Ecosystem Ecology
Handouts for Ecosystem Carbon Input lectures
Reading: CMV Chap 5

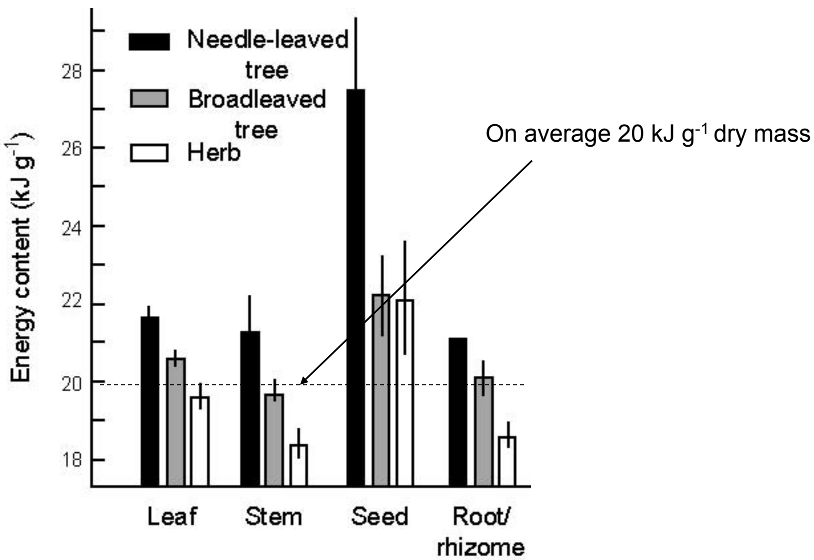
- importance of photosynthesis to ecosystems
- basic leaf anatomy
- basic photosynthetic reactions (light-harvesting and C-fixation reactions)
- environmental controls on photosynthesis (CO_2, light, water, N, T)
- leaf-level vs canopy-level controls on photosynthesis
- stomatal conductance, water/C tradeoff

Carbon inputs to ecosystems

- Occurs via photosynthesis

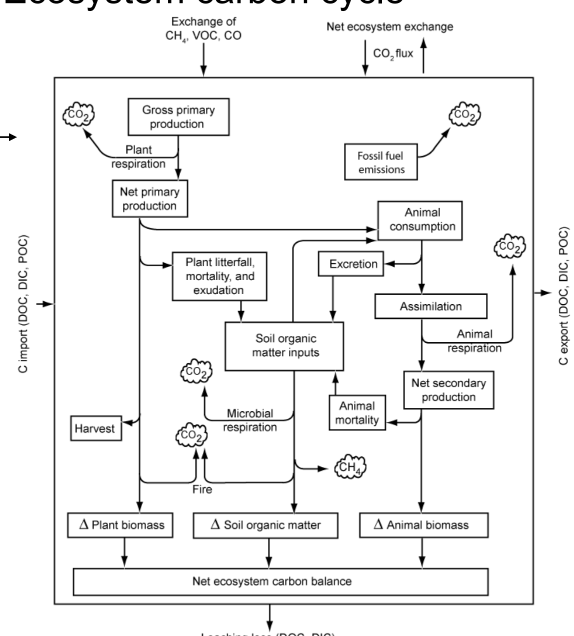
- Importance
  - Energy that drives all biotic processes
  - C accounts for half of organic matter on Earth

