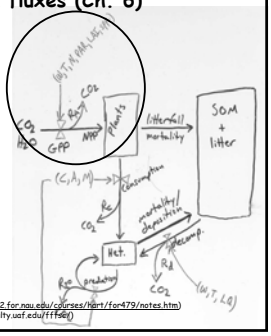
The Carbon Cycle 2

I. Introduction: Changes to Global C Cycle (Ch. 15)
II. C-cycle overview: pools & fluxes (Ch. 6)
III. Controls on GPP (Ch. 5)
IV. Controls on NPP (Ch. 6)
V. Controls on NEP (Ch. 6)



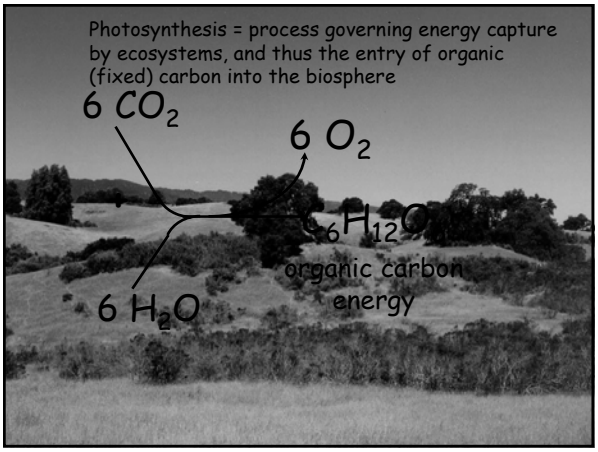
Powerpoint modified from Harte & Hungate (http://www2.for.nau.edu/courses/hart/for479/notes.htm) and Chapin (http://www.faculty.uaf.edu/fffsc/)

The Carbon Cycle

III. Controls on GPP (Ch. 5)
- A. Introduction
  - 1. Photosynthesis
  - 2. Proximal & distal controls
- B. Photosynthesis overview
  - 1. Light-harvesting & C-fixation rxns.
  - 2. C3, C4 & CAM Ps
- C. Controls on photosynthesis
  - 1. Principle of environmental control
  - 2. Limiting factors
    - a. Light: i. Leaf-level; ii. Canopy-level
    - b. CO_2 : i. Leaf-level; ii. Canopy-level
    - c. N : i. Leaf-level; ii. Canopy-level
    - d. Water : i. Leaf-level; ii. Canopy-level
    - e. Temp : i. Leaf-level; ii. Canopy-level

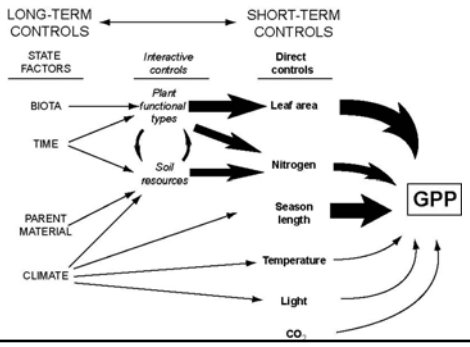
Powerpoint modified from Harte & Hungate (http://www2.for.nau.edu/courses/hart/for479/notes.htm) and Chapin (http://www.faculty.uaf.edu/fffsc/)

I. Introduction



Controls on GPP:

Across ecosystems – LAI, N, growing season length
Within ecosystems (daily, seasonal) – light, temp, nutrients



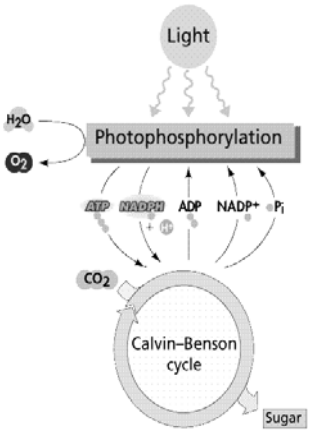
5.1

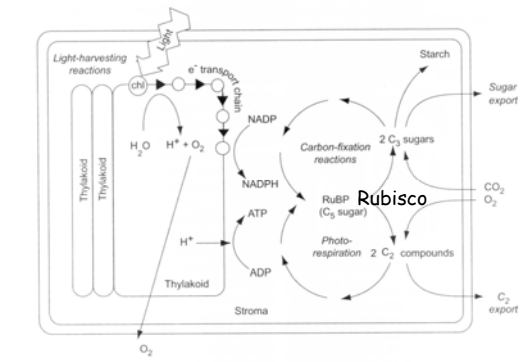
B.Photosynthesis overview

Photosynthesis
Two sets of reactions:

Light harvesting
- converts light energy to chemical energy (ATP, NADPH)
- splits H_2O and produces O_2 as byproduct

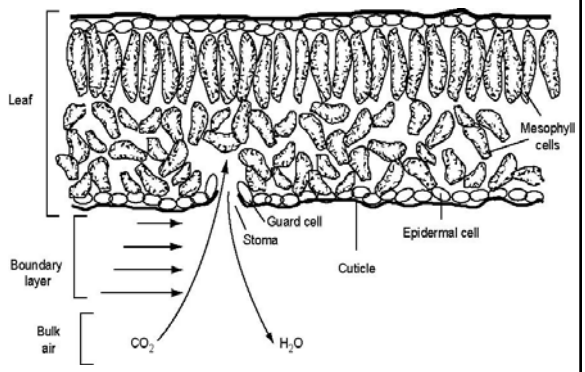
Carbon fixing
- uses ATP and NADPH from light reactions to fix CO_2 into sugar

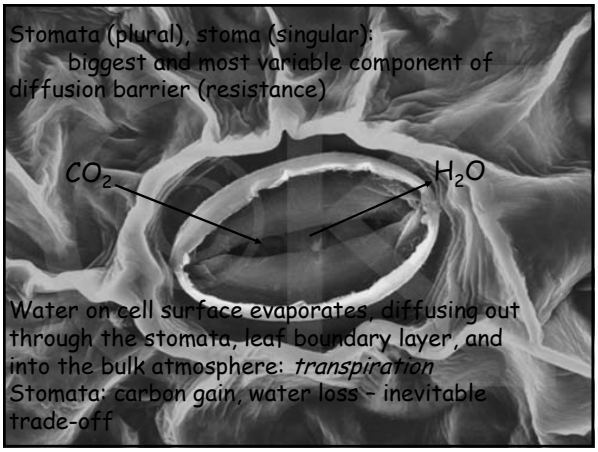




5.3

CO_2 enters leaf via diffusion

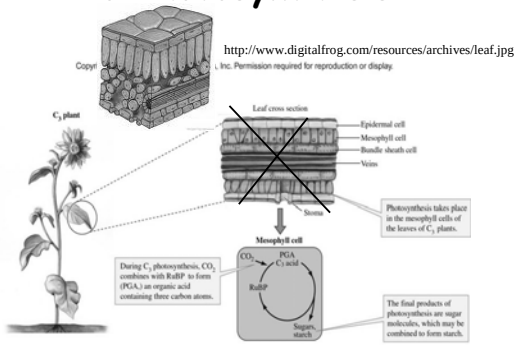




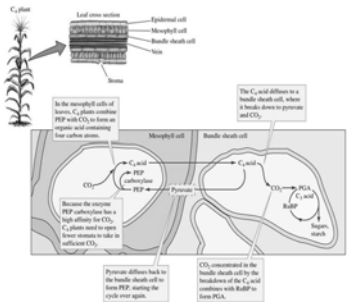
B.2. Three major photosynthetic pathways

- C3 photosynthesis
  - "Normal" photosynthesis, 85% of plants
- C4 photosynthesis
  - Spatial separation of 2 carbon fixation paths
- CAM (Crassulacean Acid Metabolism)
  - Temporal separation of 2 carbon fixation paths

C3 Photosynthesis



C4 Photosynthesis

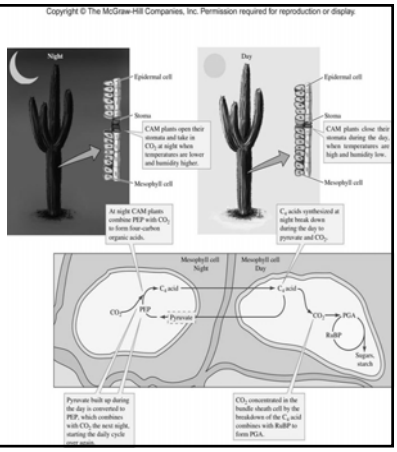


C4 Distribution

9 Temperature influences plant distribution. Distri- and C_4 grasses, as measured by relative ground g an elevational gradient in the Hawaii Volcanoes ark. (After Rundel 1980:355.)

