Chap 4. Growth and Metabolism

I. Terminology

1. Growth – Irreversible increase in size

2. Development:
   Morphogenesis - Morphological and anatomical development
   Differentiation - Physiological and biochemical specialization of plant tissues

3. Metabolism: Synthesis and degradation of organic compounds
   Anabolism - synthesis
   Catabolism – degradation (breakdown)
II. Major Chemical Processes of Plants

1. Photosynthesis

\[
12 \text{H}_2\text{O} + 6 \text{CO}_2 + \text{Light} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 + 6 \text{H}_2\text{O}
\]

(Water) (Carbon dioxide) (Energy) Chloroplast (Carbohydrate) (Oxygen) (Water)

2. Metabolism

\[
\text{C}_6\text{H}_{12}\text{O}_6 + \text{Mineral} \rightarrow \text{Various Organic Compounds}
\]

(Carbohydrate) (Fertilizer) (Cytoplasm) (Protein, fats, starch, hormones, etc.)

3. Respiration

\[
\text{Organic Compds} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{Energy} + \text{Mineral}
\]

(Substrates, Oxygen) (Mitochondria) (ATP) (Inorganic) Energy source

The energy released from respiration is used for growth and development of plants
How Do Plants Manufacture Their Own Food?
III. Photosynthesis

1. Light phase of photosynthesis

**Photolysis** – Cleavage of water into hydrogen and oxygen by light energy

\[
\begin{align*}
\text{H}_2\text{O} & \quad \text{O}_2 \\
\text{H}^+ & \quad \text{e}^- \\
\text{NADP} & \quad \text{NADPH}_2 \quad \text{(Hill Reaction)}
\end{align*}
\]

**Photophosphorylation**
Conversion of ADP to ATP by light energy

\[
\begin{align*}
\text{ADP} & \quad \text{e}^- \quad \text{ATP}
\end{align*}
\]

**Sum**: Conversion of light energy to chemical energy

\[
\begin{align*}
\text{ATP} & \quad \text{ADP} \\
\text{NADPH}_2 & \quad \text{NADP} \quad \text{H}^+ \quad \text{(Reducing power)}
\end{align*}
\]

used in many energy transfer processes of the cell
Diagram of a plant cell showing:
- Tonoplast
- Vacuole
- Nucleolus
- Nuclear envelope
- Chromatin
- Ribosomes
- Rough endoplasmic reticulum
- Smooth endoplasmic reticulum
- Mitochondrion
- Primary cell wall
- Plasma membrane
- Middle lamella
- Golgi body
- Chloroplast
- Intercellular air space

PLANT PHYSIOLOGY, Third Edition, Figure 1.4 © 2002 Sinauer Associates, Inc.
2. Dark Phase of Photosynthesis

Calvin Cycle

A series of enzymatically mediated reactions in which CO$_2$ reduced to 3-phosphoglyceraldehyde (3PGA) and the CO$_2$ receptor (Ribulosebiphosphate: RUBP) is generated.

**Net Gain**

$6\text{ CO}_2(6\text{C}) + 12\text{ H}_2\text{O} + \text{light} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6(\text{C}_6) + 6\text{ O}_2 + 6\text{ H}_2\text{O}$
3. Two Different CO$_2$ Pathways

**C$_3$ Pathway**

- C$_3$ Plants (many dicots: soybean, tomato, apple, etc.)
- The 1st product of CO$_2$ fixation is C$_3$ acids
- Only the Calvin Cycle operates
- Photorespiration exists

\[
\text{CO}_2 + \text{RuBP (C5)} \xrightarrow{\text{RuBP Carboxylase}} \text{C}_3 \text{ Acids (3PGA)}
\]

Calvin cycle

Fructose \xrightarrow{\text{Glucose}} \text{Starch}
C₄ Pathway

- C₄ Plants (Tropical grass, corn, sugarcane, some dicots like amaranth, Atriplex)
- First product of CO₂ fixation is C₄ acids
- Both C₄ pathway and Calvin cycle operate
- Lacks photorespiration
- C₄ plants grow faster than C₃ plants, due to efficient use of CO₂
4. Photorespiration

The process of respiration that consumes oxygen and releases CO$_2$ in the presence of light