Carbon and Energy Flows are Equivalent



Ecosystem carbon cycle

GPP is photosynthesis at the ecosystem scale

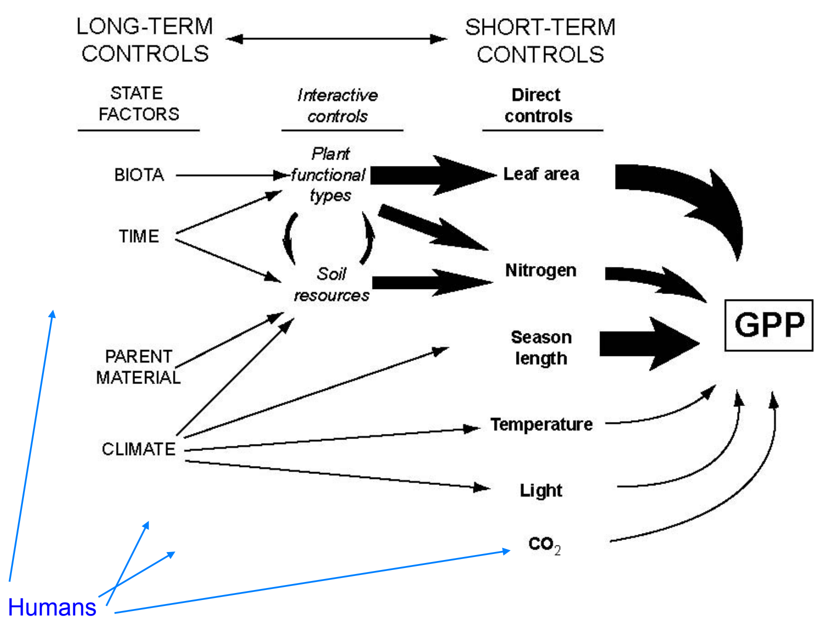


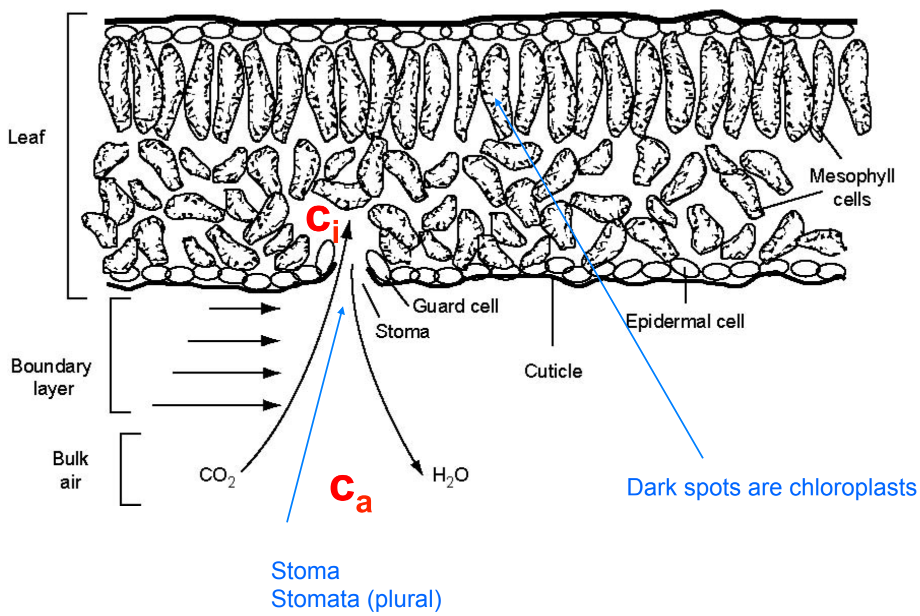
Photosynthesis

$6CO_2 + 12H_2O + \text{light} \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$

Two levels of control important to GPP:

- Controls in individual leaves
- Control by canopy processes

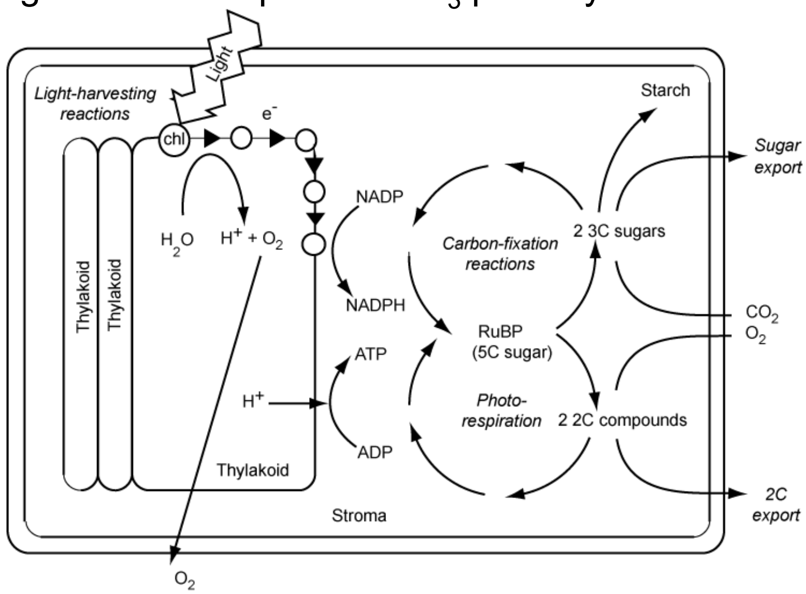




Two major sets of reactions

- <u>Light-harvesting reactions (light reactions)</u>
  - Converts light into chemical energy (ATP, NADPH)
  - N is required, 4 atoms per chlorophyll molecule, also membrane proteins
- <u>Carbon fixation reactions ("dark" reactions)</u>
  - Uses chemical energy (ATP, NADPH) to convert CO_2 into sugars
  - <u>Lots</u> of N is required, enzymes are proteins made of amino acids

Diagram of chloroplast and C_3 photosynthetic reactions

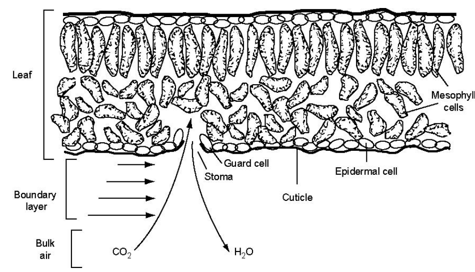


3 photosynthetic pathways

- C_3 photosynthesis
- C_4 photosynthesis
  - mainly grasses
  - about 5% of global flora, about 35% of ice-free land surface
  - tropical (and some temperate) grasslands and savannas
- CAM (crassulacean acid metabolism) photosynthesis
  - dry environments (cacti and euphorbs)
  - epiphytes
  - not very important in a global carbon sense

Plants generally equalize physical and biochemical limitations of photosynthesis

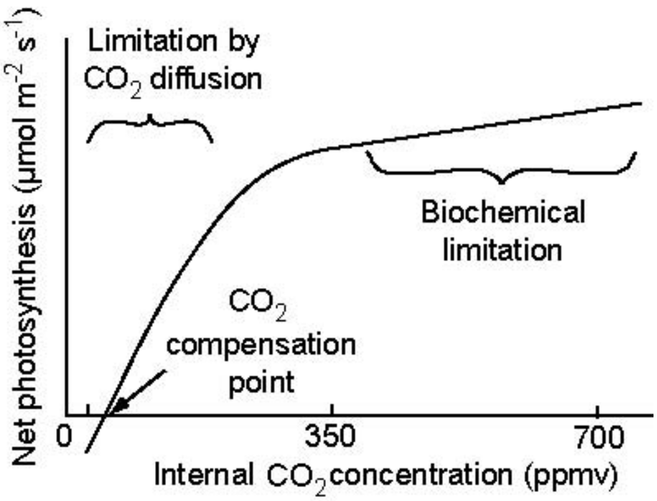
- Physical: delivery of CO_2 to leaf (stomatal adjustments)
- Biochemical: carboxylation rate (fixation of CO_2)
  - Light limitation
  - Enzyme limitation

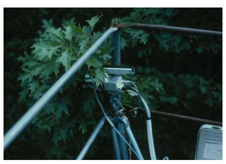


Environmental factors that influence photosynthesis

- carbon dioxide
  - particularly due to stomatal control
- water
- light
- nitrogen availability
- temperature

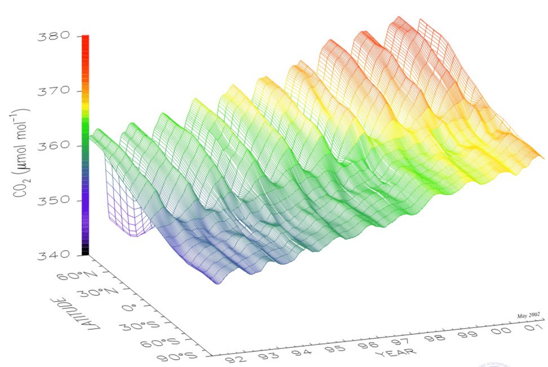
CO_2 response curve of photosynthesis (A-c_i curve)





