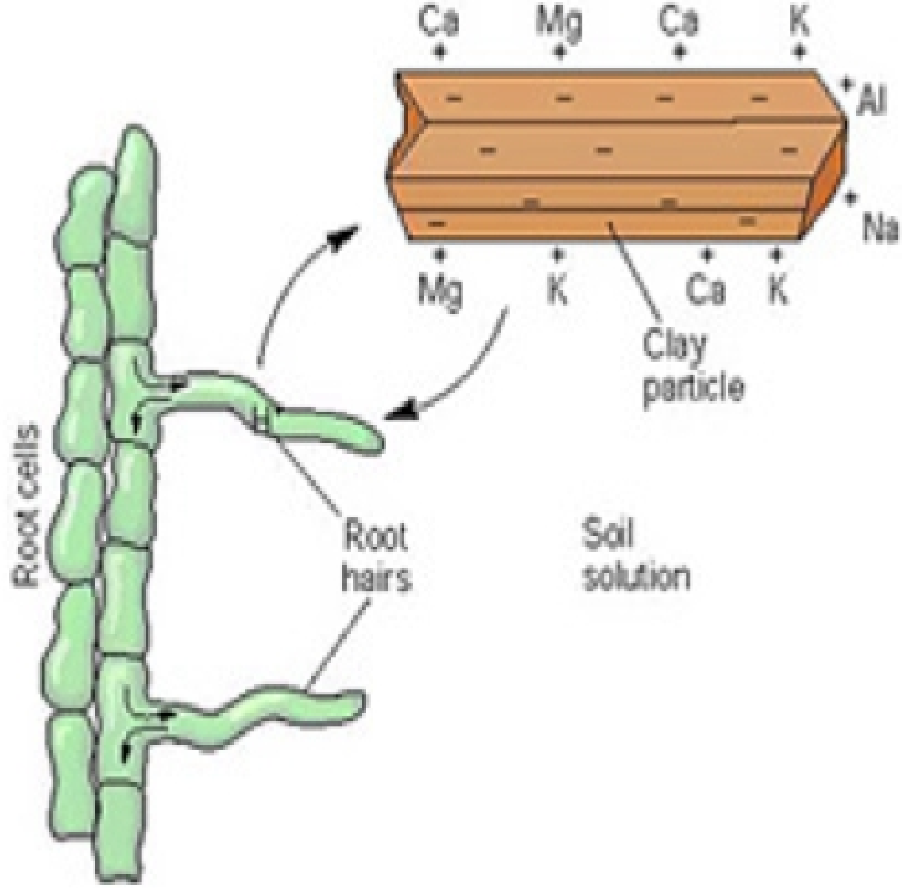
Pant nutrients

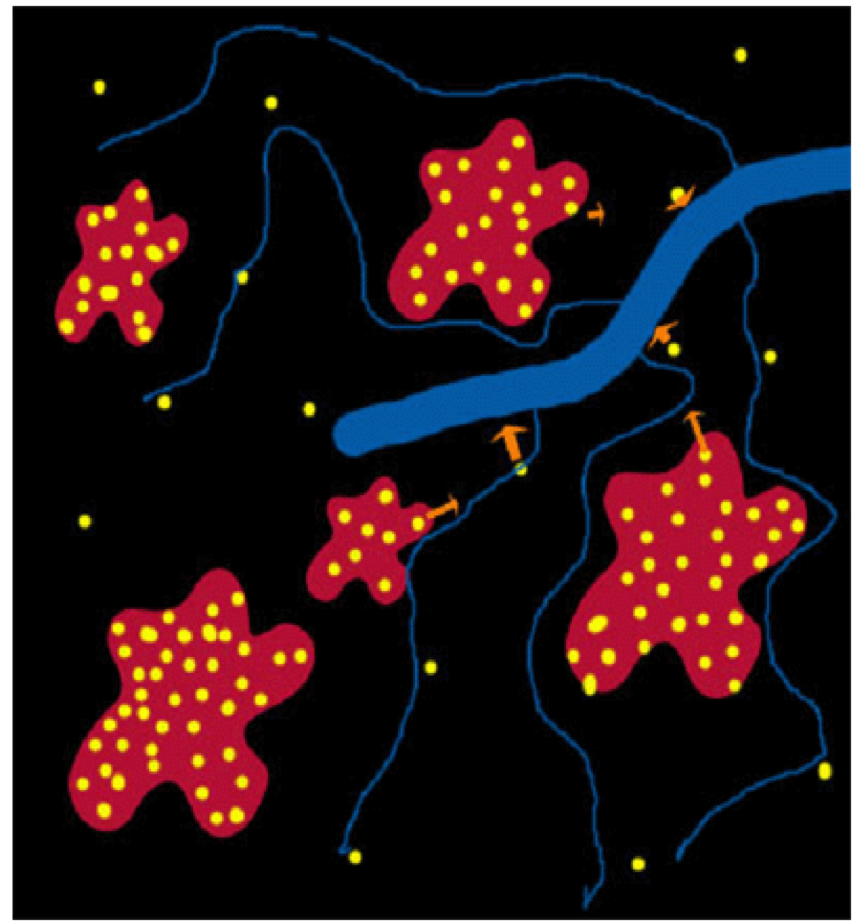
- in the soil solution
(available to the plants but rapidly leached)

- adsorbed on soil particles
(available to plants through exchange absorption)

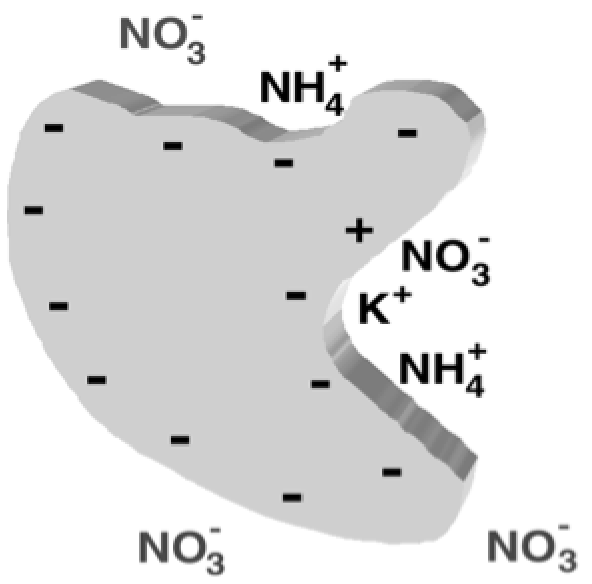
- insoluble
(poorly available to the plants)

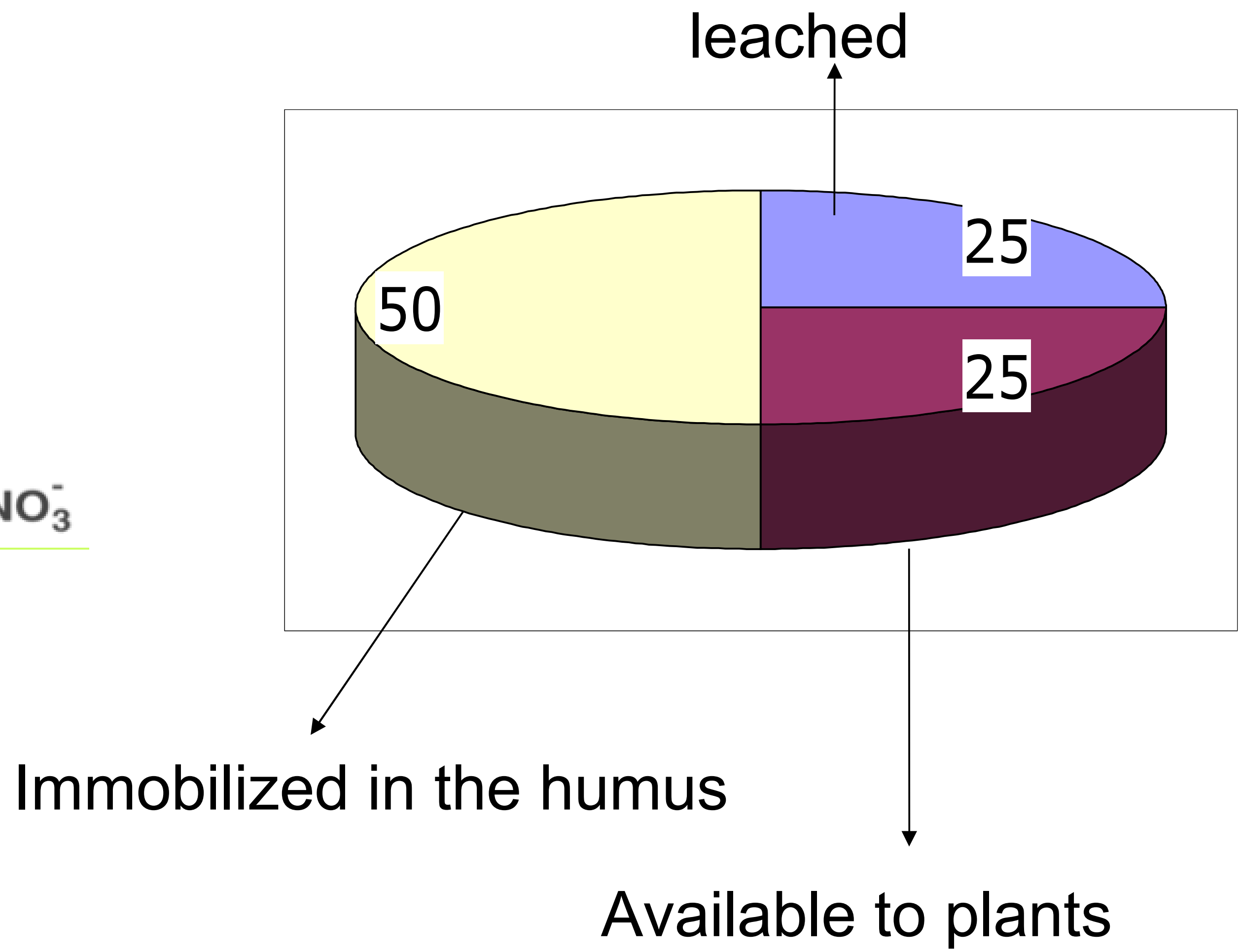
Cation exchange



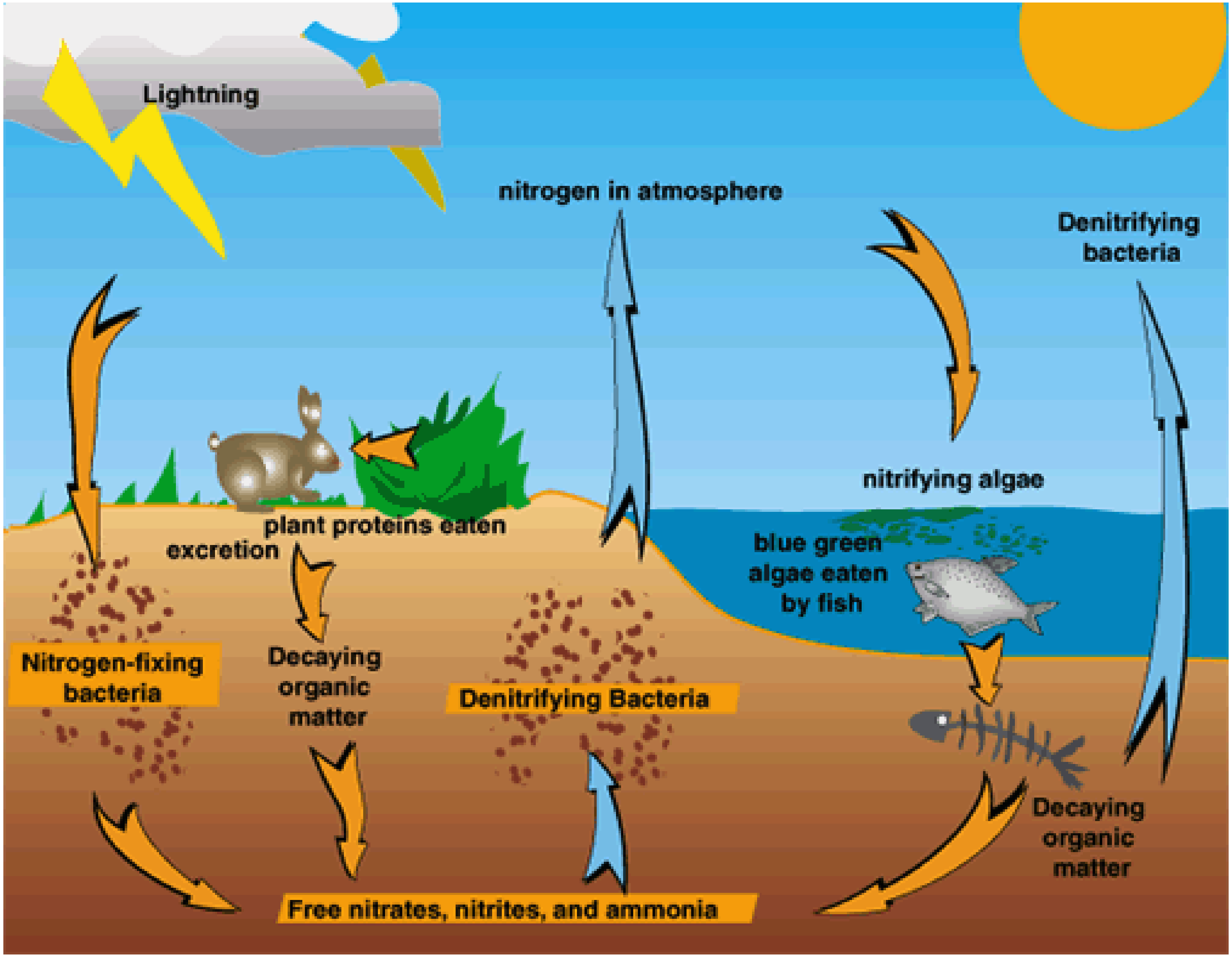


Nitrogen in the soil





Nitrogen cycle



$N \equiv N$

Why nitrogen is a limiting factor?