- Does not produce ATP
- Consumes the reducing power for reducing O$_2$ to CO$_2$
- Reduces photosynthetic efficiency
- Occurs in C$_3$ plants

![Diagram of Calvin Cycle and Photorespiration](image-url)

- **Calvin Cycle**
  - CO$_2$, H$_2$O
  - PGA C$_3$ → Sugars
  - RuBP (C5)
  - Photorespiration
  - O$_2$

- **Photorespiration**
  - PGA C$_3$
  - Phosphoglycolic Acid C$_2$
  - Peroxisomes

-(High CO$_2$, low O$_2$)

-(High O$_2$, low CO$_2$ atmosphere)
5. Carbon Dioxide Compensation Point

A steady state of CO$_2$ concentration in the air at which CO$_2$ taken up by plants via photosynthesis is the same as the CO$_2$ given off via respiration

- At CO$_2$ compensation point, no growth occurs
- Below compensation point, plants will degrade
- C$_3$ plants have higher CO$_2$ compensation points than the C$_4$ plants

CO$_2$ Compensation Points:
- Soybean (C$_3$ plant) - - - - - 50 ppm at 25°C
- Corn (C$_4$ plant) - - - - - - - 10 ppm at 25°C
- Ambient CO2 concentration: 300 ppm (0.03 %)

- Same principles apply to Light Compensation Points

Net Photosynthesis = Gross Photosynthesis - Respiration
IV. Nutrient Absorption and Translocation

1. Plant Nutrients
   - 16 elements
     - Macronutrients: Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Sulfur (S)
     - Micronutrients: Boron (B), Chloride (Cl), Copper (Cu), Iron (Fe), Manganese (Mn), Molybdenum (Mo), Zinc (Zn)

2. Ability to Manufacture Food
   - Most green plants are autotrophic
     - Autotrophic – Capable of manufacturing its own food from minerals
     - Heterotrophic – Incapable of manufacturing its own food
       Depends on other sources for organic matter
       (Immature embryo, dodder, human)
Heterotrophic (Parasitic) Plants

*Cuscuta* species (Dodders)
3. Nutrient and Water Movement

- **Diffusion** – Movement of molecules (a substance) from a region of high concentration to the region of low concentration

- **Osmosis** – Diffusion of water through differentially permeable membrane
  
  Reverse osmosis (RO) water - purified water low in salt content

- **Translocation** – Movement of inorganic and organic solutes from one part to another part of the plant

  Water conduction and mineral movement via xylem
  Carbohydrate translocation through phloem

- **Transpiration** – Loss of water vapor from the leaf via stomata

- **Evaporation** – Loss of water by vaporization

- **Evapo-transpiration** – Loss of water by evaporation and transpiration
V. Plant Respiration

1. Reverse of Photosynthesis
   The process of releasing energy, CO₂ and water from organic materials by oxidation
   \[
   \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 \rightarrow 6 \text{H}_2\text{O} + 6 \text{CO}_2 + \text{Energy}
   \]

2. Chemical Process
   - **Glycolysis** – Conversion of C₆ sugars to CO₂ and pyruvic acid
   - **Citric Acid Cycle** (Kreb Cycle) – Oxidation of pyruvic acid to H⁺, e⁻ and CO₂ (occurs in mitochondria)

3. The Q₁₀
   - The rate of respiration doubles when temperature rises 10 °C (18 °F)
   - Respiration can be reduced by lowering O₂ and increasing CO₂ concentrations
   Application:  
   a) CO₂ storage of apples and pears  
   b) Hypobaric storage of flowers and fruits (Low atmospheric pressure)
VII. Plant Constituents

- **Carbohydrates**
  - Monosaccharides - simple carbohydrates (pentose $C_5$, hexose $C_6$)
  - Disaccharides – maltose (glu-glu), sucrose (glu-fru) $C_{12}$
  - Olygosaccharides -1-10 monosaccharides lined together
  - Polysaccharides – starch (poly glu), cellulose, hemicellulose, insulin, etc.

- **Lipids** (fats, phospholipids, waxes)
- **Proteins** (structural, soluble)
- **Aromatic Compounds** (Vanillin, flavonoids)
- **Terpenoids and Steroids**
- **Non-Protein Nitrogen Compounds** (DNA, RNA, Bases)
- **Vitamins** (Vitamin C, Thiamin B$_1$)