Influence of CO_2

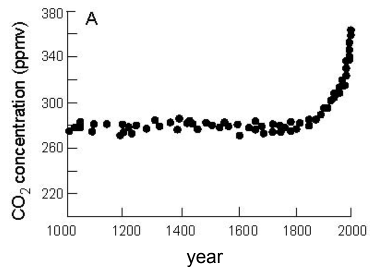
- CO_2 in air only varies seasonally/spatially by about 4% over the whole planet (400 ± 15 ppm)
- Spatial distribution of CO_2 is NOT a major control on GPP (compare to the spatial importance of water)



Three dimensional representation of the latitudinal distribution of atmospheric carbon dioxide in the marine boundary layer. Data from the NOAA CMDL cooperative air sampling network were used. The surface represents data smoothed in time and latitude. Principal investigators: Pieter Tans and Thomas Conway, NOAA CMDL Carbon Cycle Greenhouse Gases, Boulder, Colorado, (303) 497-6678 (ptans@cmdl.noaa.gov, http://www.cmdl.noaa.gov/ccgg).

Influence of CO_2

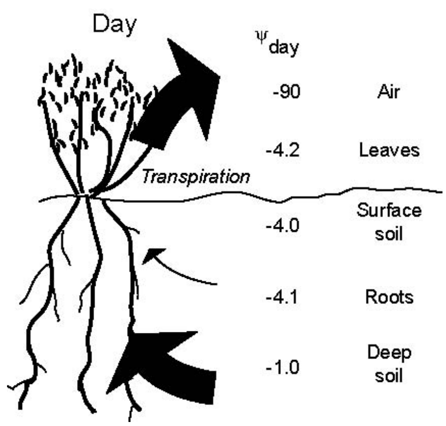
- CO_2 has risen by 43 % since 1750 (280 to 400 ppm)
- has led to increased GPP, but hard to quantify
- more CO_2 means greater photosynthesis <u>if nothing else is limiting</u>
- What about the future???



- CO_2 is most important as a control on photosynthesis because stomatal conductance influences *<u>CO_2 within leaves</u>*

flux = conductance x driving force

water flux = hydraulic conductance x $\Delta\Psi$



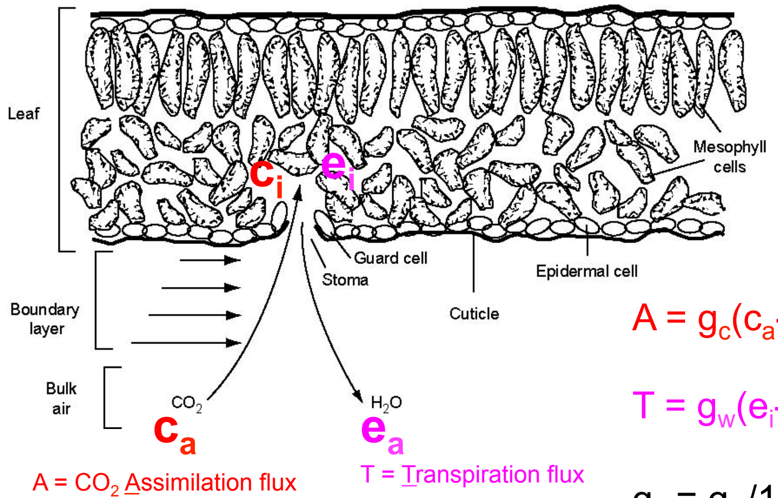
$$J_{leaf\ to\ air} = (K_{leaf\ to\ air})(\Psi_{leaf} - \Psi_{air})$$

$$J_{stem} = (K_{stem})(\Psi_{root} - \Psi_{leaf})$$

$$J_{root} = (K_{root})(\Psi_{soil} - \Psi_{root})$$

$$J_{soil} = (L_{soil}/l)(\Psi_{hi} - \Psi_{lo}) = (K_{soil})(\Psi_{hi} - \Psi_{lo})$$