7-23
The numbers shown here indicate the percentages of the total number of grass species having the C_4 pathway in each of 32 local floras in North America. The highest percentages are found in those regions with the highest temperatures during the growing season.

CAM Photosynthesis



3 photosynthetic pathways

- **See pp. 102-105, including Box 5.1**

1. **How does C3 differ from C4 in terms of initial fixation enzyme, site of initial fixation, use of Calvin cycle?**
2. **How does C4 differ from CAM?**
3. **How do C4 and CAM reduce water loss and photorespiration?**
4. **What tradeoffs are inherent in C4 & CAM?**

Bottom line: C4 and CAM reduce water loss and reduce photorespiration because PEP carboxylase has a higher affinity for CO_2 and no affinity for O_2.

These adaptations are most important in hot, dry environments.

C.Controls on Photosynthesis

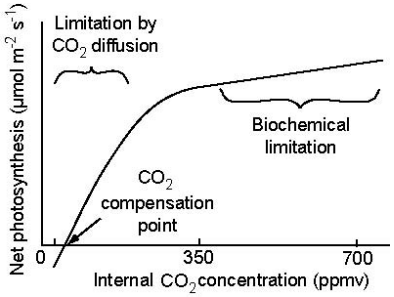
Net Ps = C-fixation – mitochondrial resp – photoresp

(not to be confused with NPP)

1.Basic principle of environmental control

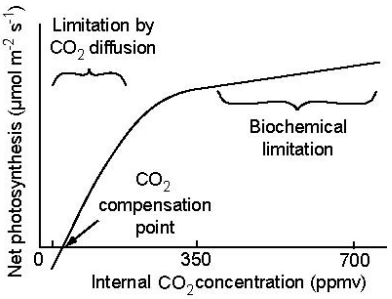
CO_2 response curve of photosynthesis:

1. Net Ps
2. Compensation point
3. CO_2 diffusion
4. Biochem limits: light-harvesting, Rubisco (N), RuBP (P)



5.6

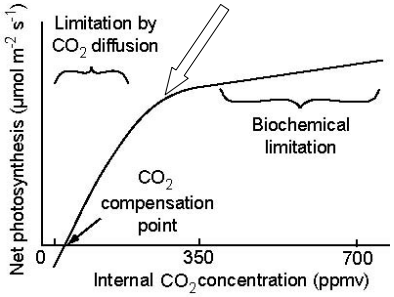
Where is leaf most efficiently allocating its resources for C gain?



5.6

Basic Principle of Environmental Control: Equalize physical and biochemical limitations of photosynthesis

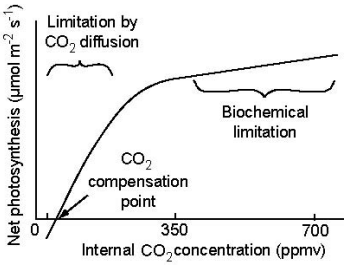
Plants adjust photosynthetic "machinery" and internal CO_2 to operate at the balance point



5.6

HOW?

- **Shade vs. sun?**
- **Fertile vs. infertile soils?**
- **Wet vs. dry environments?**



5.6

C. Controls on photosynthesis

- **Most leaf-level controls still function in entire canopies**
- **Leaves at top of canopy carry out most photosynthesis**
  - **Receive most light**
  - **Youngest, most N-rich leaves**

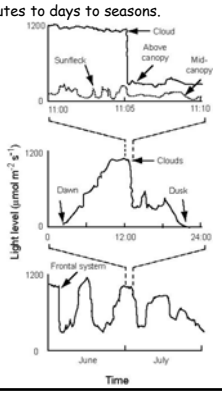
C. Controls on photosynthesis

2. Limiting factors

a. Light

i. Leaf-level

Point 1: Light can vary greatly at time scales of tenths of seconds to minutes to days to seasons.



- Large control of temporal variation in photosynthesis within ecosystems

- But, light doesn't account for differences across ecosystems.

