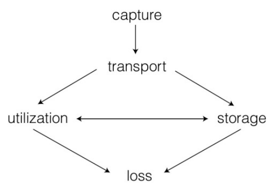
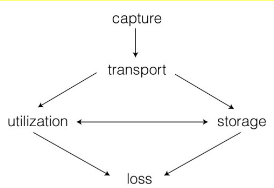
Plants allocate resources to enhance performance



- Allocation of photosynthetic products (GPP) to NPP and R_p
- Allocation of NPP
- Allocation of energy to R_p
- Phytochromes and plant environment sensing
- Nutrient allocation: nitrogen example
- Defense allocation: herbivore example

Plants function as integrated systems



$NPP = GPP - R_p$ (plant C balance)

$GPP = NPP + R_p$

NPP = new plant material (biomass)

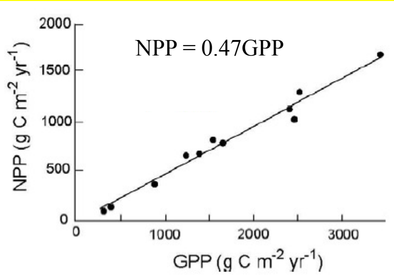
R_p = use of biochemical (C) energy

Products of photosynthesis

- New biomass

- Growth respiration
- Maintenance respiration
- Transport respiration

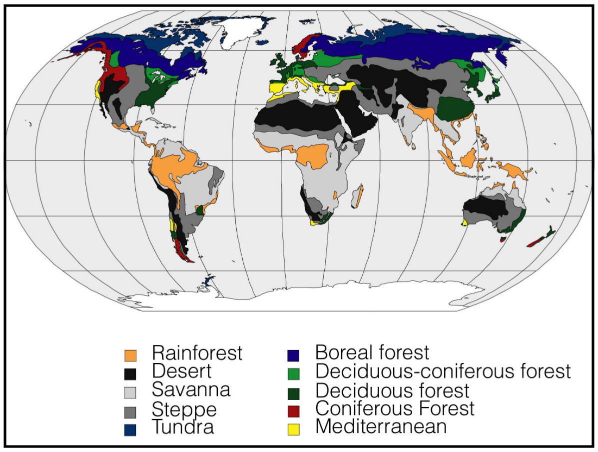
Allocation of photosynthetic products (GPP)



(Williams et al., 1997, *Ecological Applications*)

Data from 11 forests in the U.S., Australia, and New Zealand shows approximately half allocated to new biomass and half to respiration.

$NPP / GPP \approx 0.5$

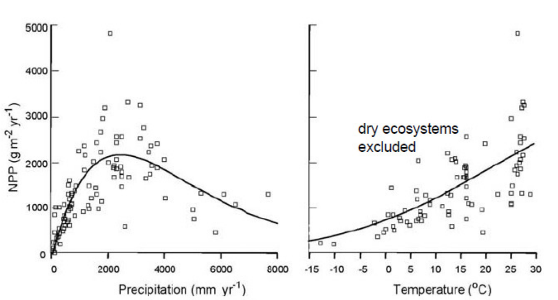


Average annual rates of net primary productivity (NPP)

Biome	NPP [g C m^{-2} yr^{-1}]
Tropical rain forest	1000-3500
Savanna	200-2000
Grassland	100-1500
Desert	0-250
Mediterranean	250-1500
Temperate forest	600-2500
Boreal forest	200-1500
Tundra	100-400
Cultivated land	100-4000
Wetlands	800-4000

(Lieth, 1975, *Primary Productivity of the Biosphere*)

Global patterns of net primary productivity vary with climate



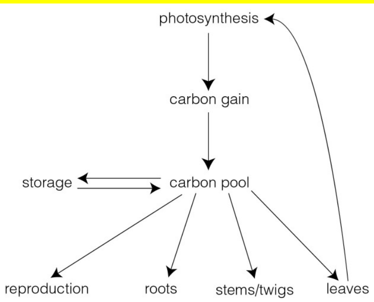
(Schuur, 2003, *Ecology*)

Allocation of photosynthetic products to NPP

Components of NPP	% of NPP
New plant biomass	40-70
Leaves and reproductive parts (litterfall)	10-30
Apical stem growth	0-10
Secondary stem growth	0-30
New roots	30-40
Root secretions	20-40
Root exudates	10-30
Root transfers to mycorrhizae	10-30
Losses to herbivores, mortality, and fire	1-40
Volatile emissions	0-5

Typically only these three are measured, lots of uncertainty

Allocation of NPP to leaves, reproductive parts, stems/branches, and roots is dependent on environment and demand for resources

