

Carbon Balance, Respiration and Environment

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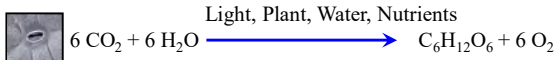
Carbon Balance, Respiration and Environment

Goals and learning objectives are to:

- Understand the respiration costs associated with various growth process - maintenance of biomass, growth of various organs, and transport and uptake of ions.
- Understand plant organ bio-chemical composition and their construction costs.
- The influence of environmental stresses on respiration process.

Photosynthesis

Plants grow through photosynthesis, a process that uses the energy from sunlight to combine carbon dioxide (CO₂) from the air with water to make carbohydrates plus oxygen.



The carbohydrates formed through photosynthesis feed not only the plants, but also almost all other organisms on earth, including those that eat the plants and those that eat the animals that eat the plants.

Factors that affect this process:

Solar radiation, CO₂, temperature, UV-B radiation, water, nutrient availability etc.,

Photosynthesis and Respiration and Growth Process

- Photosynthesis is certainly responsible for most of the gain in plant biomass, however, can we really derive essential information on growth rate and yield from measurements of photosynthesis?
- Rates of photosynthesis per unit leaf area are poorly correlated with rates of growth, almost even more poorly with final yield.
- The reason for this is that all carbohydrates that are gained in photosynthesis and subsequently used in respiration varies considerably. Slow growing species use relatively more carbohydrates for respiration than fast growing species.
- The response of photosynthesis and respiration to environmental factors differ based on the intensity of the stresses.

What is Respiration?

- The process of converting sugars and starches into energy through a series of biochemical steps is called respiration.
- This energy is used for growth and building new tissues.
- It is almost the reverse process of photosynthesis, which requires energy (light) and produces food, using carbon dioxide and producing oxygen.
- Respiration is the chemical process opposite of photosynthesis because it releases energy, using food and oxygen and producing carbon dioxide.



Photosynthesis and Respiration

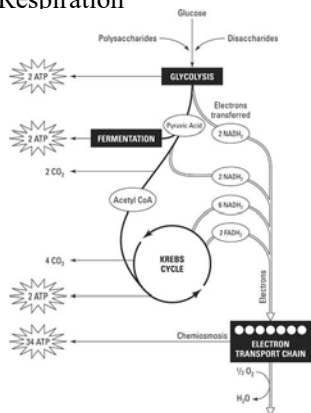
Photosynthesis	Respiration
Produces food (Sugars and starch)	Uses the food (Burns sugars for energy)
Stores energy	Releases energy
Uses water	Produces water
Uses CO ₂	Produces CO ₂
Releases O ₂	Uses O ₂
Occurs in light	Occurs at all times
Only in cells containing chloroplasts	All cells, but rates are tissue-specific

What is Respiration

Respiration can be divided into the following three stages or steps:

1. Glycolysis is the breakdown of a 6-carbon glucose molecule into two molecules of 3-carbon pyruvate; it takes place in the cytoplasm of *all* living cells. If oxygen is present (aerobic respiration), pyruvate is used in the following reactions that takes place in the mitochondria:
2. The Krebs cycle (citric acid cycle) occurs in the matrix.
3. Electron transport chain and oxidative phosphorylation occur deep in the cristae.

If oxygen is not present (anaerobic respiration), pyruvate is used in fermentation. Lactate formation occurs in animal, bacteria, fungi, and protist cells. Alcohol fermentation occurs in yeast and plant cells.



Environmental Conditions and Respiratory Process

Environmental Conditions and Respiratory Process

1. Flooded, Hypoxia and Anoxia Soils:

Plants growing in flooded soil are sometimes exposed to:

- a. **Hypoxic** (low-oxygen); b. **Anoxic** (no-oxygen)

In the root environment, they experience a number of problems, including insufficient supply of oxygen and accumulation of CO₂.

Flooding → O₂ will be deprived and will be replaced by water. **The diffusion of gases in water is approximately 10,000 times slower than that in air. The solubility of oxygen in water is less than in air** (at 25°C, for example, 0.5 mmole O₂ dissolves in one liter of water where as air contains about 10 mmol of O₂).