5.7

Point 2. Light response curve of photosynthesis

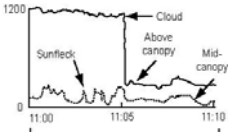
6 points: I_{sat}, Ps_{max}, LCP, Ps at low light, decline (photo-ox.), LUE
(draw)

Point 3.Plants have a variety of mechanisms for adjusting to variation in light

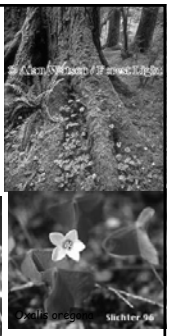
- **Acclimation (physiological adjustment)**
  - **Sun leaves**
    - **More cell layers (draw mesophyll)**
    - **Higher photosynthetic capacity**
  - **Shade leaves**
    - **thinner, more surface area/g**
    - **More light-harvesting pigments**
- **Adaptation (genetic changes)**
  - **Mechanisms same as for acclimation**
  - **Traits persist even when plants grown in similar conditions**

Point 3. Mechanisms of adjusting to variation in light

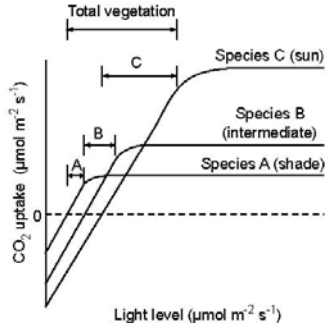
- **Other neat tricks**
  - **Maximize/minimize leaf area**
    - **More leaves**
    - **Thin leaves or cylindrical leaves**
  - **Leaf angle**
  - **Leaf movements**
  - **Efficient use of sun flecks**



Adenostoma fasciculatum (chamise)

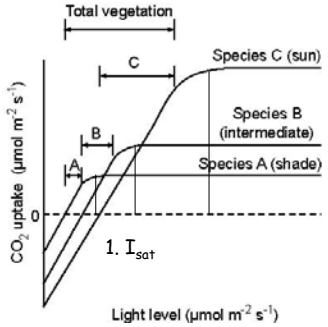


Adaptation/Acclimation result in different light response curves for 5/6 of the components we discussed



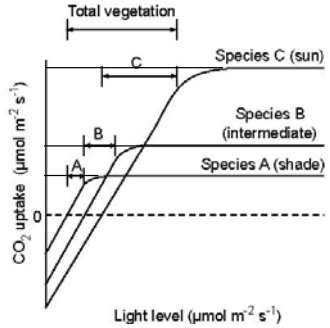
5.9

Adaptation/Acclimation result in different light response curves for 5/6 of the components we discussed



5.9

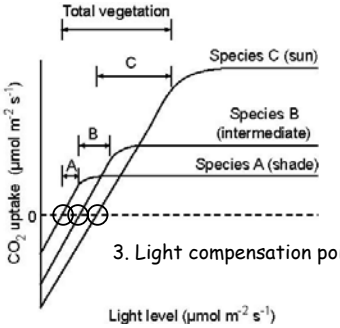
Adaptation/Acclimation result in different light response curves for 5/6 of the components we discussed



2. Ps_{max}

5.9

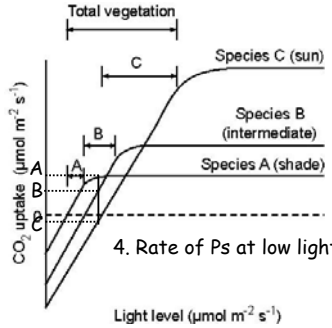
Adaptation/Acclimation result in different light response curves for 5/6 of the components we discussed



3. Light compensation point

5.9

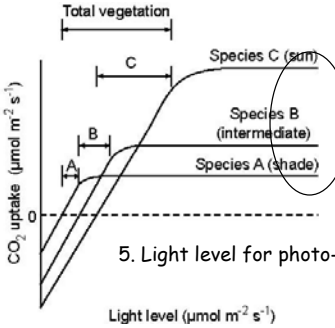
Adaptation/Acclimation result in different light response curves for 5/6 of the components we discussed



4. Rate of Ps at low light

5.9

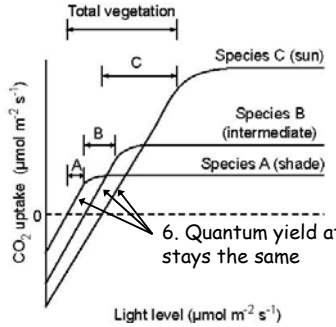
Adaptation/Acclimation result in different light response curves for 5/6 of the components we discussed