There is a tradeoff between CO_2 uptake and loss of H_2O vapor



$A = g_c(c_a - c_i)$

$T = g_w(e_i - e_a)$

$g_c = g_w/1.6$

Water use efficiency (WUE = A/T) is dependent on stomatal conductance

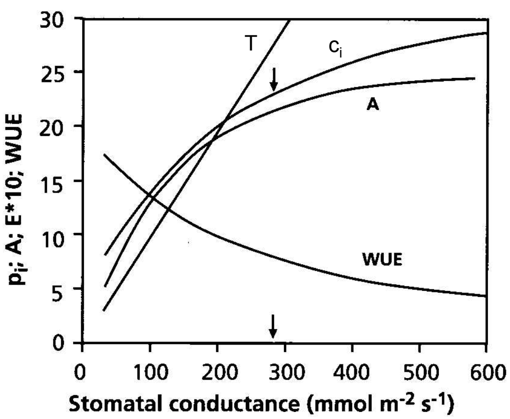


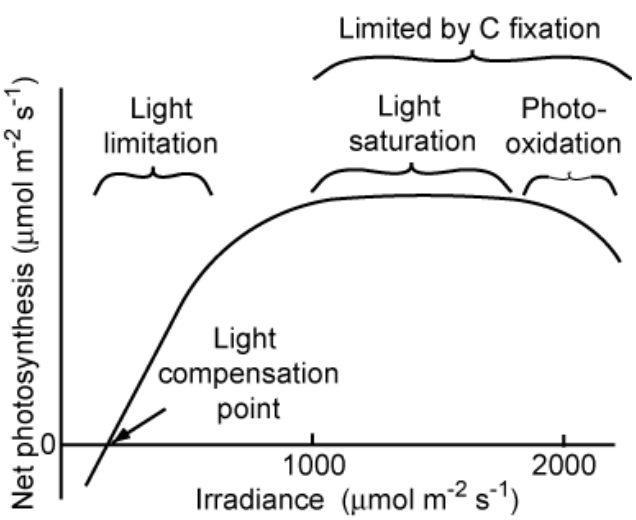
FIGURE 28. The effect of stomatal conductance (g_s) on the transpiration rate (E, mmol $m^{-2} s^{-1}$), rate of CO_2 assimilation (A, µmol $m^{-2} s^{-1}$), intercellular CO_2 partial pressure (p_i, Pa), and photosynthetic water-use efficiency [WUE, mmol CO_2 (mol H_2O)$^{-1}$]. Calculations were made for a constant leaf temperature of 25°C and without any boundary layer resistance. The arrow indicates g_s at the colimitation point of carboxylation and electron transport. For the calculations, equations as described in Box 1 have been used.

Lambers et al. (1998)

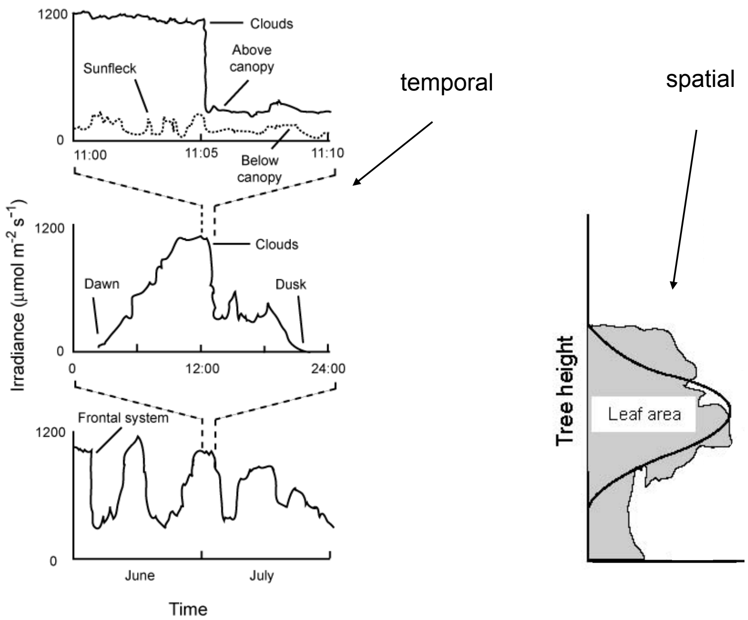
Response of plants to water limitation (including humidity)

- Short-term response (minutes to days)
  - reduce stomatal conductance (decreases photosynthesis)
  - wilting (helps to decrease light input, decreases photosynthesis)
- Long-term response (days to months)
  - reduce leaf area (maintains high LUE, decreases overall photosynthesis for a plant)
  - drought deciduous plants
  - invest more C in root growth
  - alter leaf albedo (e.g., grow leaf hairs)