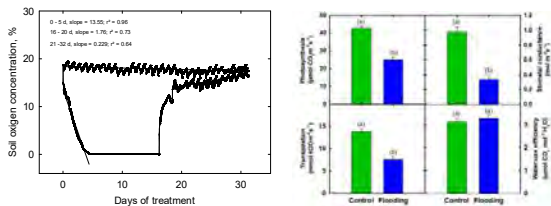
Prolonged flooded conditions will result in anoxic conditions and ATP production will be restricted and synthesis of RNA and proteins is strongly suppressed.

Environmental Conditions and Respiratory Process

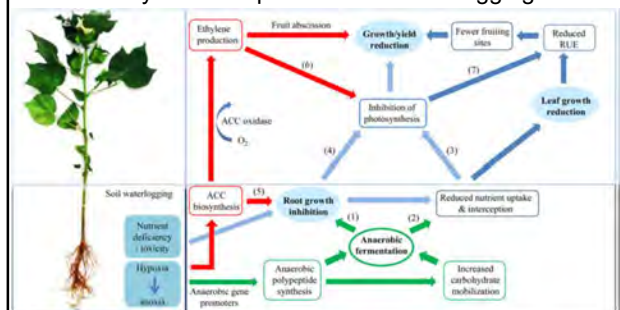
1. Flooded, Hypoxia and Anoxia Soils (Continued):

- However, specific m-RNAs and anaerobic polypeptides including fermentative enzyme, alcohol dehydrogenase will be produced. When this occurs in roots, fermentation starts and ATP may be produced through fermentative process in glycolysis.
- The byproducts of this process, ethanol and sometimes lactate, seem to be toxic for cells.
- The energetic efficiency of ethanol formation is very poor compared to aerobic respiration; 2 ATP versus 36 ATP per unit of glucose.

Flooding and Plant and Soil Processes



Changes in cotton growth and yield in response to soil waterlogging



Flows are represented in four categories: green (biochemical pathway); red (hormonal/signalling pathway); light blue (physiological pathways); dark blue (morphological changes).

Najeeb et al., AOB Plants, 2015

Environmental Conditions and Respiratory Process

2. Salinity and Water stress:

- Sudden exposure of sensitive plants to salinity or water stress often enhances respiration.
- Root respiration generally increases when roots are suddenly exposed to increased ion concentration, which is a phenomenon known as **salt respiration**. The stimulation of respiration is at least partly due to the increased demand for energy for ion transport.
- Long-term exposure of sensitive plants to salinity or drought gradually decreases respiration, which is in part of the general decline in carbon assimilation and overall metabolism associated with slow growth under stress conditions.



Environmental Conditions and Respiratory Process

3. Nutrient availability:

- When plants are grown at low supply of nutrients, their rate of root respiration is lower than that of plants that are well-supplied with mineral nutrients. This is expected, because their rates of growth and ion uptake are greatly reduced; however, rates of root respiration per ion absorbed or per unit of root biomass produced at the low nutrient supply are relatively high compared to plants well-supplied with nutrients.
- The effect of nutrient supply on shoot respiration is not as pronounced nor as consistent or not even well studied.

Environmental Conditions and Respiratory Process

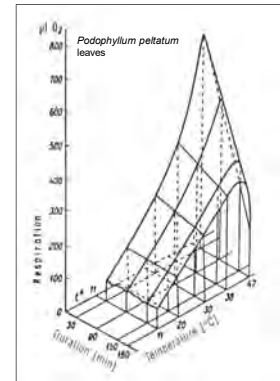
4. Irradiance or Solar radiation:

- Respiratory response of plants to light and assimilatory supply depends strongly on time scale. The immediate effect of low light is to reduce the **carbohydrate status** of the plant and, therefore, supply of substrates available to support respiration.

Environmental Conditions and Respiratory Process

5. Temperature:

- Dark respiration increases exponentially with rising temperature.
- The lower respiration rates at lower temperatures are due to the rule that at low temperatures the enzyme reactions are rate-limited
- At higher temperatures, the biochemical reactions proceed so rapidly that substrate and metabolites cannot be provided quickly enough to meet those demands and respiration rate slows down.
- At extremely high temperatures, (50 to 60°C), heat damage to enzymes and functionally important membrane structures causes respiration to cease.
- Respiration rates also depend on the duration of exposure.