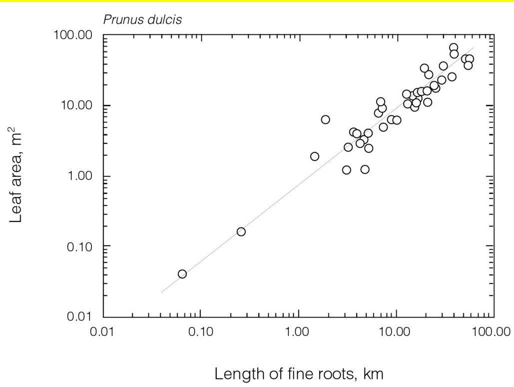


Allocation of a resource to one organ or tissue means the resource is not available to another tissue or organ.

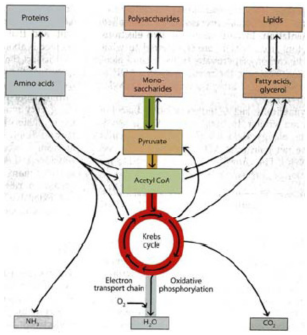
Multiple tradeoffs:

- Photosynthesis in leaves is dependent on water and nutrient uptake in roots.
- Photosynthesis in leaves is also dependent on water and nutrient transport up stems.
- Increased capacity to capture resources in roots and transport resources in shoots depends on photosynthesis in leaves and subsequent transport.
- Reproduction depends on energy from photosynthesis and water/nutrients from roots.

Plants function as integrated systems



Allocation of photosynthetic products to R_p



(Raven et al., 1999, *Biology of Plants*)

Organic materials (C-based energy in the form of sugars, proteins, and lipids) are broken down during aerobic respiration:

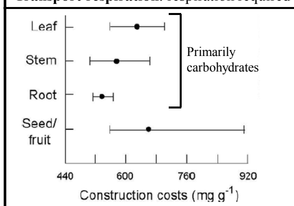
- Releases energy stored in chemical bonds
- Consumes O_2
- Produces CO_2

Energy released is used for essential plant processes:

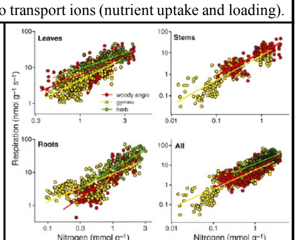
- Growth (construction costs)
- Maintenance
- Transport (ion uptake)

Growth, maintenance, and transport respiration

Growth respiration: respiration required per unit increment in biomass.
Maintenance respiration: respiration required to maintain living tissues.
Transport respiration: respiration required to transport ions (nutrient uptake and loading).



(Poorter, 1994, *A Whole Plant Perspective of Carbon-Nitrogen Interactions*)

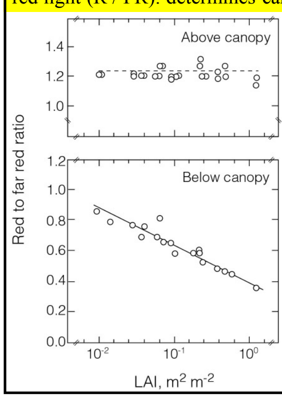


(Reich et al., 2008, *Ecology Letters*)

- Construction costs: lipids > proteins > carbohydrates.
- Proteins require a lot of energy for maintenance.

- Nutrient concentration: roots > soil (gradient does not favor ion diffusion into root).
- Active transport required: 30-50 % of energy transported to root is used for nutrient uptake.

Phytochromes in the apical meristem detect ratio of red light to far-red light (R / FR): determines canopy position and resource allocation



Phytochrome: pigment that changes configuration dependent on R / FR.

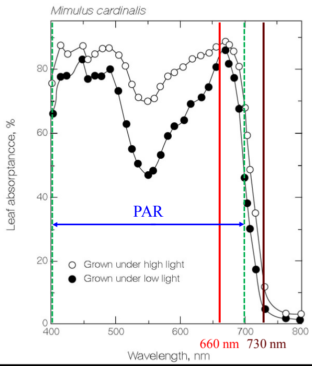
P_{Red} → Red = 660 nm → $P_{Far\text{-}red}$

$P_{Far\text{-}red}$ → Far-red = 730 nm → P_{Red}

Configuration of phytochrome regulates multiple plant functions:

- Timing of flowering.
- Germination of seeds.
- Elongation of seedlings.
- Distance between leaves.
- Leaf number, size, and shape.
- Allocation of resources to leaves.

Red wavelengths are within the photosynthetically active range, far red wavelengths are not



High absorptance of red light by chlorophyll, low transmission to lower canopy layers.