5. Light level for photo-oxidation

5.9

Adaptation/Acclimation result in different light response curves for 5/6 of the components we discussed

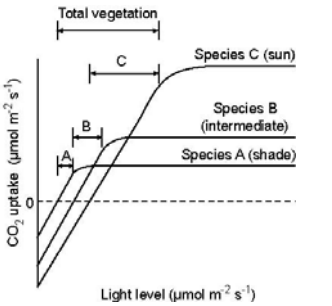


6. Quantum yield at low light stays the same

5.9

These adaptations are the same for

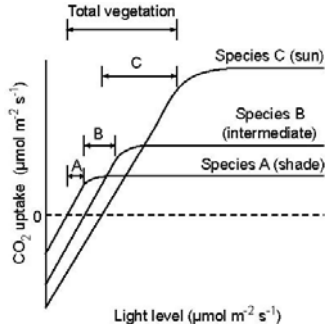
1. Leaves on the same individual in different environments
2. Individuals of the same species in different environments
3. Different species specifically adapted to different environments



5.9

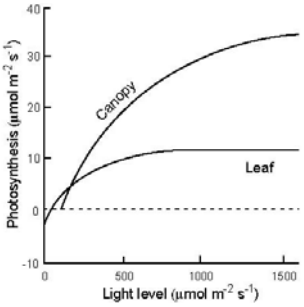
ii. Light – Canopy level controls

Point 1. Multiple species increase range of light levels over which light use efficiency remains constant



5.9

Canopy processes increase range of light intensities over which LUE is constant



Point 2. Vegetation maintains relatively constant LUE

- **Leaf level regulation**
  - **Balance biochemical and physical limitations to photosynthesis**
- **Canopy level regulation**
  - **Maintain highest Ps capacity at top of canopy**
  - **Shed leaves that don't maintain positive carbon balance**

Point 3. Leaf area

- **Leaf area determines both amount of light intercepted and light environment in the canopy.**
- **Leaf area responds to availability of soil resources (more soil resources, more growth)**
- **Light declines exponentially within canopy.**
- **LAI ~1-8 m^2 leaf/m^2 ground**
- **Projected vs. total LAI – what's the diff?**

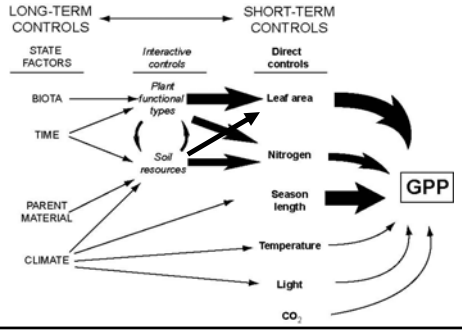
C. Controls on photosynthesis

2. Limiting factors

b. CO_2 – see book

c. Nitrogen

Soil resources (nutrients, water) influence both
- amount of plant growth (leaf area)
- amount of N in photosynthetic machinery in those leaves.

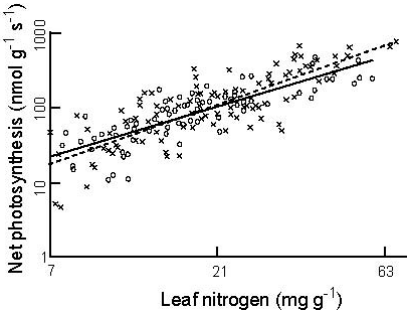


5.1

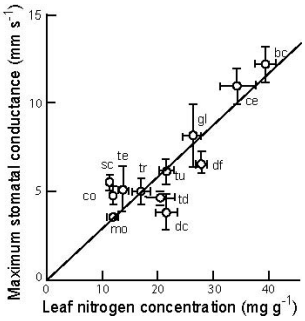
i. Leaf-level

Point 1. Leaf nitrogen determines photosynthetic capacity

Why?