Environmental Conditions and Respiratory Process

6. Partial pressure of CO₂:

I. Soils and CO₂

- The information is too scanty to draw a specific conclusion that CO₂ levels normally occurring in well-drained soils inhibit respiration to a major extent.

II. Plants and CO₂

- The long-term exposure of plants to elevated CO₂, such as expected in the latter part of 21st century, on plant respiration is also not yet conclusive (stimulation and inhibitions are reported). The effects are, however, **indirect**, due to changes in allocation, plant growth rate, chemical composition of the biomass, and so on., rather than accounted for by the **direct** effect.

Fruit storage: The process that takes advantage of low temperatures and low oxygen is **fruit storage**, in which it is common to maintain fruits in the cold under conditions of 2 to 3% oxygen (instead of about 21% current concentration), and 3 to 5% CO₂ (instead of about 0.041% of current concentration). Reduced temperature and oxygen lowers respiration and increased CO₂ is used to block the effect of the ethylene (a ripening hormone) production.

Carbon Balance in Plants

A large portion of the carbohydrates that a plant assimilates each day are expended in respiration and growth during the same period.

TABLE 1. Utilization of photosynthates in plants, as dependent on the nutrient supply.

Item	Utilization of photosynthates % of C fixed	
	Free nutrient availability	Limiting nutrient supply
Shoot growth	40*-57	15-27*
Root growth	17-18*	33-35
Shoot respiration	17-24*	19-20*
Root respiration	8-19*	38-52
* growth	3.5-4.6*	6*-9
* maintenance	0.6-2.6*	?
* ion acquisition	4-13*	?
Volatile losses	0-8	0-8
Exudation	~5	≤23
N ₂ -fixation	negligible	5-24
Mycorrhiza	negligible	7-20

Source: Van der Werf et al. 1994.
*, inherently slow-growing species; †, no information for nutrient-limited conditions.

Respiration and Growth Process

The rate of respiration depends on 3 major energy-requiring processes:

1. **Maintenance** of biomass
2. **Growth** of various organs
3. **Transport and uptake** of ions

Respiration and Growth Process

The rate of respiration depends on 3 major energy-requiring processes:

I. Maintenance of Biomass:

Once biomass is produced, energy must be expended for repair and maintenance. Estimates of the cost of maintaining biomass range from 20 to 60% of the photosynthesis produced per day.

Major part of the maintenance energy costs is supposed to associated with:

- **Protein turn over, 3 to 5% of dry matter per day** (2 to 5% of the protein is replaced daily with extremes as high as 20%). Approximately 75% of the amino acids are recycled, but the remaining 25% must be synthesized from basic carbon skeletons (28 to 53 mg glucose per day).
- **Lipids (e.g. membrane turnover), 0.2% of dry matter per day** (1.7 mg glucose per day).

Respiration and Growth Process

I. Maintenance of Biomass:

- **Maintenance of ion gradients** is approximately 30% of the the respiratory costs involved in ion uptake, or about 20% of the total respiratory costs of the young roots.
- **Other processes** (e.g., turnover of other cellular constituents) also have a relatively small cost to maintain.

Respiration and Growth Process

The rate of respiration depends on 3 major energy-requiring processes:

I. Maintenance

II. Growth Respiration:

The production of biomass requires input of carbohydrates, partly to generate ATP and NADPH for biosynthetic reactions and partly to provide carbon skeletons present in biomass.

The costs for biosynthesis can be derived from detailed information on the biochemical composition, combined with biochemical data on the costs of synthesis of all major compounds such as:

1. Proteins
2. Total nonstructural carbohydrates (e.g. sucrose, starch, fructoses)
3. Total structural carbohydrates (e.g. cellulose, hemicellulose)
4. Lignins
5. Lipids
6. Organic acids
7. Minerals

Respiration and Growth Process

TABLE 12. An example of a simplified calculation of the variables that characterize biosynthesis of biomass from glucose, nitrate, and minerals.