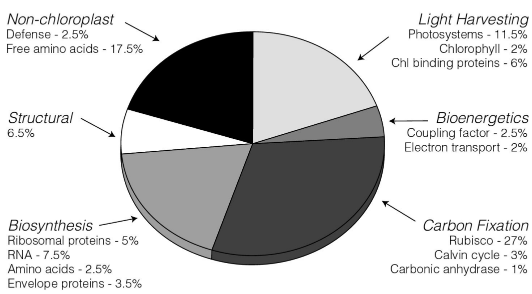
Low absorptance of far red light by chlorophyll, high transmission to lower canopy layers.

Top of canopy: high R / FR.

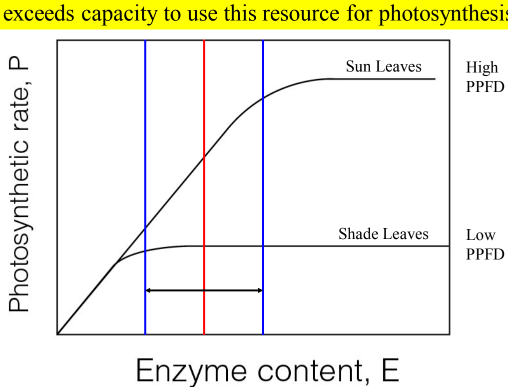
Bottom of canopy: low R / FR.

Much of the protein in leaves is associated with photosynthesis

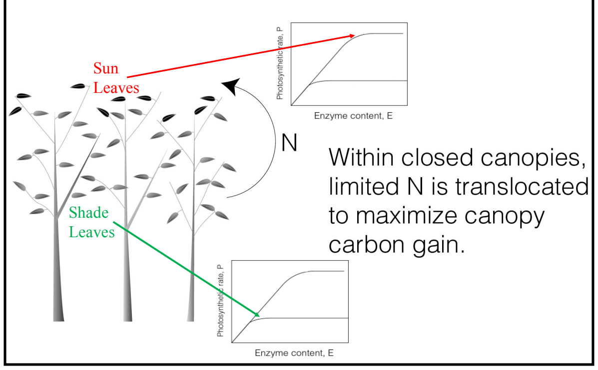
Proportional allocation of leaf nitrogen in *Acer negundo*



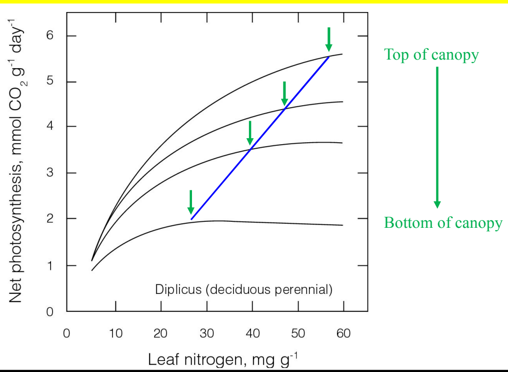
Plants will re-allocate leaf nitrogen when enzyme content exceeds capacity to use this resource for photosynthesis



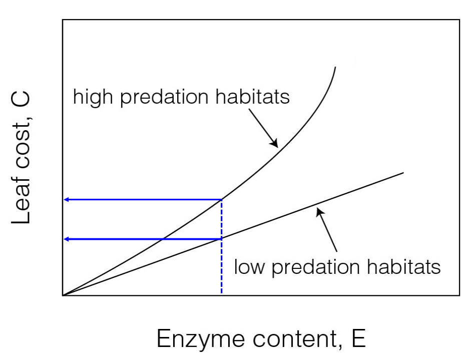
Plants re-allocate nitrogen among leaves in order to increase the overall rate of net photosynthesis by the entire canopy



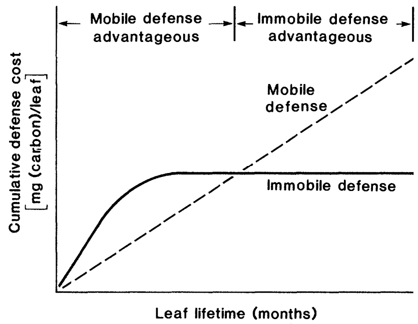
Plants re-allocate resources to optimize net photosynthesis at each canopy layer



Defense against herbivory can represent a substantial construction and maintenance cost (investments in alkaloids, tannins, other deterrents)