$N_2 + 3H_2$ $\longrightarrow$---> $2NH_3$

300-500 °C, 25 MPa (246 atm)
Harber-Bosch process

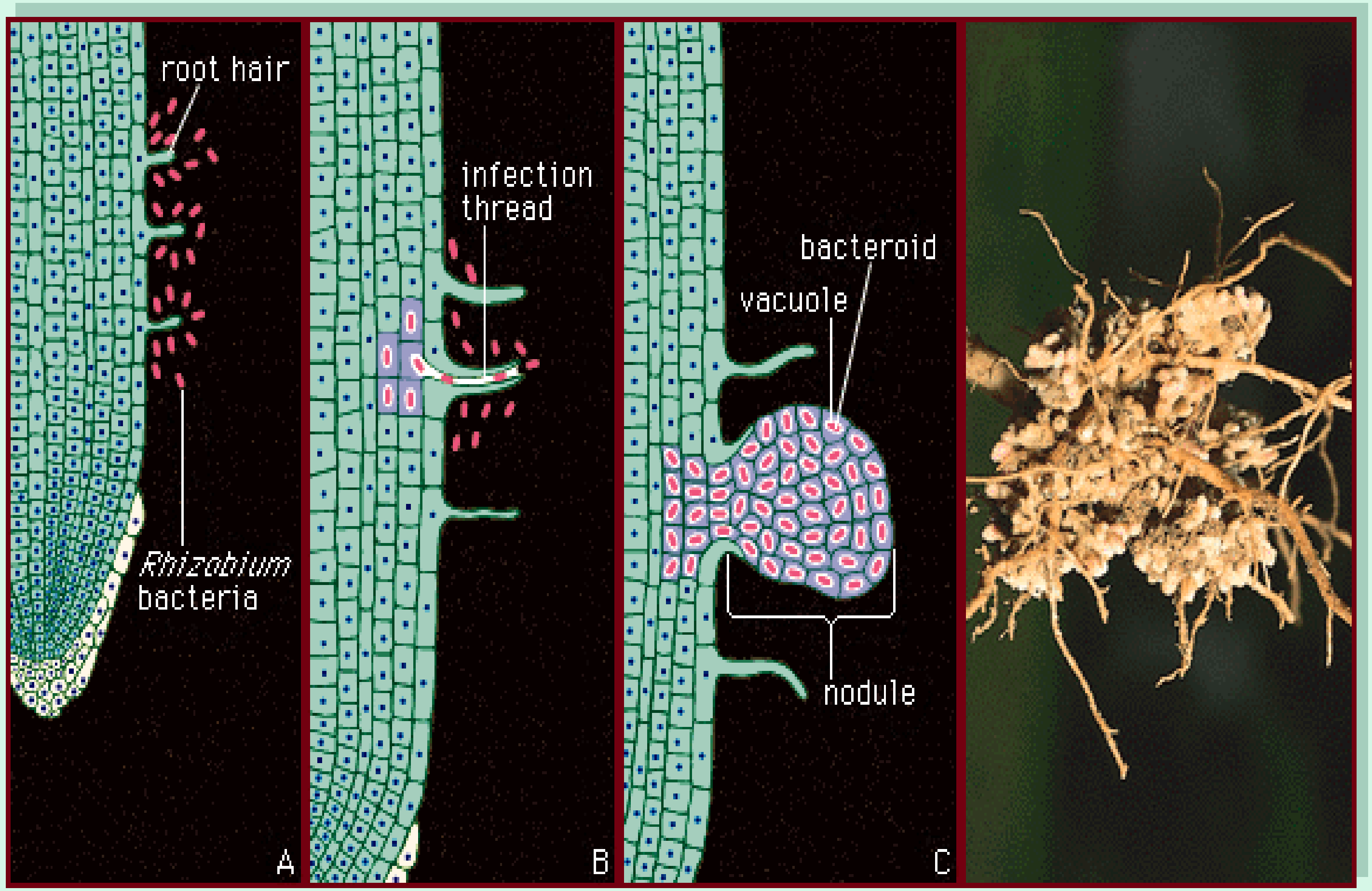
Bacteriorhiza, symbiosis with nitrogen-fixing bacteria

Peas grown in sand culture (no N supply)

1, 2 – no N-fiing bacteria,
3 – N-fixing bacteria (nodules) on the roots

University of Reading, *Rhizobium* research group

Bacteriorhiza, symbiosis with nitrogen-fixing bacteria



The role of symbiosis with N-fixing bacteria:

· Plants acquire vitamins, anzymes and other physiologically active substances produced by microorganisms

· Microorganisms use organic substances produced by the plants

· Bacteria that fix atmospheric N: *Azotobacter, Clostridium, Klebsiella, Rhizobium, Actinomyces, Frankia, Azospirillum, Anabaena, Nostoc*

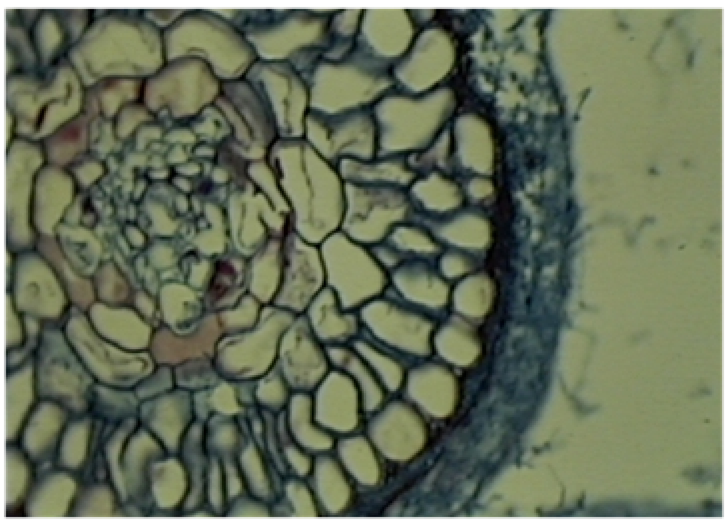
Enzyme nitrogenase converts N_2 into forms available to plants.

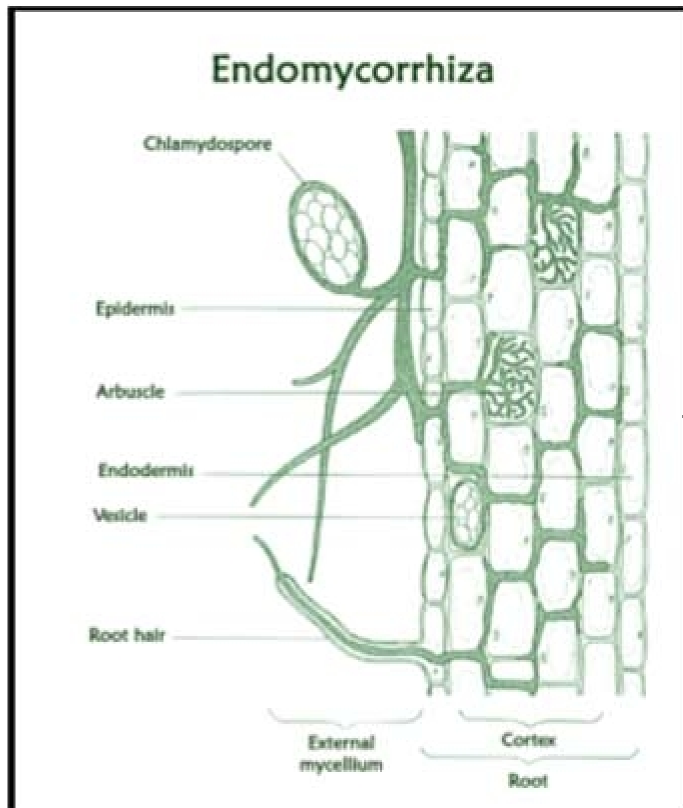
Mycorrhiza, symbiosis with fungi

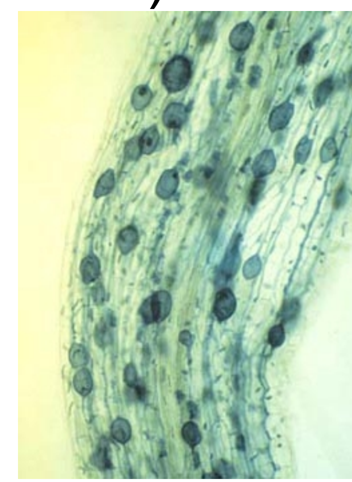
ECTOMYCORRHIZA

(10% of plans, woody species)

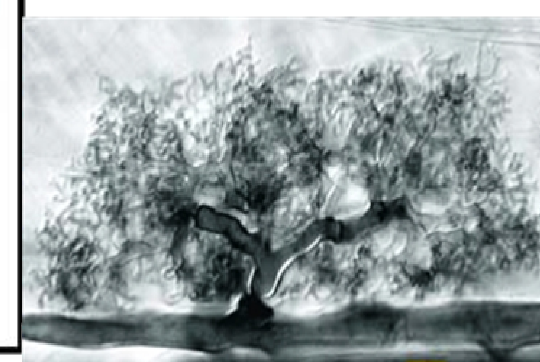
ENDOMYCORRHIZA (vesicular-arbuscular mycorrhiza, VAM)





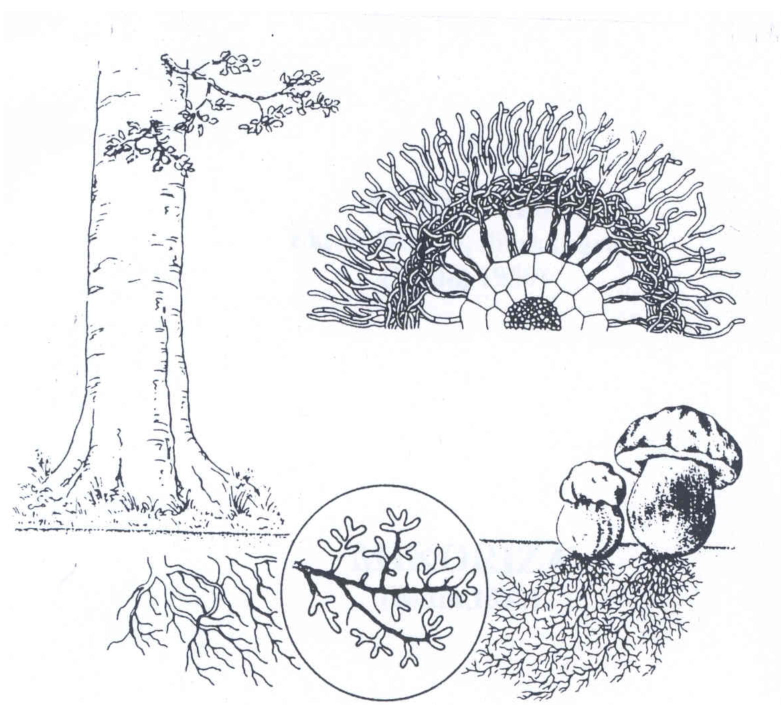


The American Phytopathological Society



http://plantscience4u.blogspot.com/2013/03/ectomycorrhizae-and-endomycorrhizae.html

The role of mycorrhiza:



Ectomycorrhiza on *Fagus* roots
Mohr, Schopfer 1995

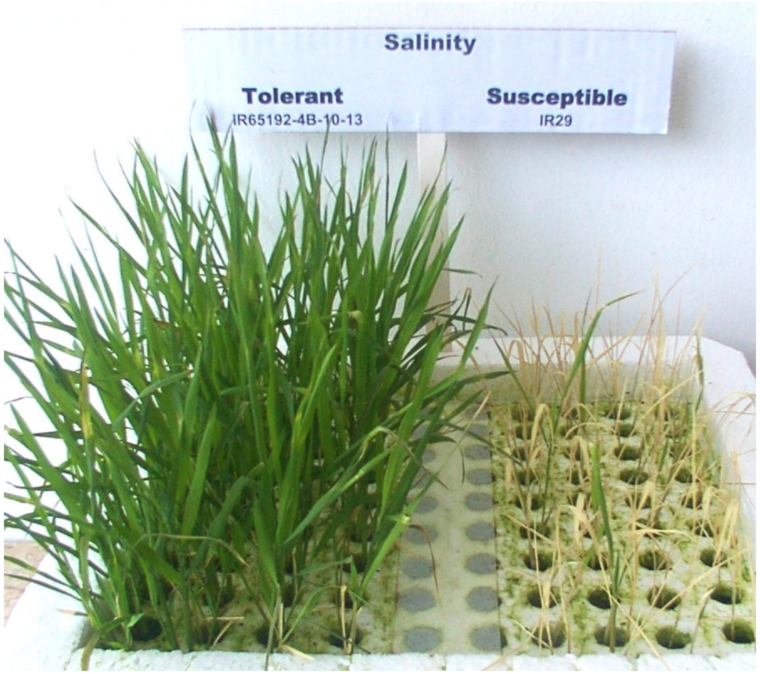
- increased root surface area
- fungal exudates lower soil pH that enhances uptake of *kas sekmē P, Zn, Cu*
- fungi produce enzymes that degrade organic substances in the soil
- Fungi produce antibiotics, phenols and other chemicals that inhibit pathogenic fungi e.g. *Boletus bovinus* on *Picea* roots inhibits root rot (*Heterobasidion*)
- Fungi bind heavy metals.
- Plants supply fungi with carbohydrates, vitamins and other organic substances

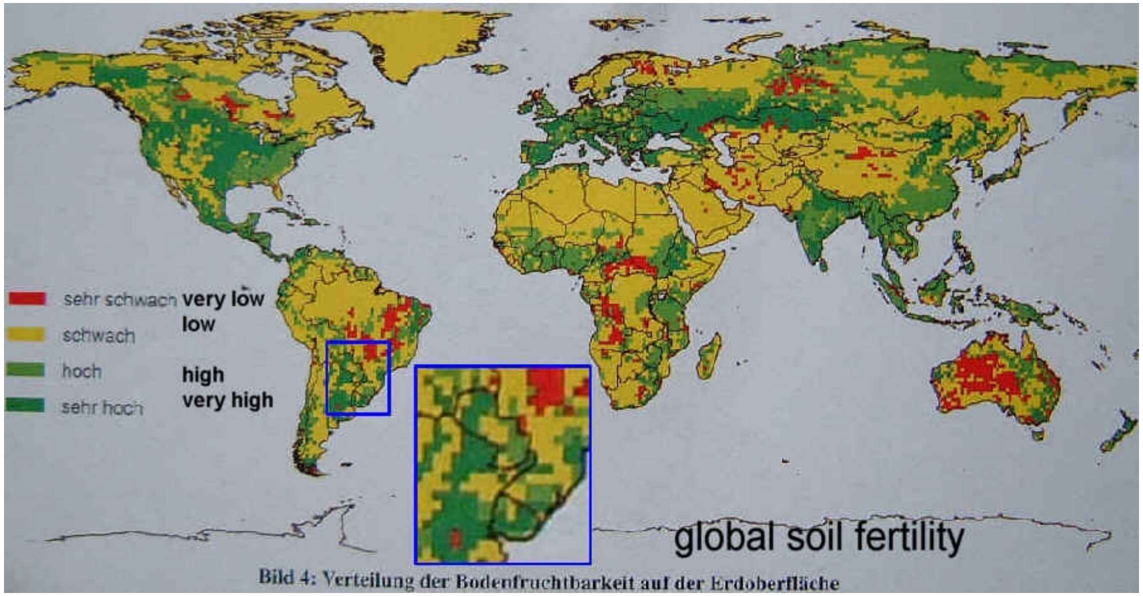
Soil salinity:

