Plant Adaptations to the Environment

Part 2: Physiological and Symbiotic Adaptations

(see Chapter 2 in GSF for background)

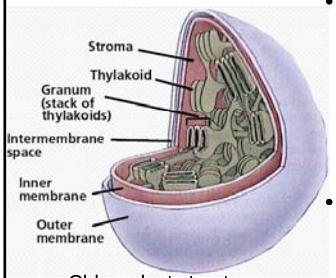
Physiological adaptations

- photosynthesis
- respiration
- growth rates
- abcission layer formation (deciduousness)
- seed and bud dormancy
- sprouting (apical dominance)
- chemical defenses against herbivory.

What are the three main modes of photosynthesis and how do they work?

- Put away your notes
- Collaborate with a partner to summarize your present understanding of photosynthesis
- Make notes of main points
- Use diagrams and equations to illustrate the points

Two steps of Ps: Light reactions and light-independent reactions



Chloroplast structure

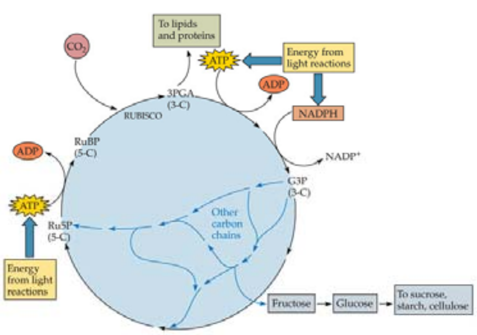
- In the grana, pigments absorb light energy and convert it to ATP
  - "photophosphorylation"
  - Why do light reactions use low-energy red/orange wavelengths?
- In the stroma, carboxylating enzymes fix CO_2 into organic compounds

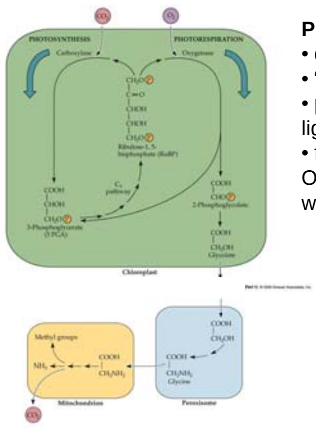
Three modes of photosynthesis

C3 pathway, aka Calvin cycle, most common.

- Ribulose bisphosphate (RuBP, Rubisco) most abundant protein on Earth; enzyme captures CO_2 but also has high affinity for O_2.
- Phosphoglyceric acid (PGA) is 3-C sugar formed during CO_2 uptake.
- Photorespiration makes photosynthesis less efficient but also protects cells from excess light energy.
- At high CO_2:O_2 ratios, Rubisco is more efficient, thus C3 plants respond more to elevated CO_2 than do C4 plants
- Most trees, shrubs, cool-season grasses

Calvin Cycle





Photorespiration

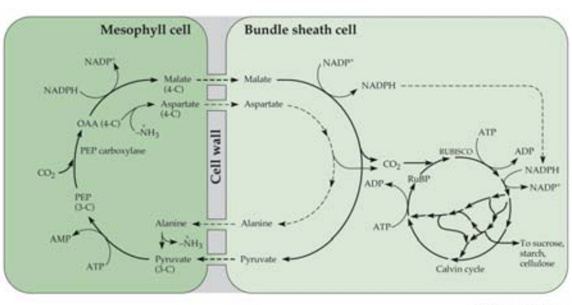
- depends on light
- "wastes" CO_2
- protects against light damage
- favored by high O_2, low CO_2 and warm temperatures

9/11/09 7

Three modes of photosynthesis

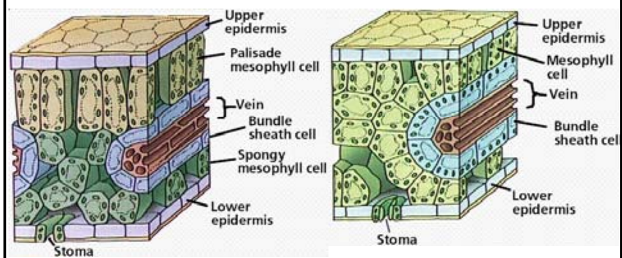
- C4 pathway, aka Hatch-Slack, has additional enzyme, PEP carboxylase, with much higher affinity for CO_2.
  - Oxaloacetate (OAA) is 4-C sugar formed during CO_2 uptake.
  - Rubisco concentrated in bundle sheath cells, where OAA delivers CO_2.
  - Photorespiration limited because CO_2:O_2 is much higher inside bundle sheath cells than in C3's.
  - Less Rubisco needed for psn means higher N-use efficiency.

9/11/09 8



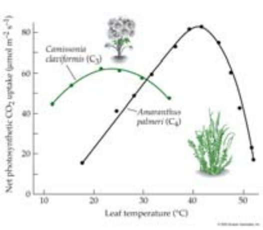
9/11/09 9

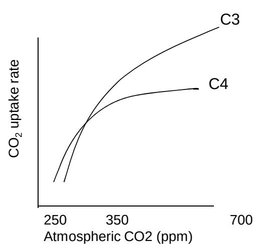
C3 vs C4 leaf anatomy



Three modes of photosynthesis

- C4 pathway
  - Higher T optimum and light saturation.
  - High water use efficiency (C gained per H_2O lost) because stomates can be partly closed.
  - Lower response to elevated CO_2
  - Cost of C4: additional ATP is needed for PEP cycle, which may limit C4 growth at low light levels
  - 2000 species in 18 families; half of all grass (Poaceae) species (warm-season grasses)