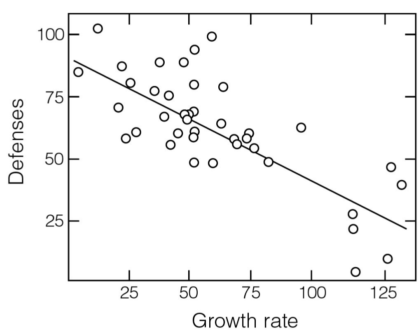


The type of defense is determined by leaf lifetime

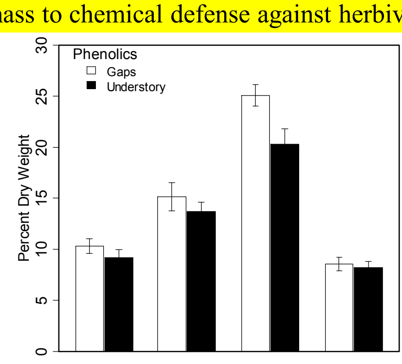


Coley et al., 1985, *Science*

Plant growth rate is slower when more of the carbon gain is allocated to defense



Plants may allocate as much as 25% of their mass to chemical defense against herbivores

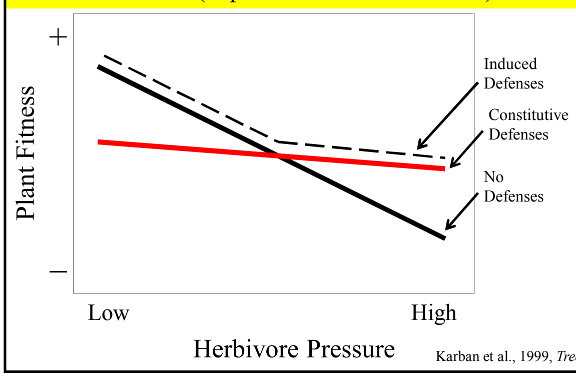


Bixenmann et al., 2010, *Oecologia*

There are many hypotheses that attempt to predict the type and quantity of defenses plants invest in

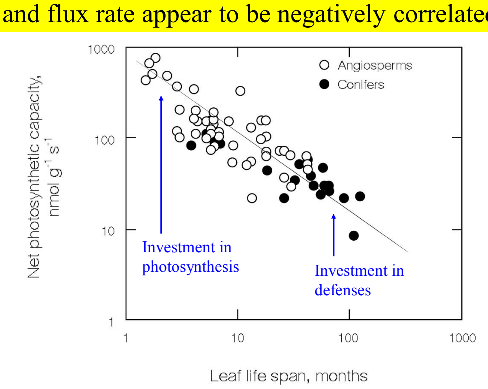
- **Resource Availability**: Plants adapted to low resource environments produce more defenses.
- **Carbon-Nutrient**: Plants with excess nutrients (nitrogen, phosphorus) invest in nutrient defenses; plants with excess carbon invest in carbon defenses.
- **Optimal Defense**: Reduce redundancy in defenses.

Plant defenses: constitutive (always present) versus induced (dependent on environment)

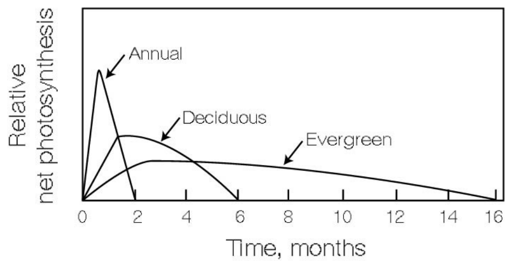


Karban et al., 1999, *Tree*

Across a wide range of species, leaf life expectancy and flux rate appear to be negatively correlated

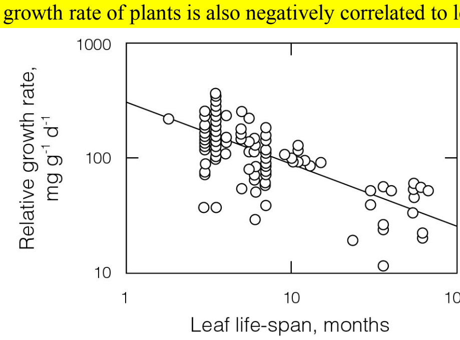


Across a wide range of life forms, leaf life expectancy and flux rate appear to be negatively correlated



Tradeoff between traits that maximize photosynthesis and traits that maximize leaf longevity: investment in photosynthetic machinery versus investment in maintenance and defenses (water or temperature stress, pathogens, herbivores).

The growth rate of plants is also negatively correlated to leaf life



Leaf tissues are a primary target of herbivores, because of their high protein content.

The longer the lifetime of a tissue, the greater the overall requirement to allocate resources for maintenance respiration and for defenses; less resources for growth.

Growth rates are more similar within a life form than among life forms