•Impaired water uptake

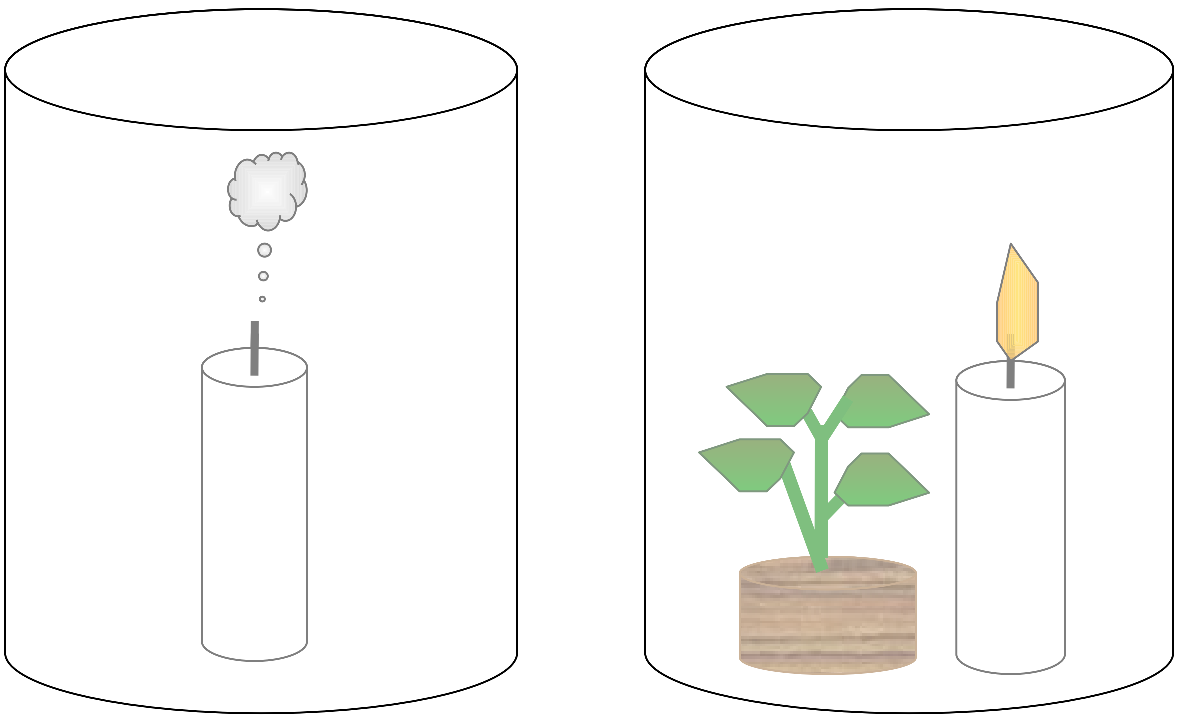
•Impaired nutrient uptake

•Na^+, Cl^-, and Mg^{2+} toxicity





Photosynthesis



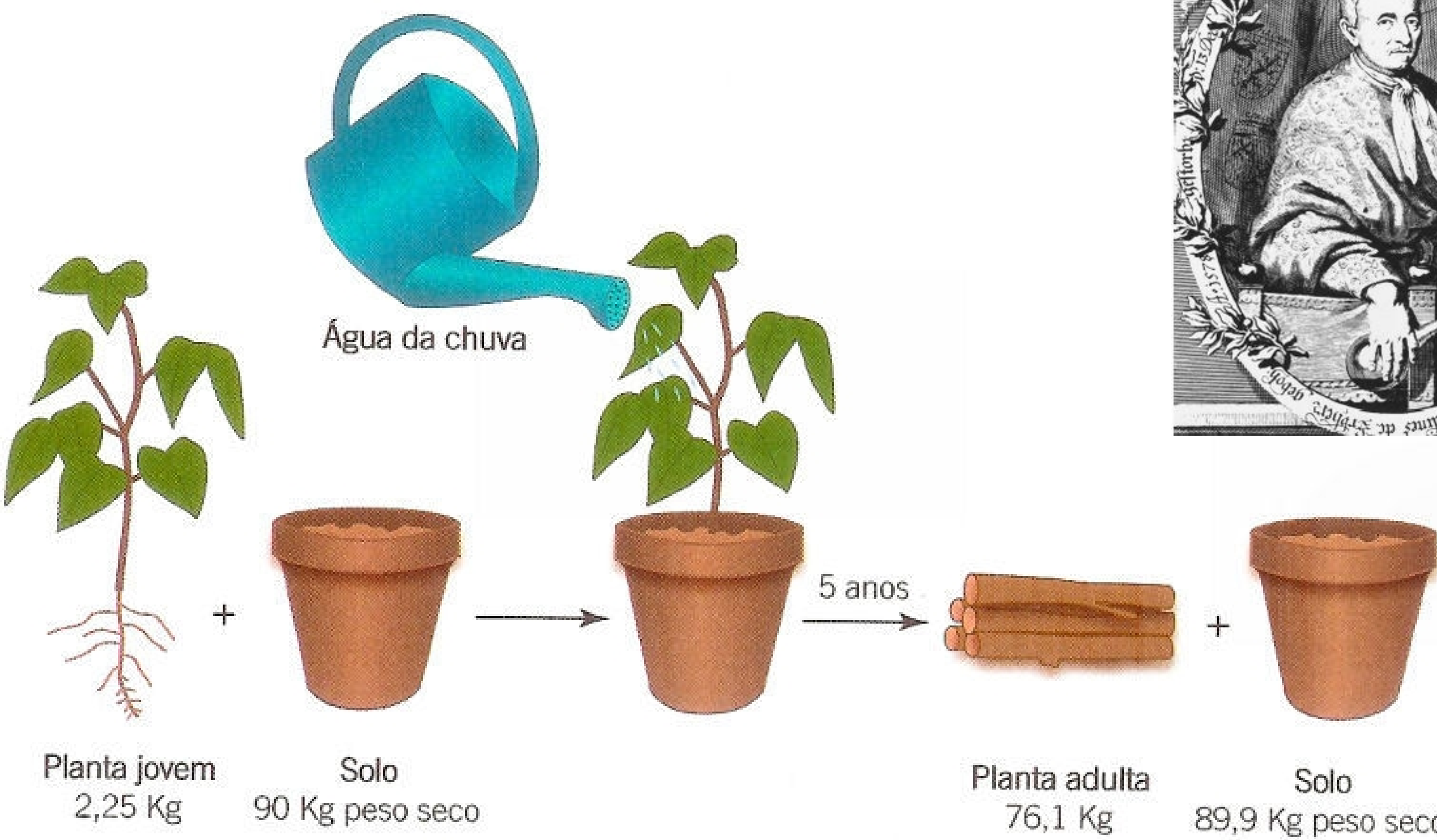
1771. g. J. Priestley's experiment

Joseph Priestley

Photosynthesis – transformation of light energy into chemical energy of organic molecules, using carbon dioxide and water. Photosynthesizing organisms are green plants and some bacteria

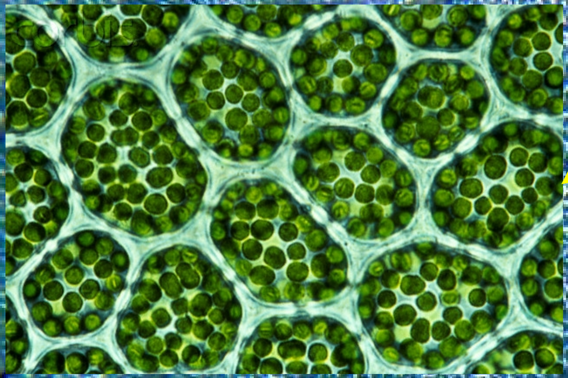
$$CO_2 + H_2O = [CH_2O] + O_2$$

Van Helmont's experiment, XVII century

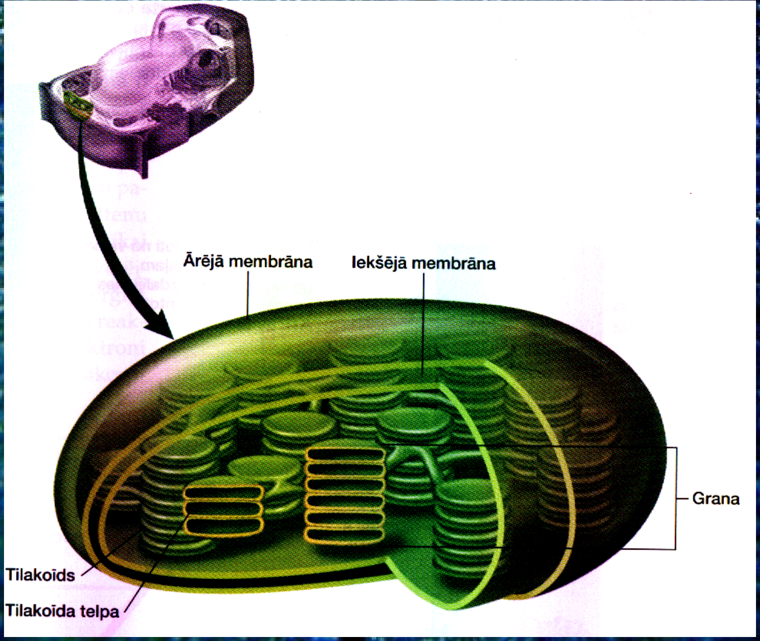


Does plant mass come from air and water?

n x 10^3 to n x 10^6 cells in a leaf



1-500 chloroplasts per cell

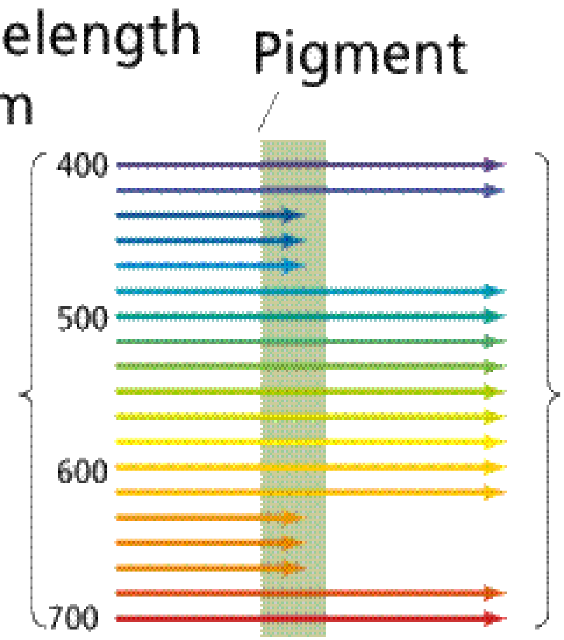


Plant leaves absorb light

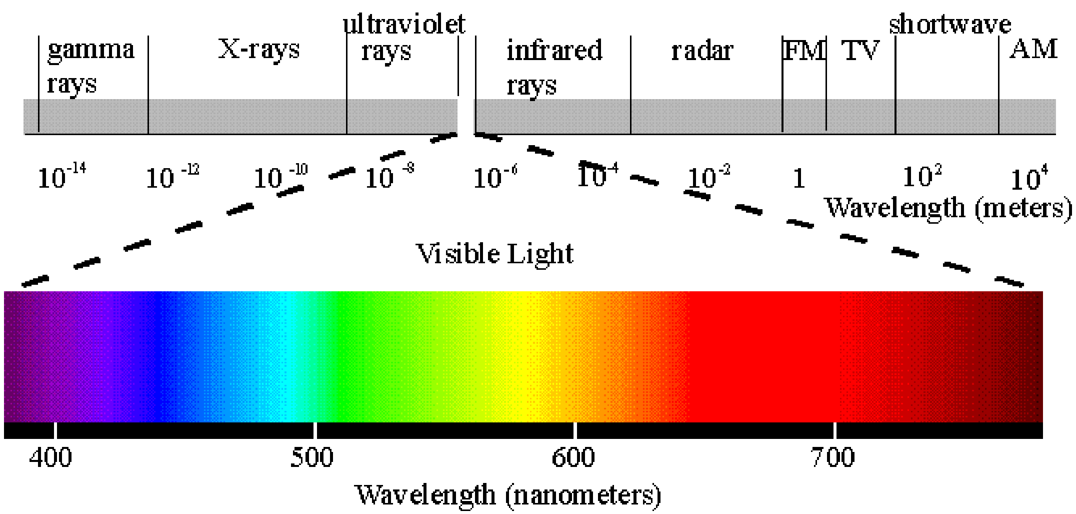
CHLOROPHYLL molecules are located on thylakoid membranes