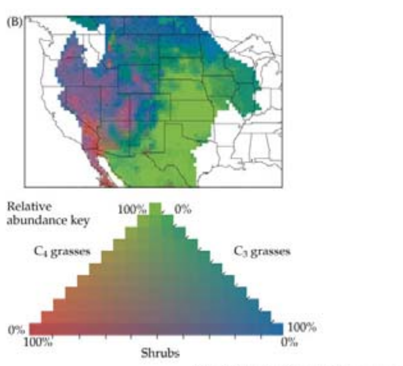


Three modes of photosynthesis

- CAM pathway, aka Crassulacean Acid Metabolism, named after plant family
  - Similar biochemistry as C4 but stomates open only at night
  - Rubisco requires light energy so fixation uses organic acids stored overnight
  - Maximum photosynthetic rates are slower but very high WUE
  - Some CAM plants also use C3 when conditions are favorable (“facultative”)
  - 20,000 species in 25 families

	C3	C4	CAM
Optimum temp for photosynth. (°C)	16-30	30-45	30-35
Light saturation threshold (mmol m^{-2} s^{-1})	.6-1.2	1.6-2	
Rate of Photosynthesis (mg CO_2 dm^{-2} h^{-1})	15-35	40-80	3-8
WUE: g CO_2 fixed per kg H_2O lost	1-3	2-5	10-40

Relative abundance of C3 and C4 grasses and shrubs



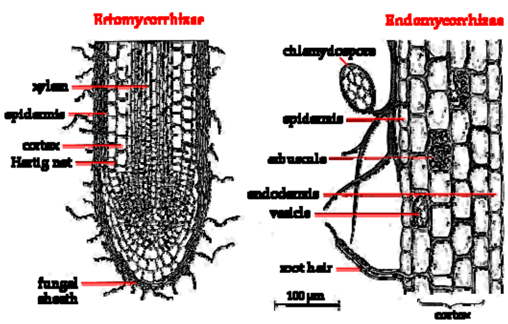
Mutualism and symbiotic adaptations

Mutualisms are broadly important in all ecological systems

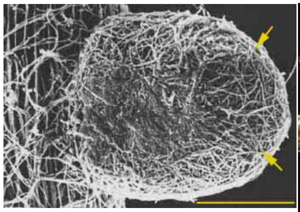
- Eukaryotic cells are thought to have evolved from an obligate mutualism between prokaryotic organisms.
- Defined as having mutual positive effects, facultative or obligate
- Benefit may be small and hard to document
- Symbioses need not be mutually beneficial

Mycorrhizae

- Fungal associations with roots of higher plants
  - Endomycorrhizae penetrate the cell wall
    - Proliferate around root
    - Common in grasses, herbs, and tropical trees
    - A.k.a vesicular arbuscular mycorrhizae (VAM)
  - Ectomycorrhizae do not penetrate cell wall
    - form a thick mantle of hyphae (haustoria) at the root tip, or penetrate root between cortical cells
    - Common in temperate zone trees and shrubs



Examples of ectomycorrizae



SEM of pine root with mantle hyphae (scale 100 μm)

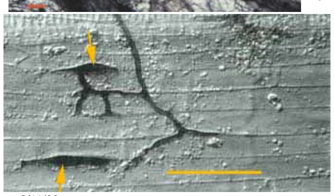
Pinus radiata with *Amanita muscaria* ECM (24x)

9/11/09 19

Examples of endomycorrhizae

Spores germinate and hyphae grow in soil, eventually contacting root surface

(*Glomus mossea*)



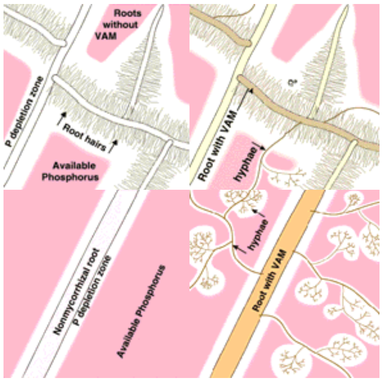
Appressoria grow on root surface between epidermal cells; they penetrate into cortex from here

9/11/09 20

Mycorrhizae

- Main function is in absorbing nutrients, which are transferred both ways
- P, Ca, K are absorbed by mycorrhizae and transferred to plant
- Amino acids and sugars are made by plant and used by mycorrhizae
- Most plant families have mycorrhizal associations, some more specific than others

9/11/09 21



Mycorrhizas are more important to some roots than others… Diameter of hyphae is about 0.01 mm, compared to 0.1-2 mm for fine roots

http://www.ffp.csiro.au/research/mycorrhiza/index.html

Nitrogen fixation

- Conversion of atmospheric N_2 into ammonium (NH_3) by prokaryotic organisms (free-living or symbiotic)
- N is an essential element but is often limiting to growth
- Positive correlation between leaf N and photosynthetic rate: Rubisco requires N

Nitrogen fixation

- Symbiotic N fixation provides C source to the symbiont
  - Legumes have *Rhizobium* bacteria that form root nodules Aquatic fern *Azolla* is symbiotic with blue-green alga *Anabaena*; 3/4 of rice N can be provided by *Azolla* cultivation in paddies
  - Actinomycetes (filamentous bacteria resembling fungi, e.g., *Frankia*) form nodules in at least 285 species of plants, including *Alnus, Shepherdia, Cercocarpus, Dryas, Purshia, Rubus*