Compound	Concentration in biomass (mg g ⁻¹ DM)	Glucose required for synthesis (mg)	O ₂ required for synthesis (μmol)	CO ₂ production during synthesis (μmol)	NAD(P)H required for synthesis (mmol)	ATP required for synthesis (mmol)
N-compounds	230	23%	371	65	2,100	7.14
Carbohydrates	565	56%	662	0	857	-2.03
Lipids	25	2.5%	71	0	807	0.25
Lignin	80	8%	166	230	918	-0.34
Organic acids	50	5%	45	0	-52	-0.23
Minerals	50	5%	0	0	0	0
Total	1000		1315	295	4630	3.68

Source: Penning de Vries et al. 1974.

Respiration and Growth Process

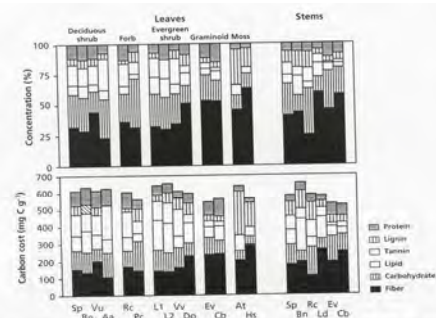


FIGURE 23. The chemical composition and carbon cost of producing leaves and stems of thirteen species of temperate plants. Species shown are *Salix purpurea* Lign. *Rhus glabra* (Rc), *Vaccinium vitis-idaea* (Vv), *Arctostaphylos alpinus* (At), *Rubus chamaemorus* (Rc), *Panicum capillare* (Pc), *Lolium perenne* (L1, L2), including 1-year-old, 13, and 2-year-old, 12, leaves, *Vaccinium vitis-idaea* (Vv), *Oxalis fragrans* (Of), *Erigeron ramosus* (Er), *Carex lasiocarpa* (Cl), *Andropogon scoparius* (As), *Agrostis alba* (Ag), *Alopecurus pratensis* (Ap), and *Phlebotium spiroideum* (Ph) (Chapin 1989). Copyright by The University of Chicago.

Respiration and Growth Process

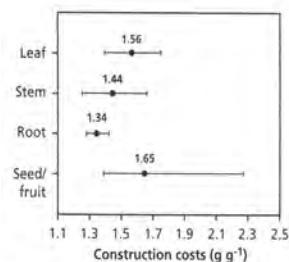


FIGURE 24. Range of construction costs for a survey of leaves ($n = 123$), stems ($n = 38$), roots ($n = 35$), and fruits/seeds ($n = 31$). Values are means and 10th and 90th percentiles (Poorter 1994). Copyright SPB Academic Publishing.

Respiration and Growth Process

The rate of respiration depends on 3 major energy-requiring processes:

I. Growth

II. Maintenance

III. Ion Transport:

Ion transport across membranes may occur via ion channels and costs energy to transport from the rhizosphere.

Respiration and Growth Process

Utilization of Photoassimilates:

Growth Processes: % of C fixed

1. Shoot 40-57
2. Root 17-24

Respiratory Processes:

1. Shoot 17-27
2. Root 8-19

Others:

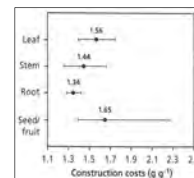
1. Volatilization 0-8
2. Exudation <5

Respiration and Growth Process

The rate of respiration depends on 3 major energy-requiring processes:

1. **Maintenance** of biomass – 20 to 60%
 - Protein turnover (3-5% of DW)
 - Lipid turnover (0.2% of DW)
 - Cellular turnover (relatively small cost)
 - Ion gradients (about 30% of root respiration)

1. **Growth** of various organs – varies depending upon the biochemical composition of tissue.
2. **Transport and uptake** of ions – also requires energy



Respiration - Summary

- The concepts of respiration associated with growth, maintenance, and ion uptake are useful tools in understanding the carbon balance of plants.
- The partitioning of respiration among these functions (growth, maintenance and ion uptake) may differ substantially with environment and the type of plant material and also based on the species where it is grown.