Why plants are green

Visible light can be split into a spectrum of different wavelengths

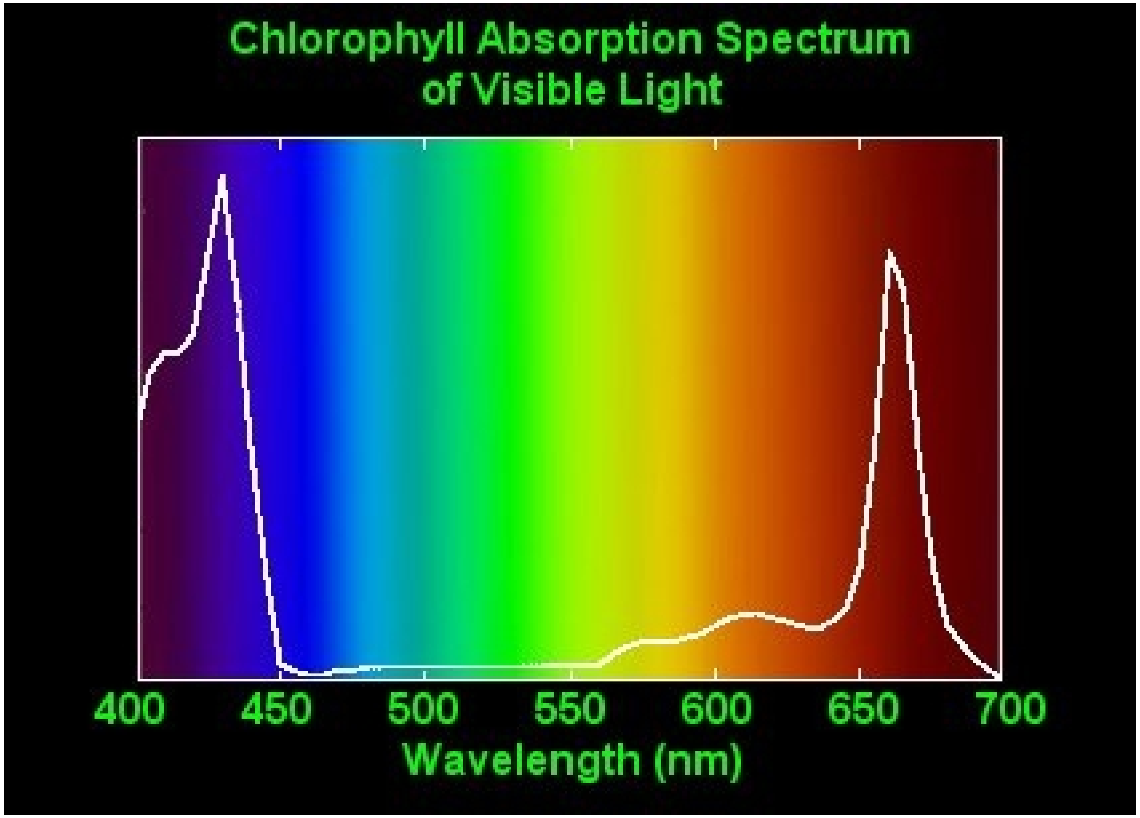


The sum of wavelenghts that are not absorbed we percieve as green



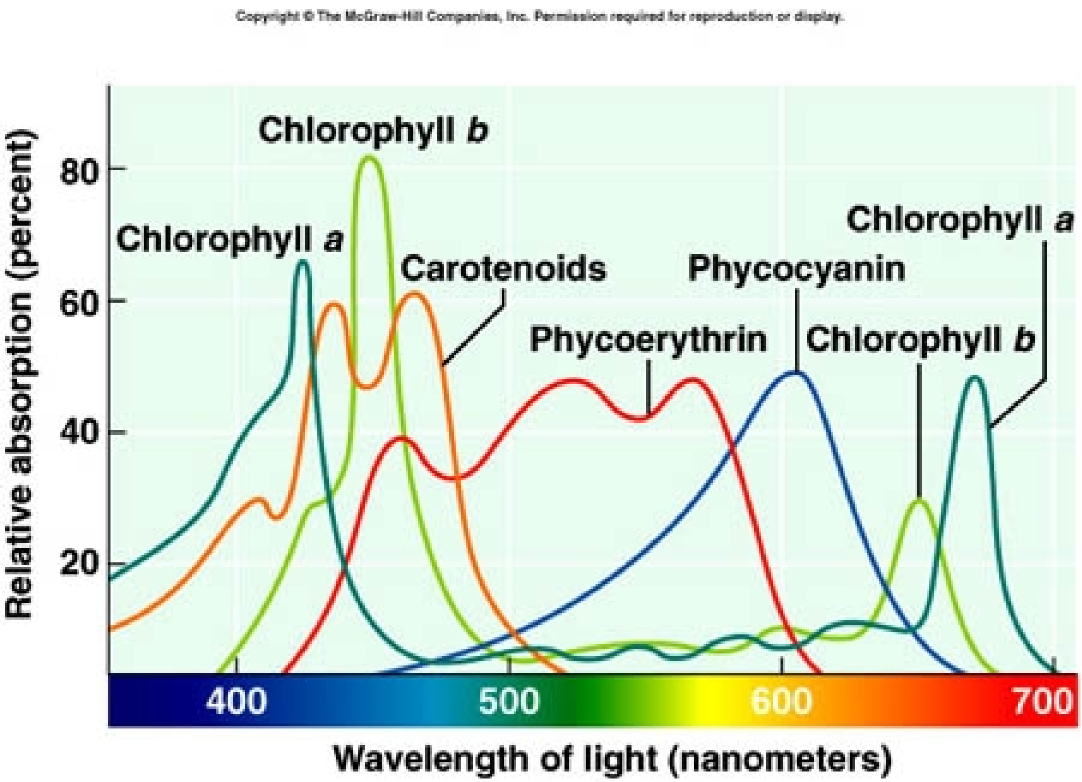
Leaf chloroplasts absorb certain wavelenghts

Absorption spectrum: shows what wavelengths are absorbed by the substance



Absorption spectrum of chlorophyll

Pigments in plant leaves



<u>Vascular plants:</u>

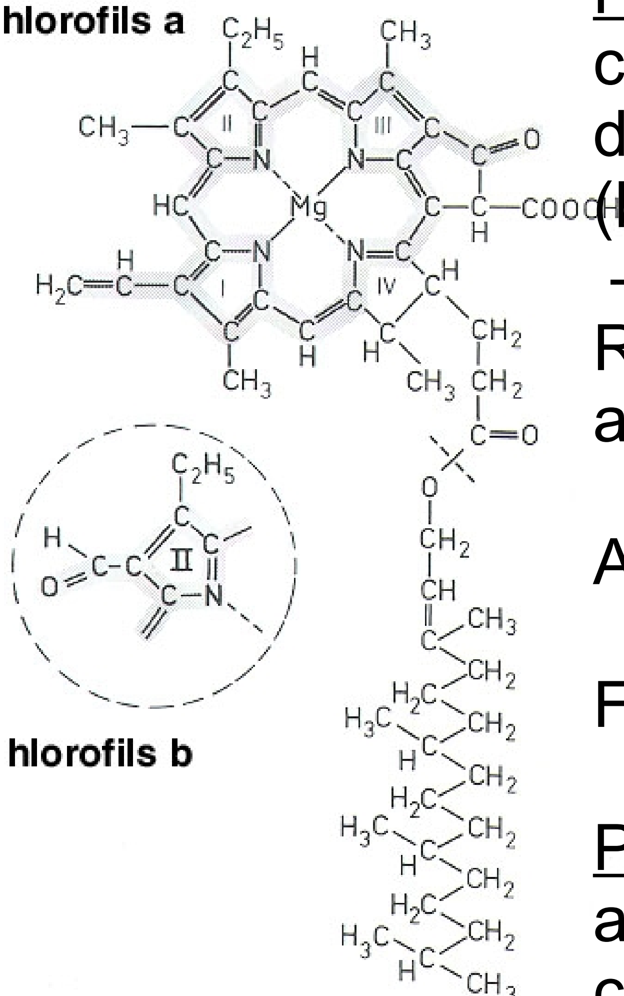
Chlorophyll (a, b)
careteniids
anthocyanins

Algae

Phycobilins
Phycocyanins

Chlorophyll

hlorofils a



hlorofils b

<u>Physical and chemical properties:</u>

compound ester
dissolves in organic solvents
(better in non-polar solvents)
 — ethanol, ether, benzene
Reacts ith strong bases (formation of chlorophyllid)
and acids (formation of phaeophytin)

Absorption maxima:

hla: 440, **660** nm; **hlb: 460**; **640** nm

Fluorescence: **668** nm

<u>Physioological function:</u>

absorbs nergy of light and transfers it to the reaction centers of the photosystems, where primary charge separaration and transformation of energy take place

Chlorophyll

Chlorophyll deficiency:

albinism: deficiency of pigment caused by genetic factors (also variegated leaves)
chlorosis: symtim of nutrient deficiency (Fe, Mg)
etiolation: pigment is not synthesized in darkness or at low light intensity

Acer campestre, lauku kļava

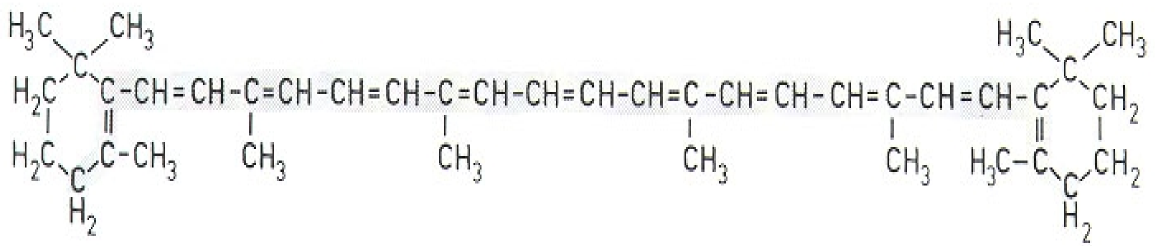
Urtica dioica, l
ielā nātre

Hepatica maxima
lielā vizbulīte

normal and etiolated plants

variegated maple form

Carotenoids



beta-carotene

Physical and chemical properties:

tetraterpenes (plymers of isoprene, modified)
dissolve in organic, non-polar solvents
acetone, benzene, chloroform

absorbtion maximum: **400-500** nm

xanthophylls — subclass of caroteoids, yellow pigments

Physiological role in plants:

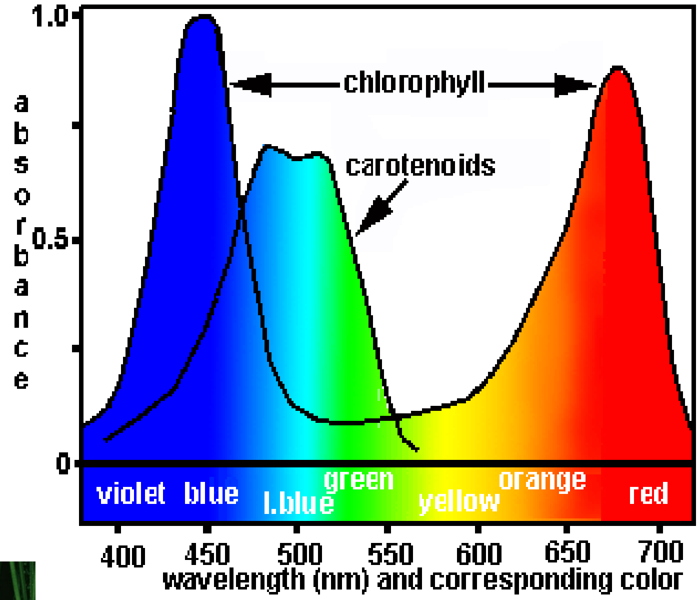
absorb light (accessory pigments), prevent damage to chlorophyll
orange and yellow colours of flowers and fruits;
beta-carotene is a precursor of vitamin A

Carotenoids

Acer saccharum, cukurkļava rudenī

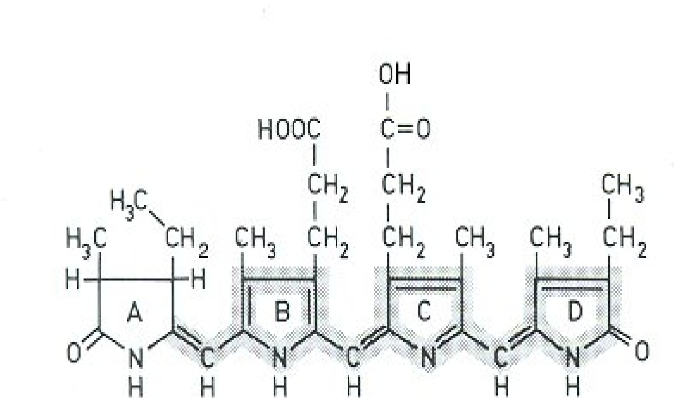
Acer palmatum, japānas kļava rudenī

Daucus carota, burkāns



Absorbtion spectra of chlorophyll and carotenoids

Phycobilins



Physical and chemical properties:

tetrapyrrholes

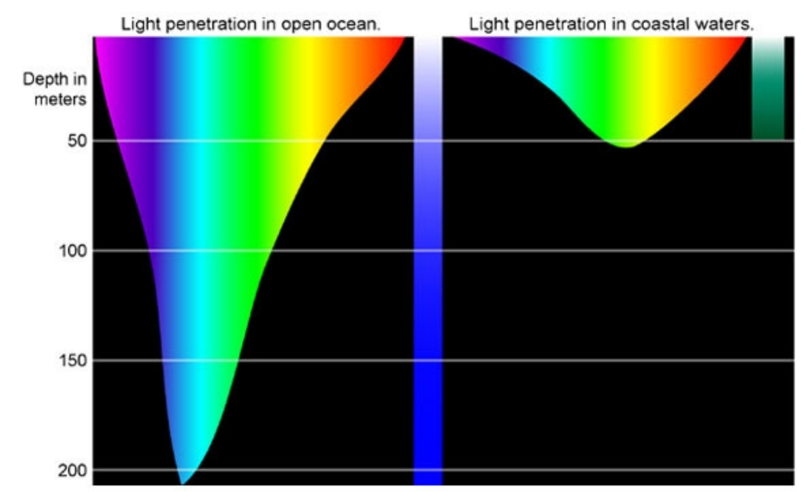
after autholysis dissolve in water,

do not dissolve in organic solvents

absorbtion maximum: **500-650** nm

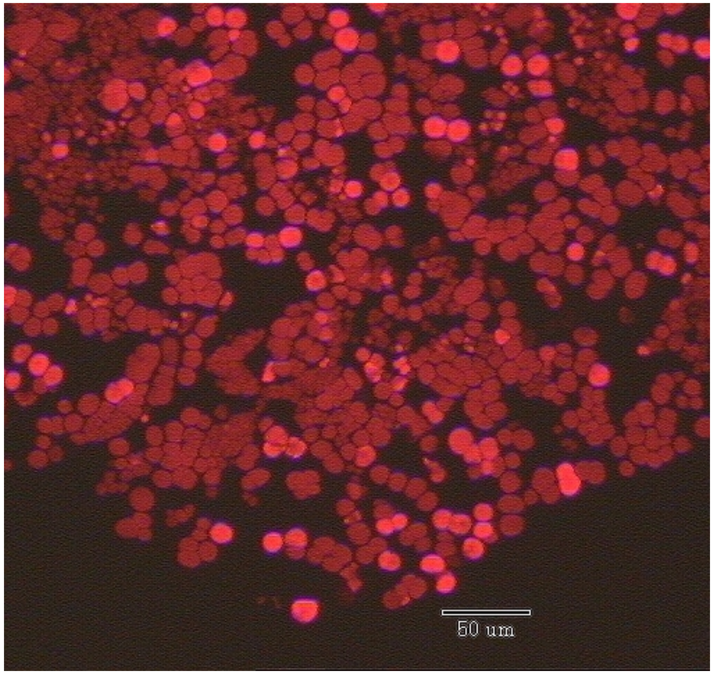
Physiological role: in algae and other photosynthesizing organisms that live in water these pigments are required for chromatic adaptation (absorb light and transfer the energy to chlorophyll)

Spectral composition of light at different depth in water:



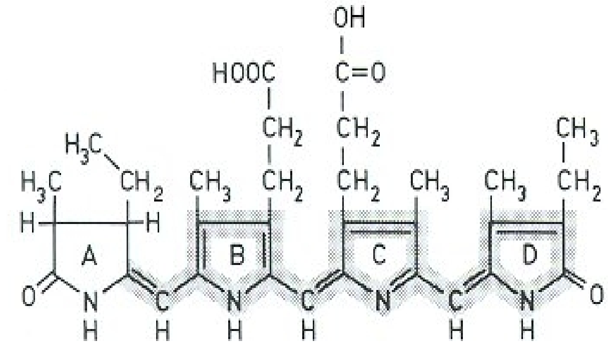
Phycobilins

Red algae
phycoerythrin



Cyanobacteria
phycocyanin

Anthocyanins



<u>Physical and chemical properties:</u>

glycosides

(polyphenolic substances bound to glucose)

dissolve in water

change colour at different pH

absorbtion maximum: 510-530 yellow, green and UV wavelengths

<u>Physiological role:</u> anthocyans are accumulated in the vacuoles, they absorb UV and excess blue light that can damage the photosystems;

give red, pink, purple, blue colours to flowers and fruits

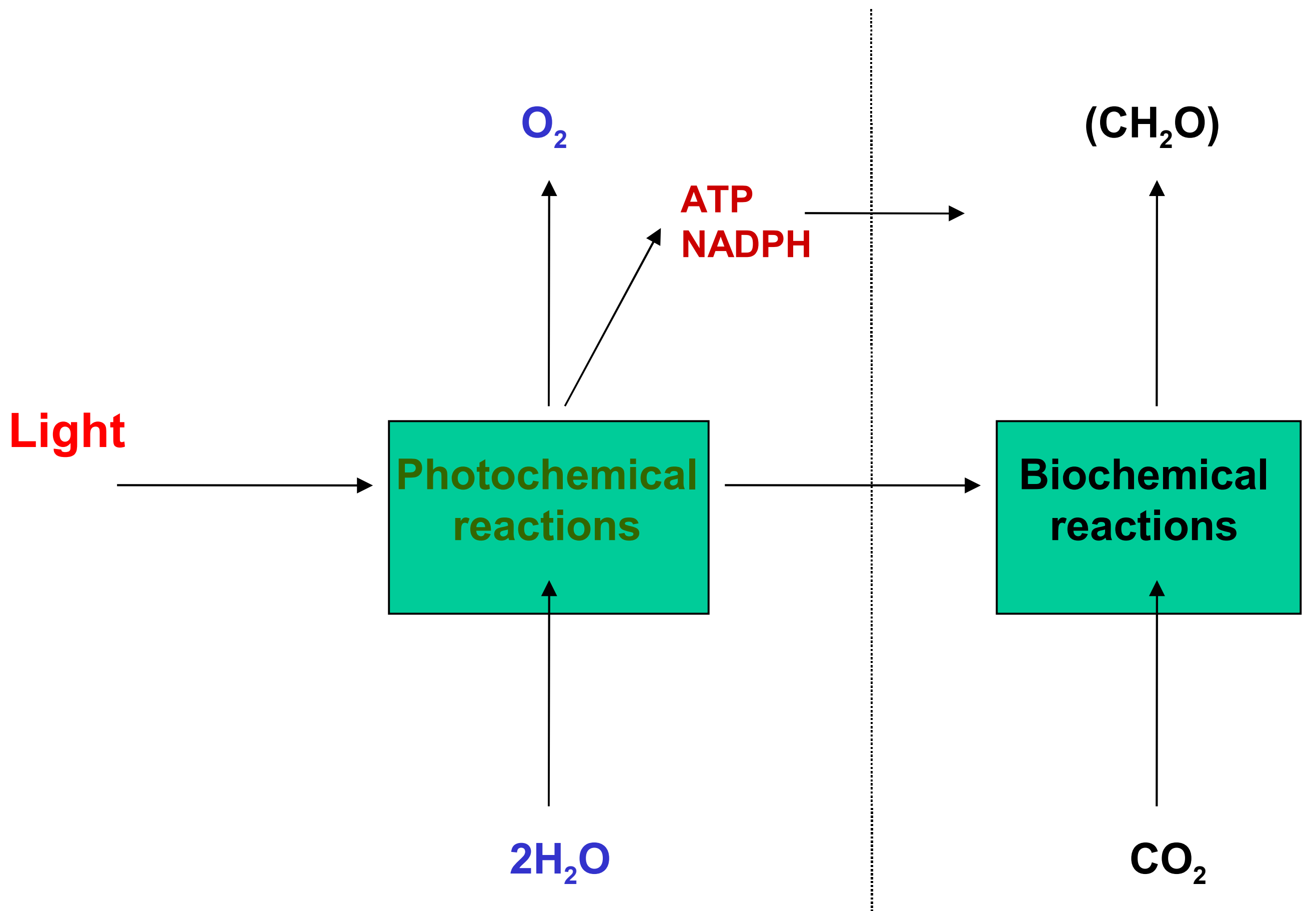
can participate in thermoregulation

participate in carbohydrate metabolism

Rubus plicatus krokainā cūcene

Fagus sylvatica – Eiropas dižskābardis Šķirne ‘*Purpurea*’

Reactions of photosynthesis



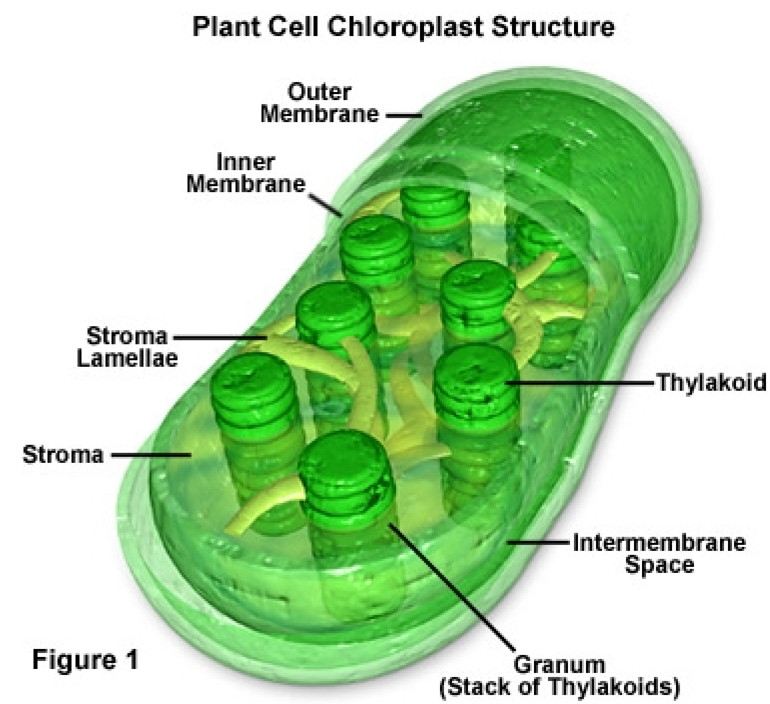
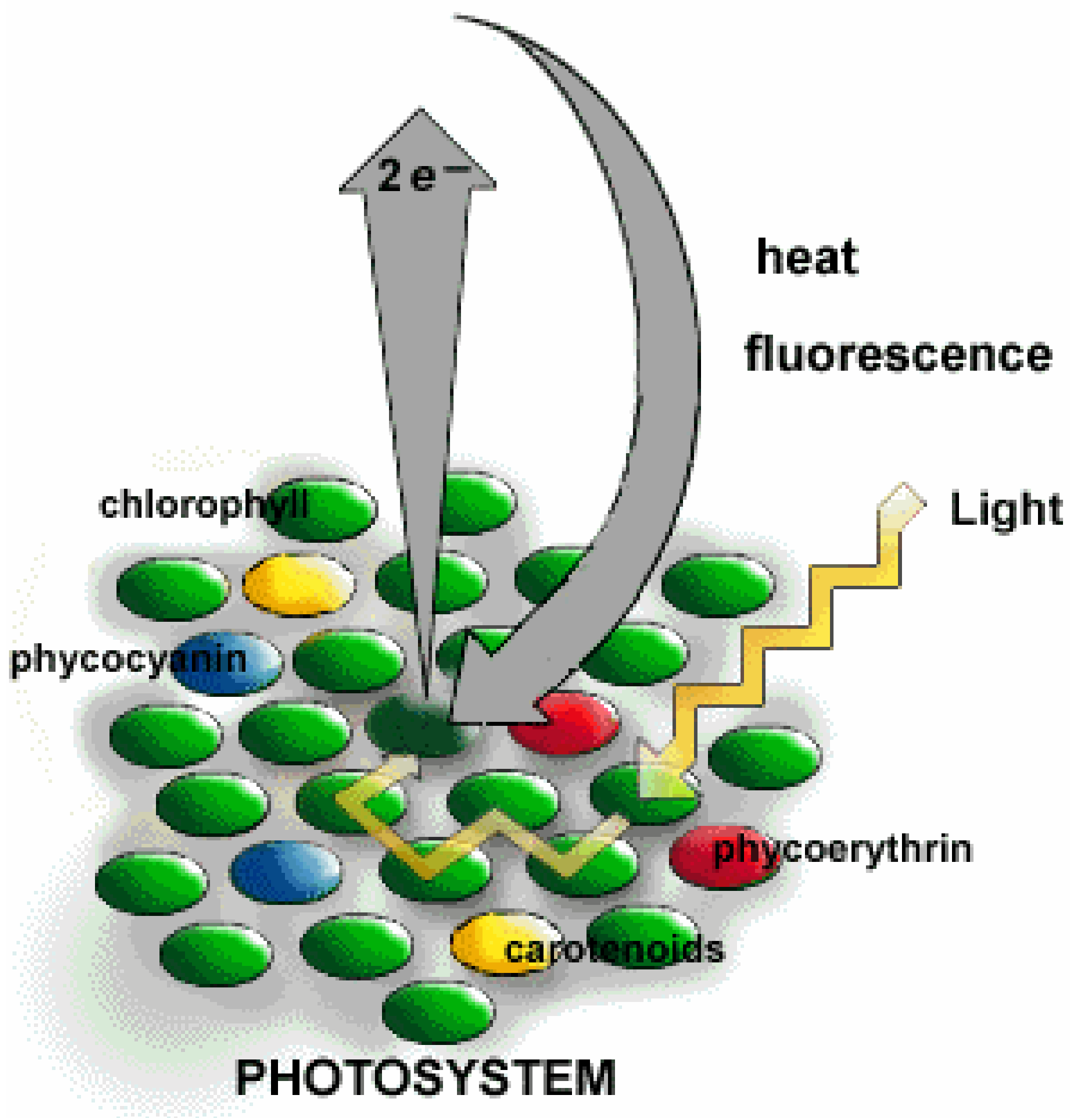