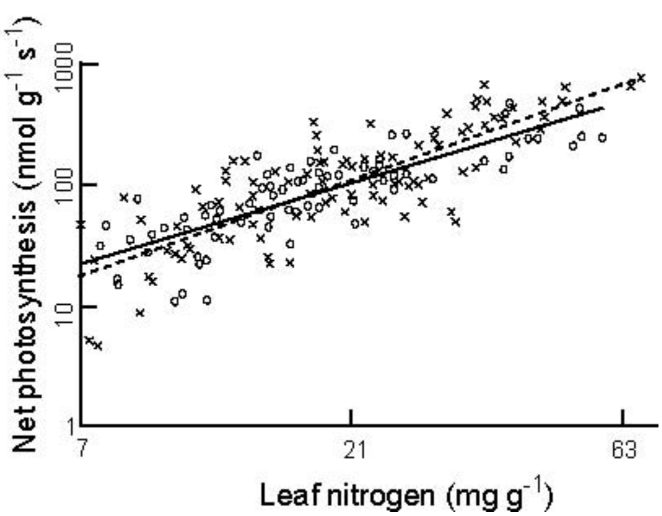
Light response curve of photosynthesis



Causes of light variation in ecosystems

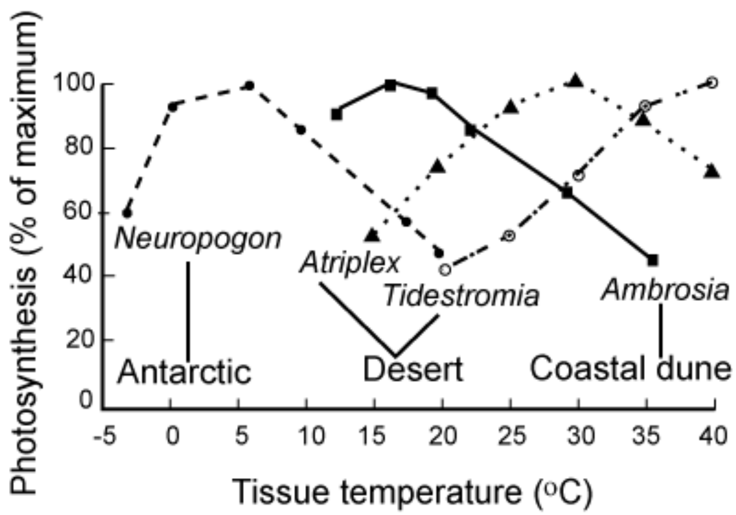


Leaf nitrogen determines photosynthetic capacity



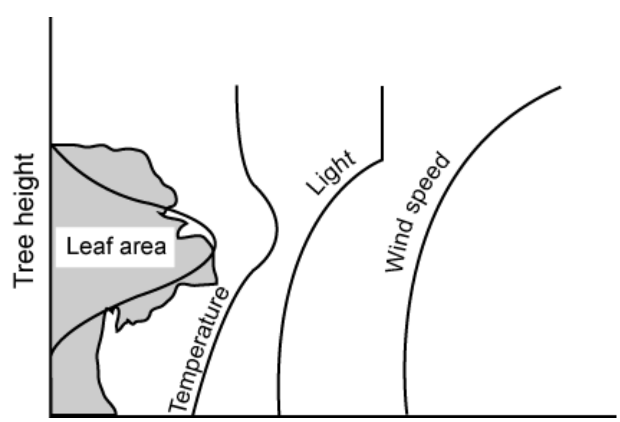
Reich et al. (1997) PNAS 94:13730-13734

Temperature response / adaptation of photosynthesis



Canopy effects on environment reinforce maximization of carbon gain at the top of the canopy

- High light, high leaf N
- High boundary layer conductance (wind)
  (facilitates CO_2 transfer into leaf)



Environmental controls on GPP

• Light, moisture, and temperature dominate diurnal and seasonal patterns

• Length of photosynthetic season
  • year round in tropics
  • summer only at high latitudes
  • summer only at most temperate locations

• Temperate evergreen forests often do not gain carbon in the winter (eg Wasatch) but some do (eg low elevation PNW)

• Quantity of leaf area – may be reduced by herbivores and pathogens