Point 2. Stomatal conductance adjusts to match photosynthetic capacity (or vice versa)



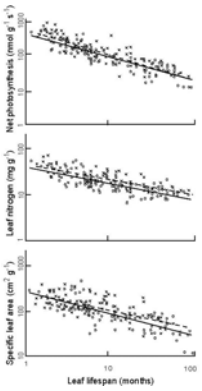
5.11

Point 3. Leaf longevity is a major factor determining photosynthetic capacity per gram tissue

Inevitable tradeoff between photosynthesis and leaf longevity

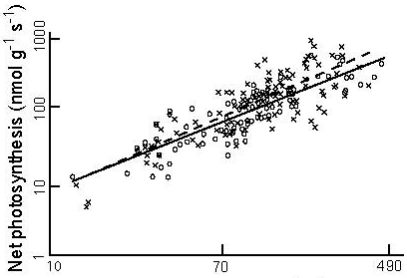
Long-lived leaves contain lots of non-photosynthetic compounds

- Herbivore protection
- Desiccation resistant



5.12

SLA is a good predictor of photosynthetic capacity



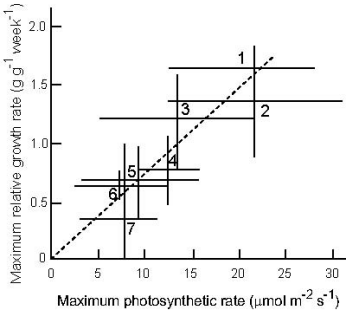
5.14

Suite of traits that influence carbon gain depends on availability of soil resources

- **Leaf longevity**
- **Leaf nitrogen concentration**
- **Photosynthetic capacity**
- **Growth rate**

ii. Canopy-level

Point 1. Fast-growing plants have high photosynthetic rates

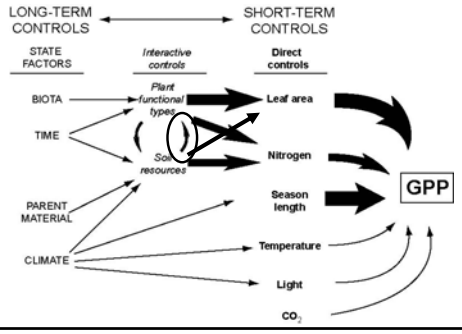


and more growth → more leaf area → more growth → …

Point 2. High soil resource availability increases competition for light

- **More growth, more leaves, decreased light near the ground.**
- **Fertile soils, high water availability select for plants with high growth rates (change in plant functional types).**
- **What allocation strategies might help a plant grow fast?**

Communities with high levels of soil resources typically support intrinsically faster growing species.



5.1

Differences among ecosystems in LAI are a major control on GPP (and NPP)

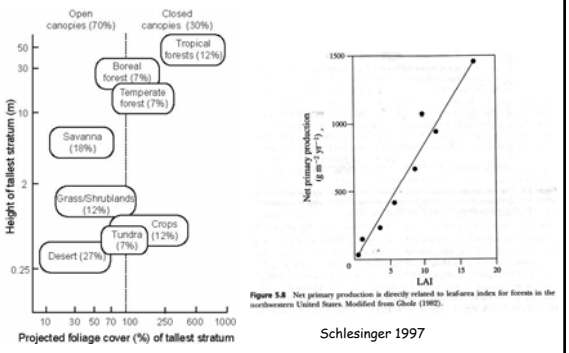


Figure 5.8 Net primary production is directly related to leaf-area index for forests in the northwestern United States. Modified from Gholz (1982).

Schlesinger 1997

5.20

Carbon gain estimated from satellites

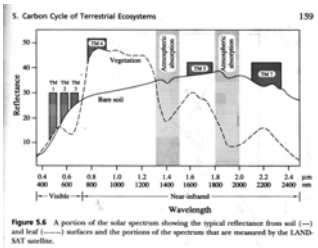


Figure 5.6 A portion of the solar spectrum showing the typical reflectance from soil (—) and leaf (·——·) surfaces and the portions of the spectrum that are measured by the LANDSAT satellite.

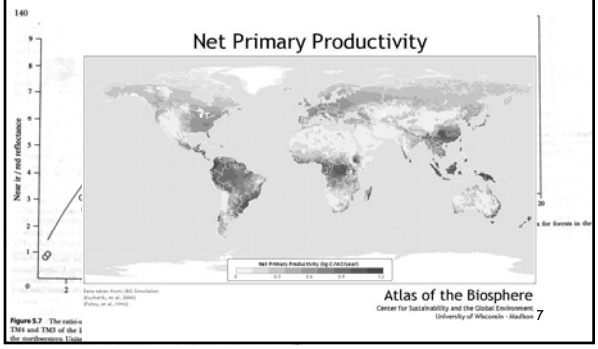
Schlesinger 1997

NDVI: Normalized difference vegetation index
NIR: Near-infrared radiation
VIS: Visible radiation