Figure 1

Chloroplast thylacoid membranes

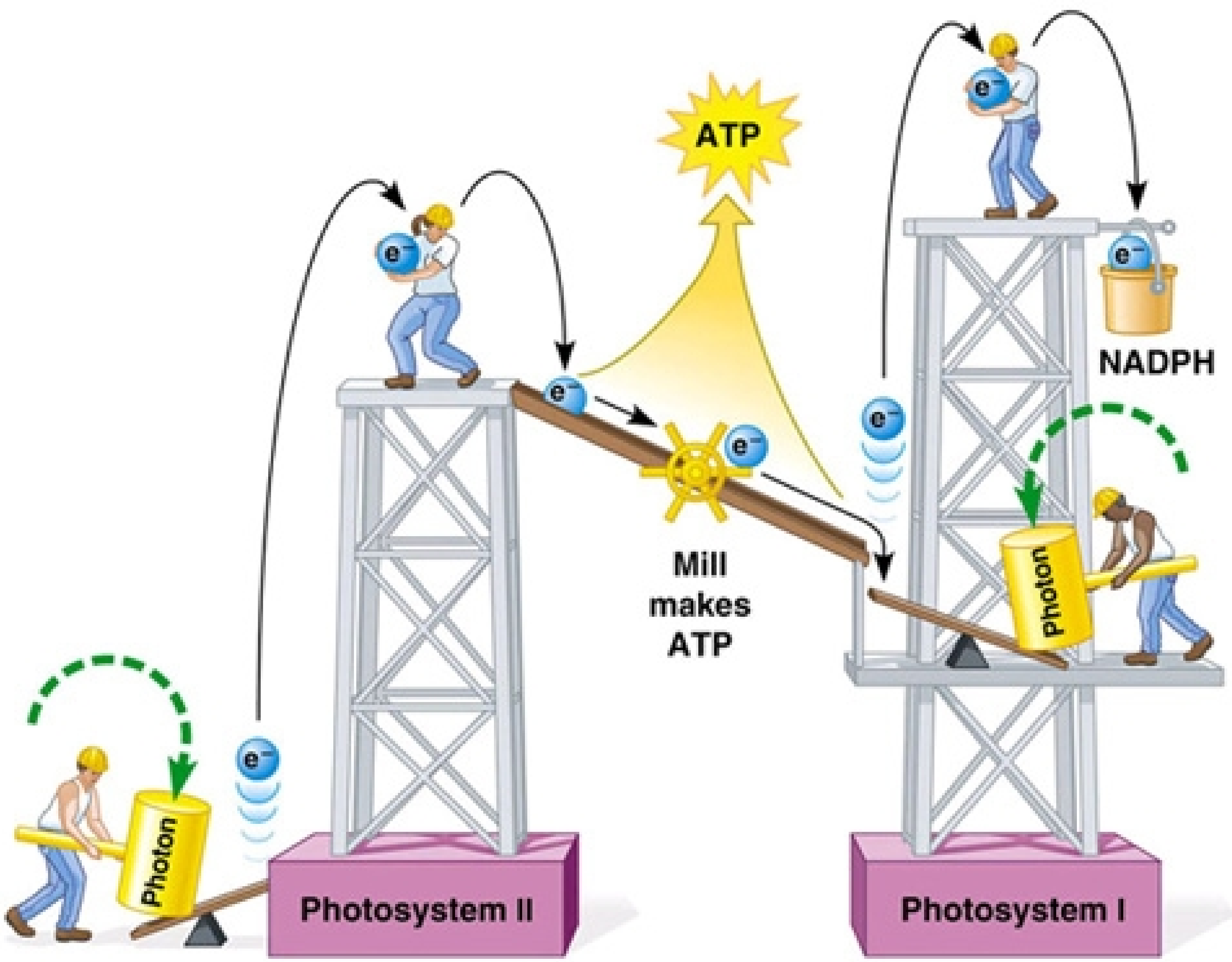
Chloroplast stroma

Photochemical reactions

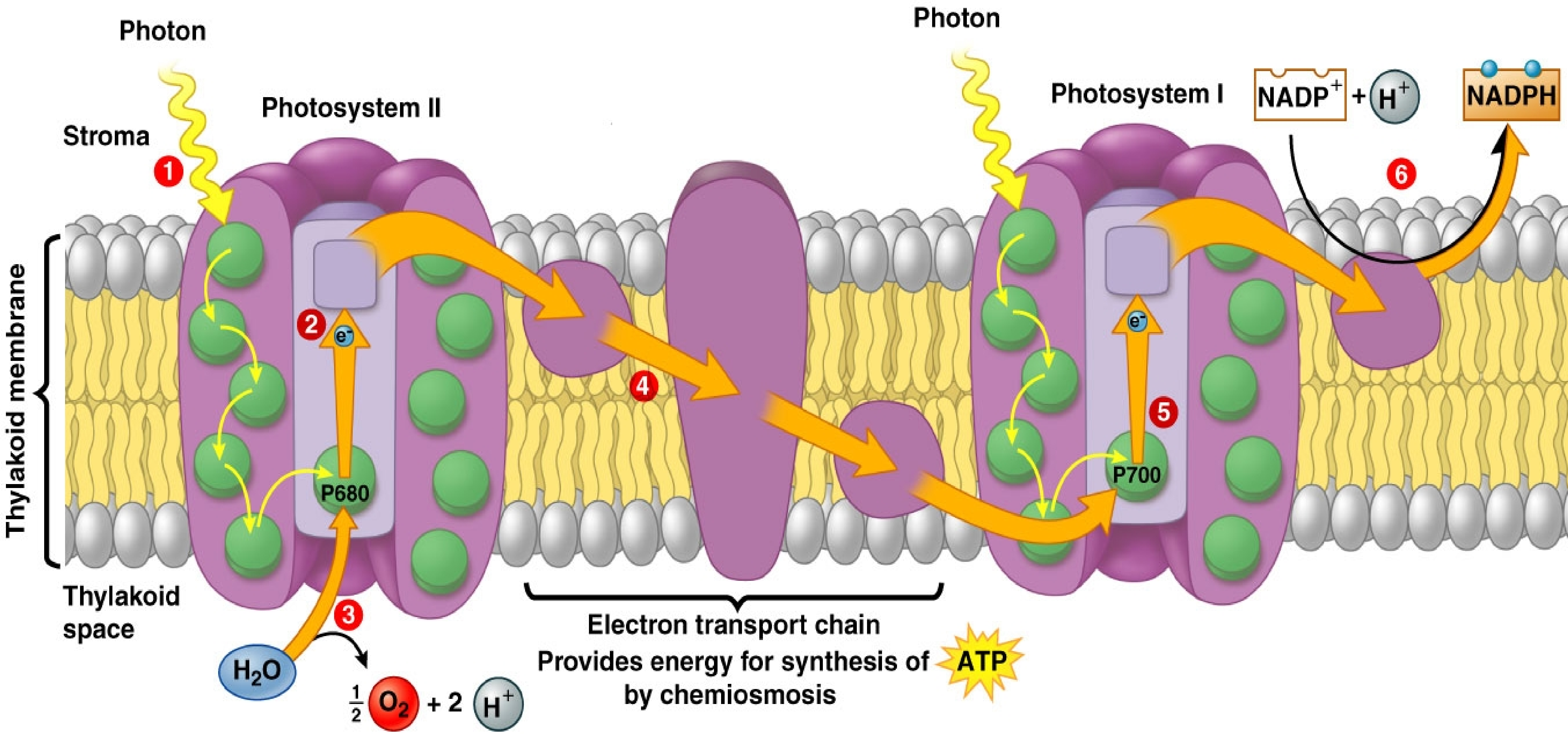


Photosystem absorbs light (energy)

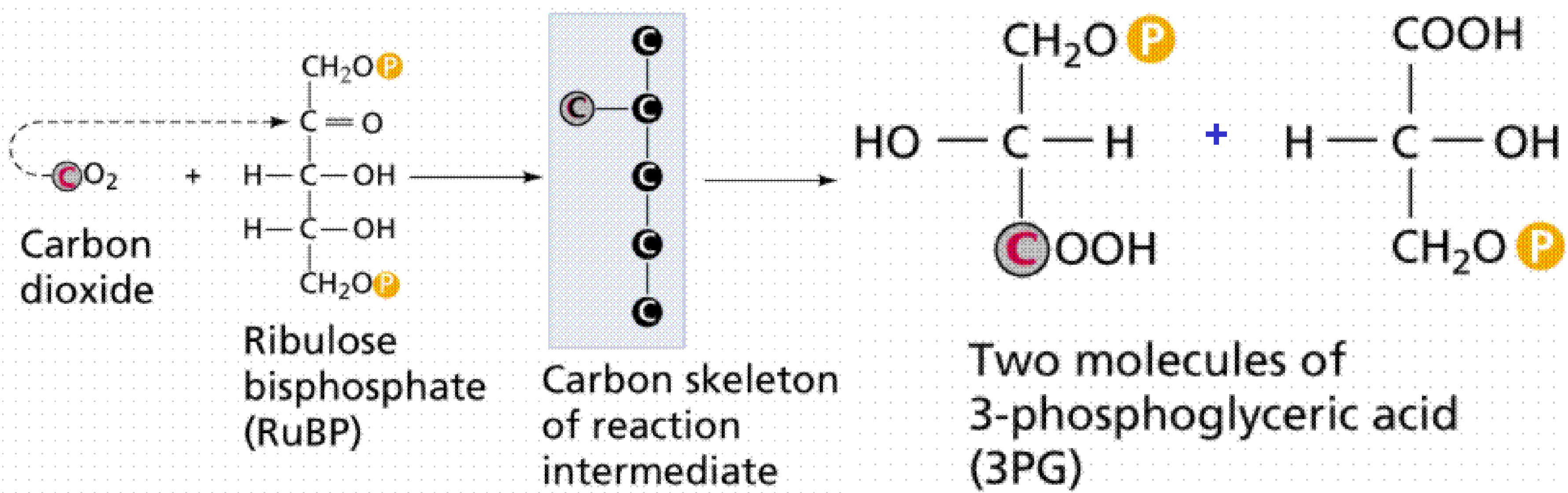
Photochemical reactions



Photochemical reactions



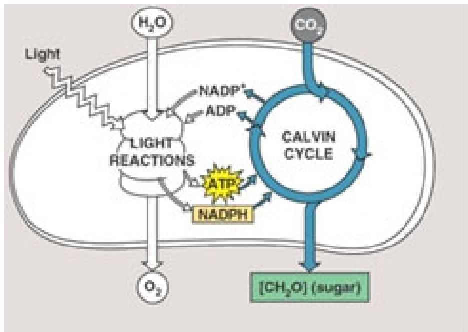
Biochemical reactions

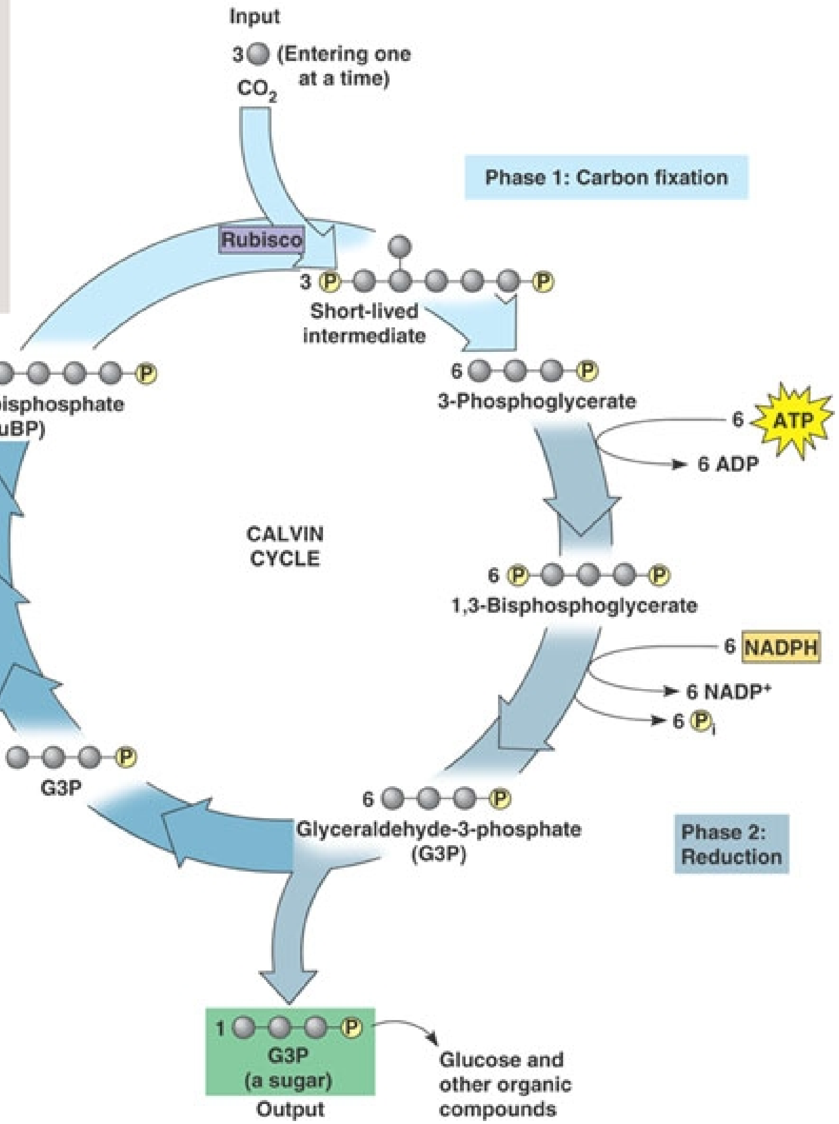


1 C + **5 C** ⟶ **6 C** ⟶ **3 C** + **3 C**

CO_2 assimilation

Biochemical reactions





CO$_2$ assimilation: Calvin cycle

Photosynthesis types

3 basic types, with different primary product of CO_2 molecule assimilation

C3

3-phosphoglyceric acid (3C)

C4

oxaloacetate (4C)

CAM

Crasulaceae **A**cid **M**etabolism

oxaloacetate (4C) – malic acid

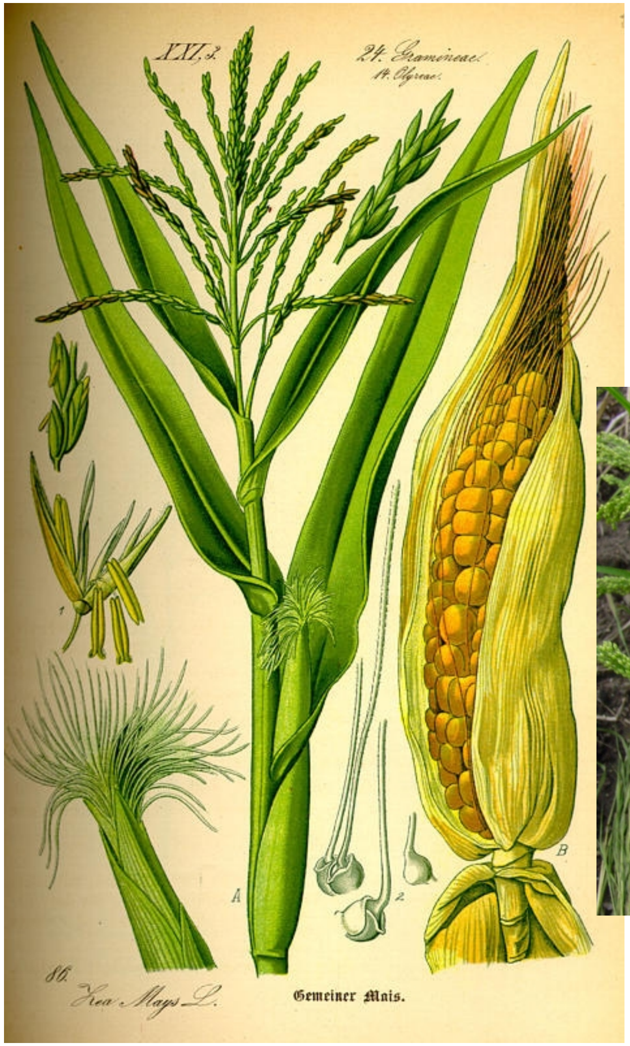
C3 type

Pinus sylvestris
parastā priede

Hepatica nobilis
zilā vizbulīte

Quercus robur
parastais ozols

C4 type

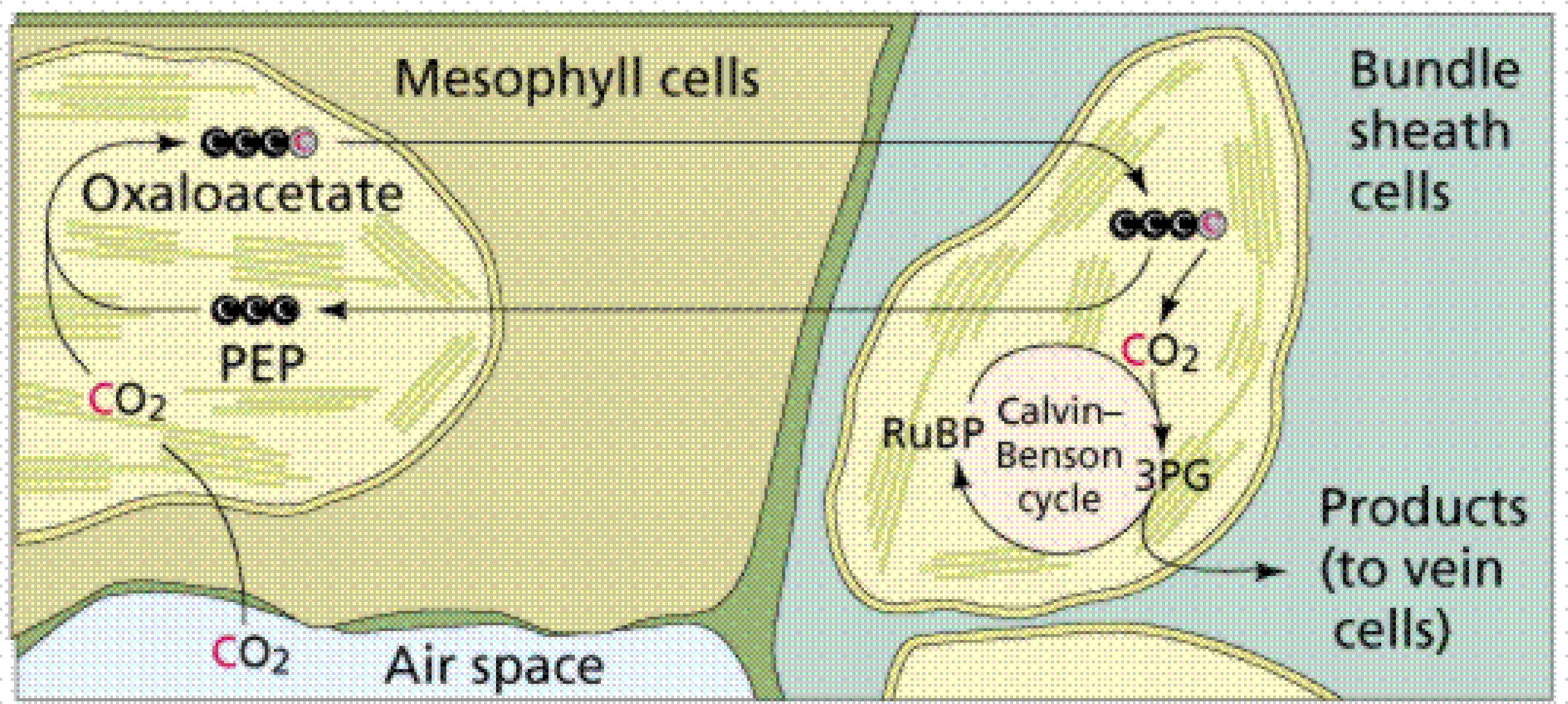


Zea mays
parastā kukurūza

Panicum miliaceum
prosa

Saccharum officinarum
cukurniedre

C4 ty[e



http://www.emc.maricopa.edu/faculty/farabee/BIOBK/C4leaf.gif

Mixed C3-C4 type

Lycopersicum esculentum ēdamais tomāts

Nicotiana tabacum parastā tabaka

Vitis labrusca Amerikas vīnkoks

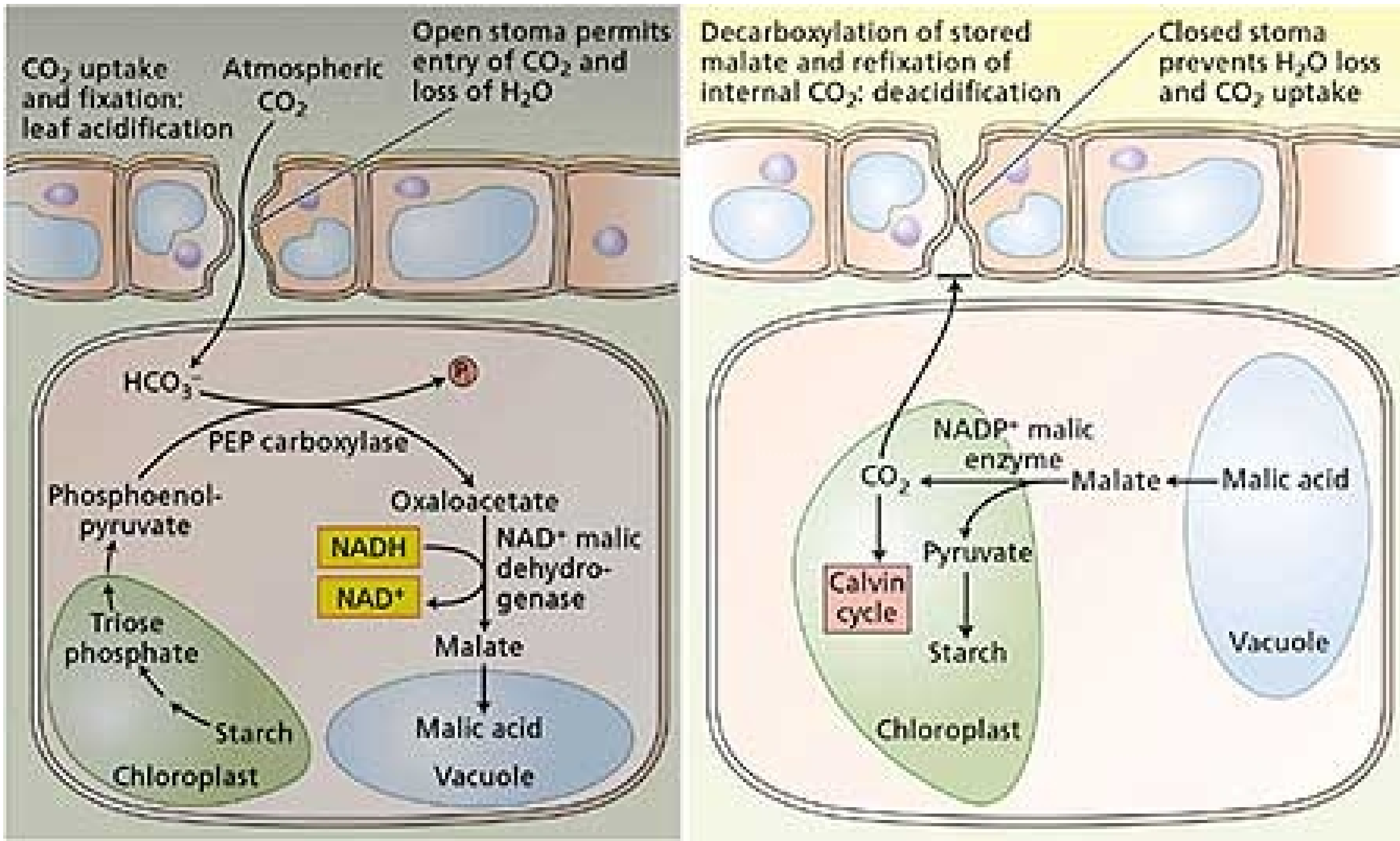
CAM type

Sedum acre
kodīgais laimiņš

Yucca filamentosa
Šķiedru juka

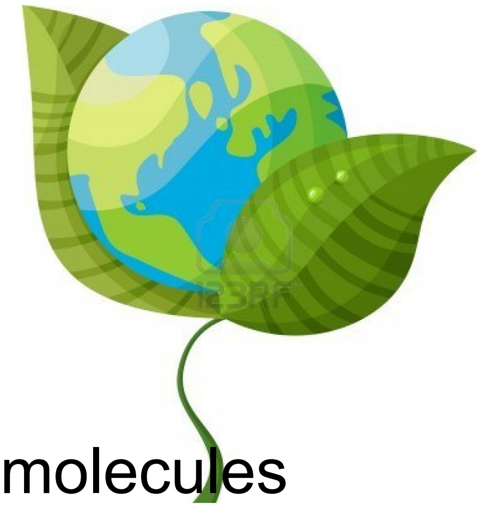
Crassula aquatica
ūdeņu biezlape

CAM type



http://www.cabnr.unr.edu/cam/images/Education/CAMDayNight.jpg

Role of photosynthesis



Transformation of solar energy into energy of organic molecules (1-2% of incident solar radiation)

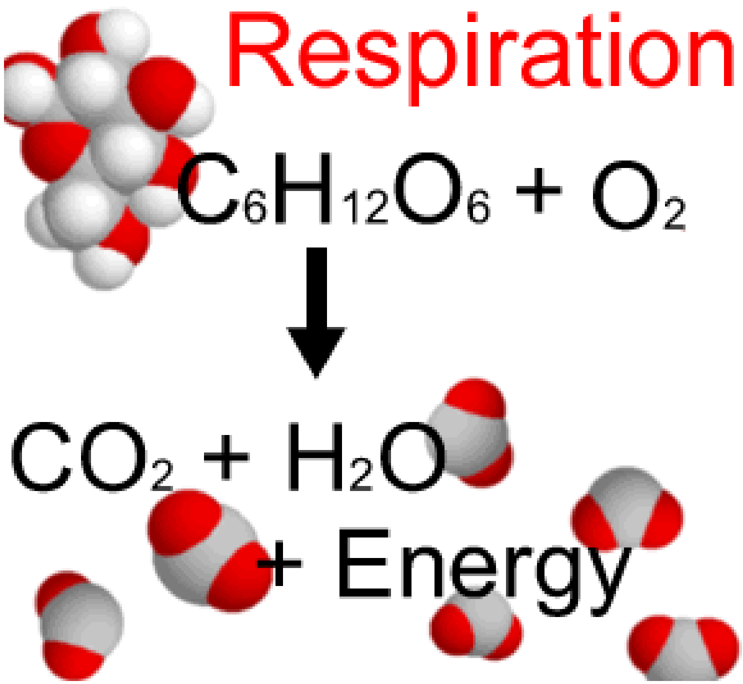
- Synthesis of organic substances (carbohydrates) (~2×10^{11} t a year)

- Renewed oxygen supply

- Prevents CO_2 build-up in the atmosphere

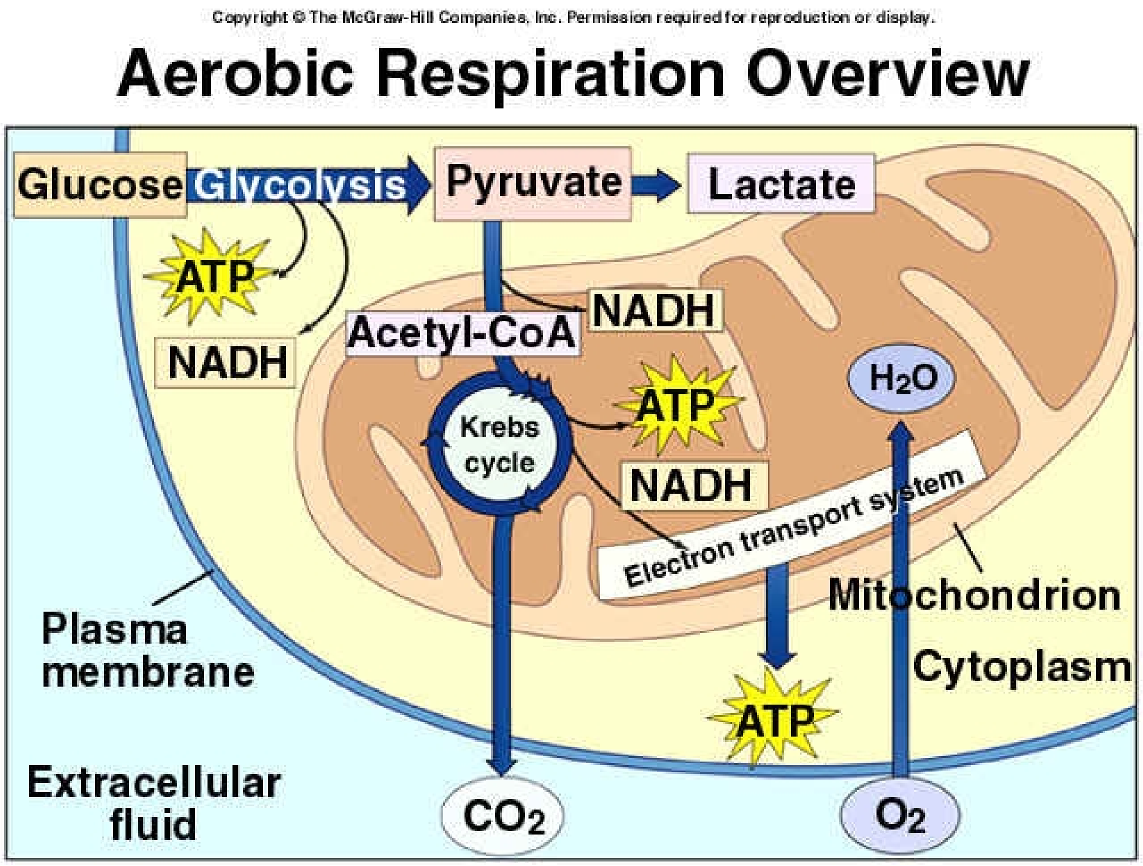
- Plants reduce pollution and influence the climate

Plant respiration



$C_6H_{12}O_6 + 6\ O_2 \text{ -> } 6\ CO_2 + 6\ H_2O + \text{energy}$

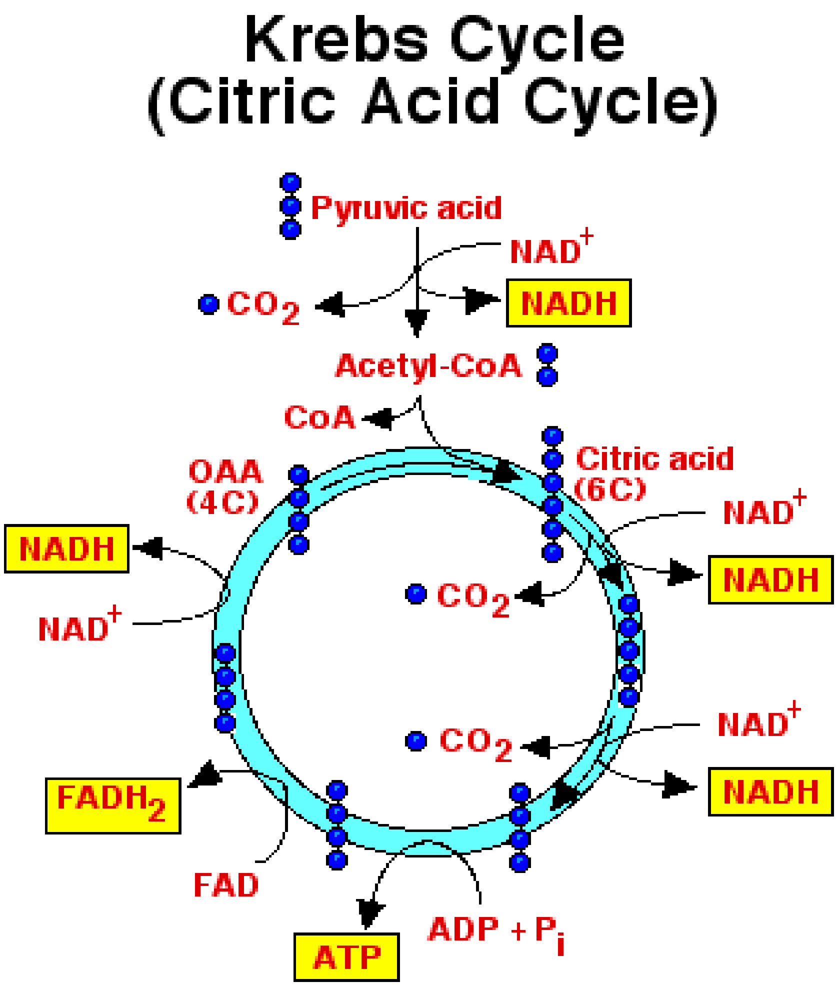
Aerobic respiration is a complex process



Glycolysis is anaerobic process, takes place in the cytoplasm and in chloroplasts