$$NDVI = \frac{(NIR-VIS)}{(NIR+VIS)}$$

LANDSAT – local
AVHRR – regional-global

LAI correlates with NDVI

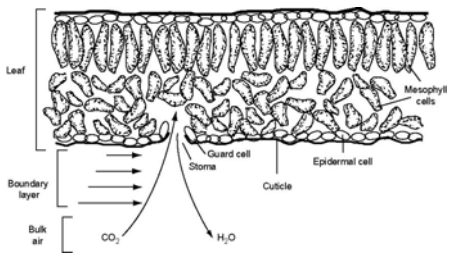


7

d.Water limitation

i. Leaf-level

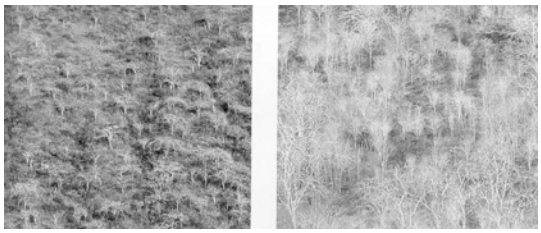
- **Short-term response: reduce stomatal conductance (reduces LUE)**



5.4

d.Water limitation

medium-term response: reduce leaf area (reduces surface area for water loss, maintains high LUE)



Tropical dry forest, Mexico

d.Water limitation

- **Long-term response (adaptation):**
  - **reduce light absorption (smaller leaves, inclined leaves, hairy leaves)**
  - **C4, CAM photosynthesis**

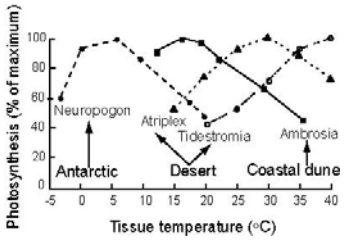
http://www.sci.sdsu.edu/plants/sdpls/plants/Adenostoma_fasciculatum.html

d. Water
ii. Canopy-level

- **We'll talk about water and temp together.**

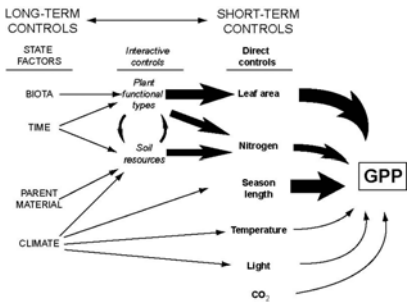
e. Temperature
i. Leaf-level

Point 1. Plants acclimate to typical temps on sunny days.
- both low and high temperature restrictions on Ps.



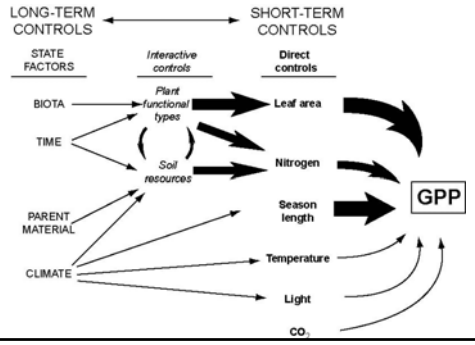
Point 2. Different adaptations in different environments
- Increased photosyn. capacity in cold environ.
- High ET in warm wet environments
- Small leaf size in warm dry environments

ii. Canopy-level
Point 1. Plant adaptations reduce differences among ecosystems directly resulting from temperature within the growing season.



ii. Canopy-level

Point 2. Differences in temp and water availability are major controls on growing season length, which has a strong effect on annual GPP.



f. Response to pollutants (see book)

- Damages photosynthetic machinery
- Reduces photosynthetic capacity
- Plants reduce stomatal conductance

Main points about photosynthesis

- Balance biochemical and physical limitations
- Match photosynthetic potential to soil resources
- Adjust leaf area to maintain constant LUE

Major controls over GPP – across ecosystems

- Quantity of leaf area
  - May be reduced by herbivores and pathogens
- Length of photosynthetic season
- Photosynthetic rate of individual leaves
  - Photosynthetic capacity
  - Environmental stress that alters stomatal conductance