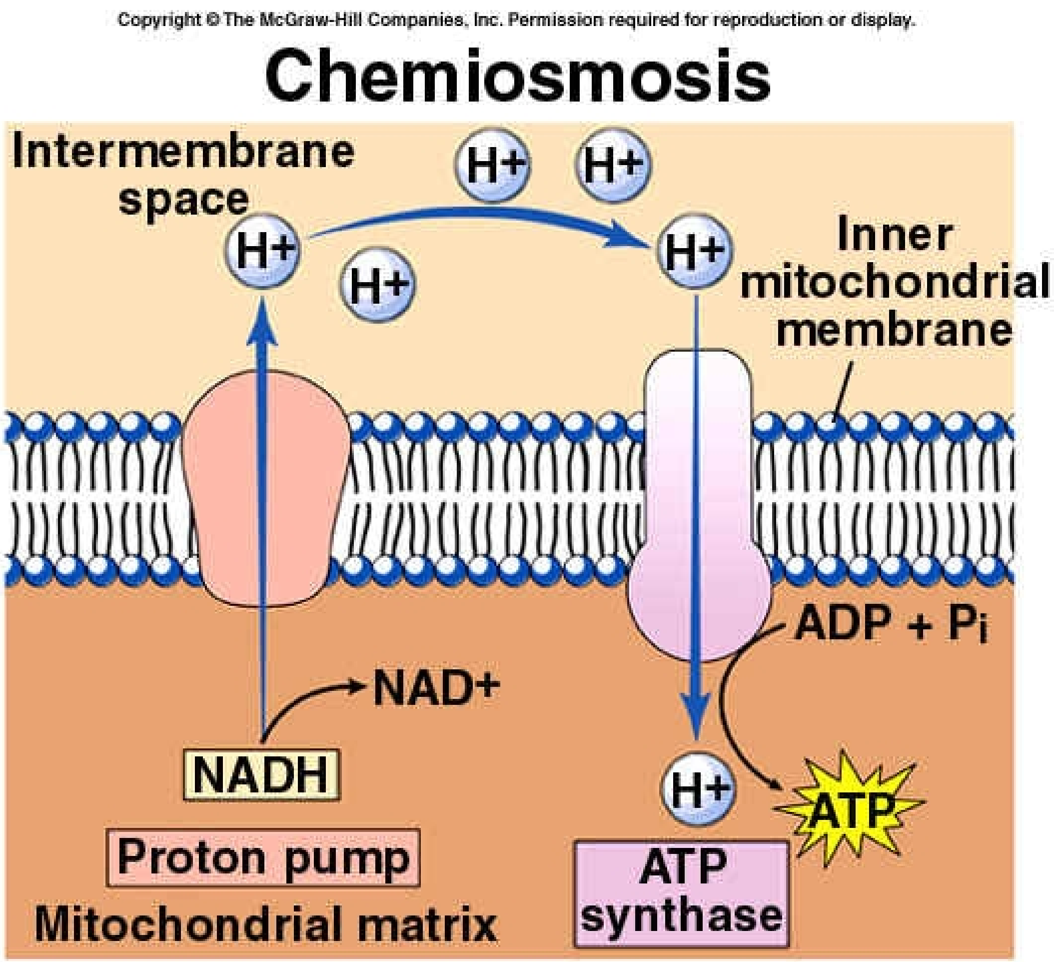
Krebs (TCA) cycle in mitochondrion matrix

ATP synthase at the mitochondrion membranes



Krebs cycle:
pyruvate produced in glycolysis is completely metabolized to CO_2 and H_2O.

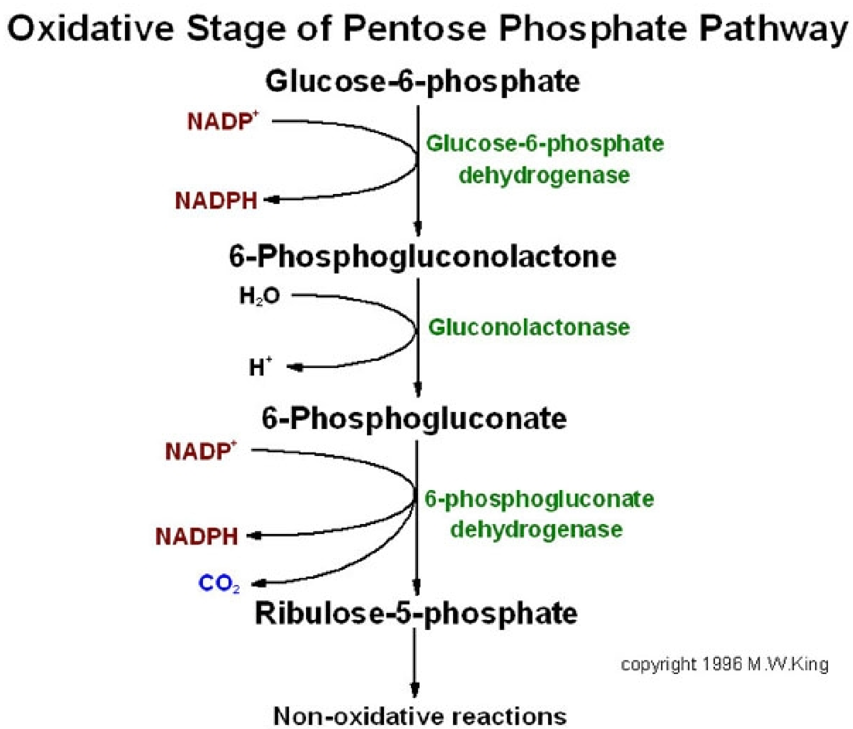
uwstudentweb.uwyo.edu



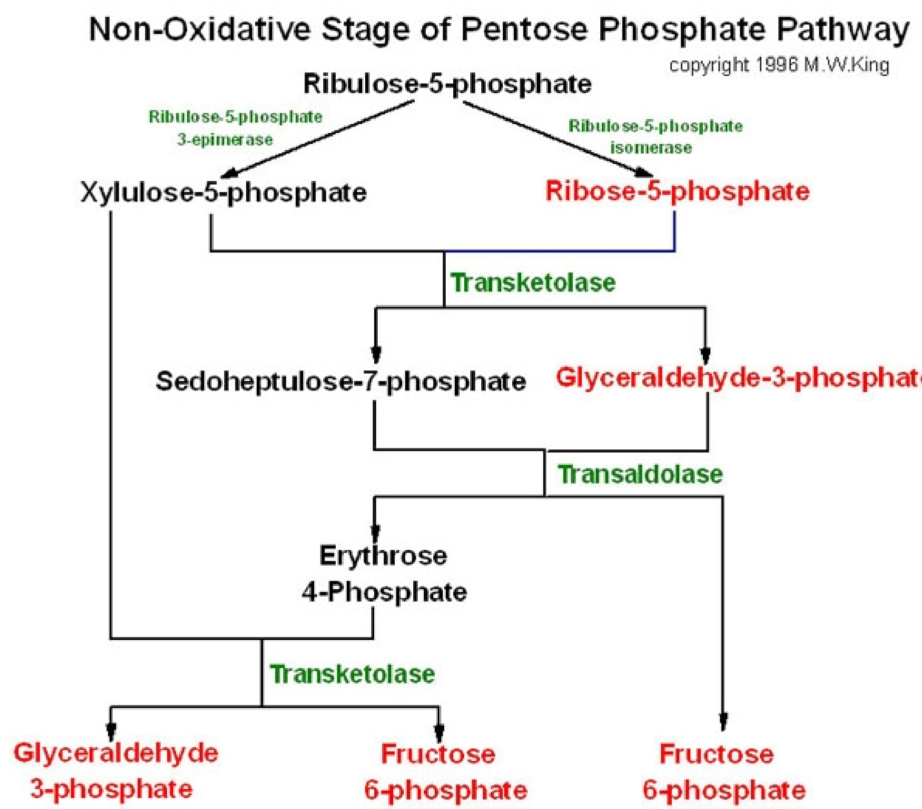
ATP synthesis in the mitochondria

http://faculty.southwest.tn.edu/rburkett/GB%201%20cell%20resp.htm

Pentose phosphate pathway



Glycose is oxidized in the cytoplams, NADPH and 5C sugar phosphates are produced that are required for nucleotide synthesis



Plant respiration is different from animal respiration

- Lower efficiency
- Alcohol fermentation
- Greater plasticity

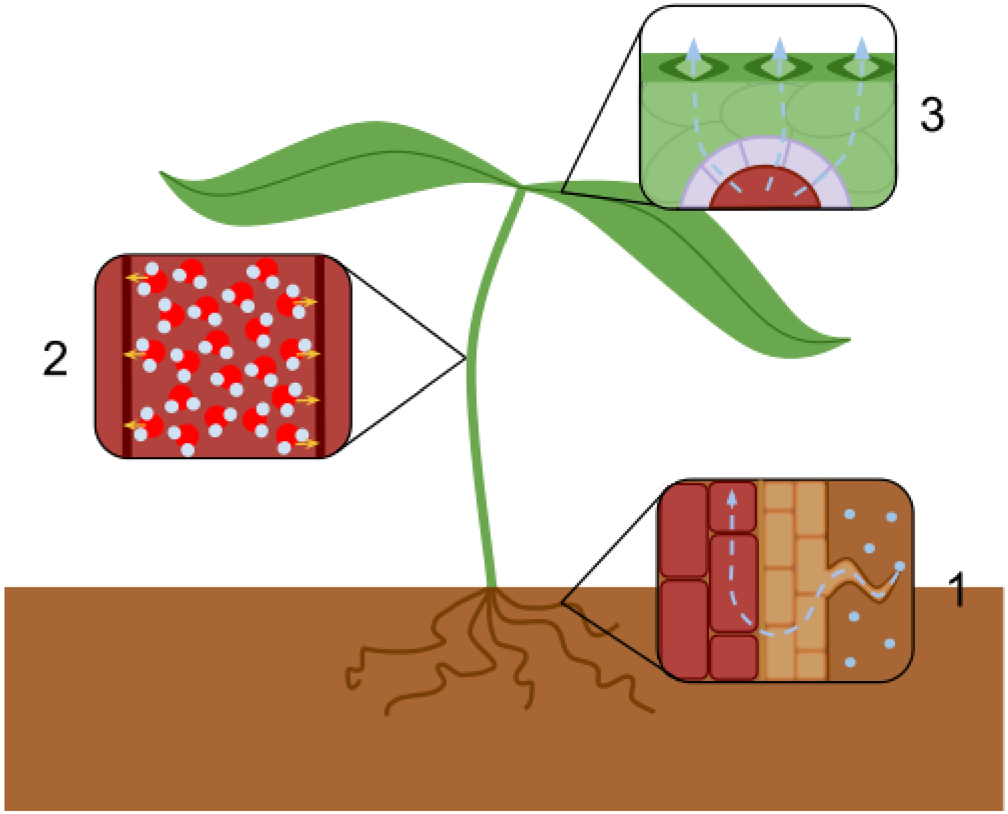
    alternative biocheical reactions

    plant-specific enzymes

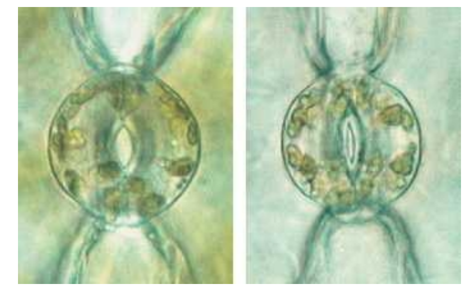
    plant-specific regulation

Transpiration

Transpiration is water movement from plant roots to above-ground organs and controlled evaporation from leaf surface



Factors that influence transpiration



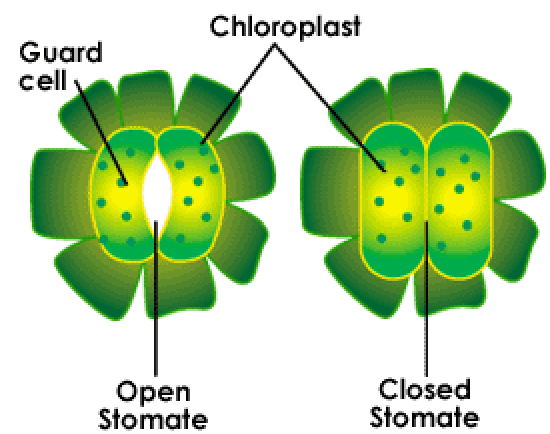
Plant properties:

- Amount and state of the stomata
- Thickness of leaf cuticule
- Morphological leaf traits (influence the boundary layer at leaf surface)

Environment:

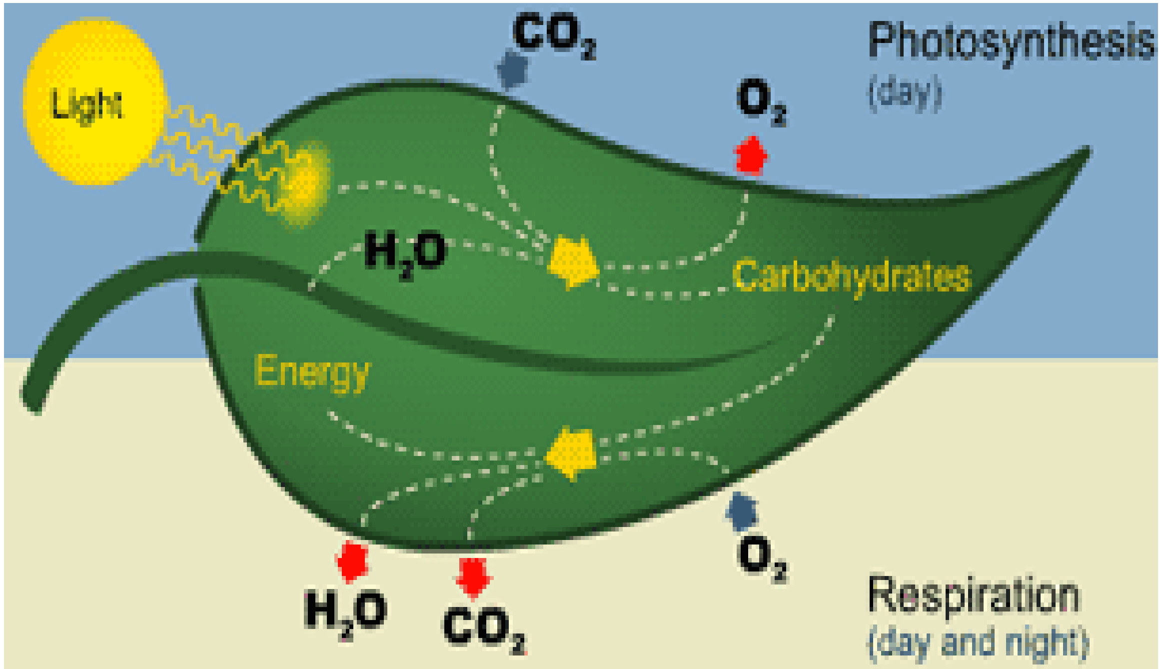
- temperature
- light
- wind
- humidity

Stomata:
leaf epidermis structures,
two specialized epidermal cells - the guard cells



http://www.sciencemag.org/site/feature/misc/webfeat/vis2005/show/transpiration.swf

Metabolic processes in plants occur simultaneously and are mutually influenced



http://www.sciencemag.org/site/feature/misc/webfeat/vis2005/show/transpiration.swf