Photosynthesis, Cellular Respiration and Plant Growth

The seed of a giant Sequoia is only about 5 mm long and about 1 mm in diameter. This tiny seed can develop into a tree as tall as a 20-story building (approximately 80 m).

To see the early growth of a Sequoia, view https://www.youtube.com/watch?v=3mGrBt0zCOU. To see the enormous size of an adult giant Sequoia, view https://www.youtube.com/watch?v=vNCH6uhB_Bs.

1a. A giant Sequoia can weigh as much as 2000 tons (more than a million kilograms). Where do you think that all this mass came from?

1b. How could a scientist investigate where the mass of a giant Sequoia comes from?

Trees gain mass by the same basic processes as other plants. To learn where plants’ mass comes from, you will analyze research results for smaller plants, since smaller plants are easier to study in the laboratory.

To understand where plants’ mass comes from, it is important to know what types of molecules are in plants. The main types of molecules in plants are water and organic molecules (e.g. sugars, starch, cellulose, and proteins). To grow and gain mass, plants take up water from the soil and plants make organic molecules.

2. Many types of plants can be grown with no soil. Instead, their roots are in water that has small amounts of dissolved minerals like nitrogen and phosphorus. What do you think these plants use to make organic molecules?

The mass of the organic molecules in a plant is called the **biomass**. This activity will focus mainly on how plants gain biomass.

3. This table shows data for a typical small plant. What is the biomass of this plant?

<table>
<thead>
<tr>
<th></th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>4.2 g</td>
</tr>
<tr>
<td>Organic molecules</td>
<td>1.4 g</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>5.6 g</strong></td>
</tr>
</tbody>
</table>

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By Drs. Ingrid Waldron, Lori Spindler and Linda Robinson, Department of Biology, University of Pennsylvania, © 2019. This Student Handout and Teacher Preparation Notes with instructional suggestions and background information are available at https://serendipstudio.org/sci_edu/waldron/#photobiomass.
Experiment 1 – Changes in Biomass for Seedlings Grown in Light vs. Dark

This figure shows the results of Experiment 1. In the beginning of the experiment, each dish had 1.46 grams of radish seeds and no soil or water. Then, each dish was exposed to light and/or water for ten days.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Biomass after 10 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light, No Water</td>
<td>1.63 g</td>
</tr>
<tr>
<td>Light, Water</td>
<td>1.46 g</td>
</tr>
<tr>
<td>No Light, No Water</td>
<td>1.20 g</td>
</tr>
</tbody>
</table>

4a. The seedlings that grew with light and water had __________ biomass than the seeds they sprouted from.
(less/more)

4b. The seedlings that grew with water, but no light had __________ biomass than the seeds they sprouted from.
(less/more)

4c. This experiment shows that both __________ and __________ are needed for seedlings to gain biomass.

A third input is needed for plants to gain biomass, but this input comes from the air, and it was not identified in this experiment. This figure summarizes additional research evidence.

5a. Put a rectangle around the part of this figure that shows photosynthesis.

5b. Which molecule provides the carbon and oxygen atoms that are responsible for most of the mass of a glucose molecule made by photosynthesis?

5c. Plant cells bond glucose monomers together to make a cellulose molecule. Explain how the carbon and oxygen atoms in CO₂ molecules can become part of a cellulose molecule in the cell wall of a leaf cell.
6. Explain why plants need light to gain biomass.

7a. In this figure, show the inputs needed for a giant Sequoia tree to gain biomass.

7b. Explain how the giant Sequoia tree used these inputs to create biomass.

7c. Which molecule was the source of most of the mass of the organic molecules in the giant Sequoia tree?

7d. In addition to the biomass, where did the rest of the mass of the giant Sequoia tree come from?

To understand why the seedlings in the dark lost biomass, we need to begin by recalling that the sugar molecules produced by photosynthesis are used for two purposes:
- to synthesize other organic molecules (e.g. starch or cellulose) or
- as input for cellular respiration.

In the light, **photosynthesis**, **cellular respiration**, and **hydrolysis of ATP** work together to provide the energy for plants’ biological processes.

8. This figure shows one of the uses of glucose molecules produced by photosynthesis. Add the other use of glucose to the figure.

In the dark, there is no photosynthesis, but plants continue to carry out multiple biological processes that require energy. The energy for these biological processes is provided by the hydrolysis of ATP. The supply of ATP is maintained by cellular respiration. Glucose and \( \text{O}_2 \) are the inputs for reactions that provide the energy to make ATP from ADP and P.

9a. When seedlings start to grow underground in the dark, the starch in the seeds is broken down to glucose. Some of the glucose is used for cellular respiration. Show this in the figure.

9b. Why do seedlings in the dark need to carry out cellular respiration?
10. Propose a hypothesis to explain how seedlings in the dark lose biomass.

Experiment 2 – Changes in CO₂ in the Air around Plants in the Light vs. Dark

11a. You class will do an experiment to evaluate changes in the concentration of CO₂ in the air around plants in the light vs. plants in the dark. Why is information about changes in CO₂ levels relevant for testing hypotheses about the causes of changes in plant biomass?

11b. Complete this table to predict the results of your class experiment.

<table>
<thead>
<tr>
<th></th>
<th>Predicted Change in the Concentration of CO₂ in the Surrounding Air</th>
<th>Explain why you made this prediction.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plants in the Light</td>
<td>Decrease ___ Increase ___ No change ___</td>
<td></td>
</tr>
<tr>
<td>Plants in the dark</td>
<td>Decrease ___ Increase ___ No change ___</td>
<td></td>
</tr>
</tbody>
</table>

12a. In your class experiment you will use change in the color of an indicator solution to evaluate changes in CO₂ concentration. Your teacher will give you some indicator solution. Record its color in the first column of the table below. Follow the instructions in the second column of the table, and record your observations in the third column.

<table>
<thead>
<tr>
<th>Beginning Color</th>
<th>Instruction</th>
<th>Final Color</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Use a straw to blow bubbles into the indicator solution in one beaker.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Use a pipette to blow bubbles of air into the indicator solution in the other beaker.</td>
<td></td>
</tr>
</tbody>
</table>

12b. What change in color indicates an increase in concentration of CO₂?

12c. Explain your reasoning.

Procedure for Class Experiment

A. Your group will work with a partner group to measure changes in CO₂ in the air around plants in the light vs. dark. One group should mark your large container with an L for light, and the other group should mark your container with a D for dark.

B. In each container, put a pan of growing plants and a petri dish with the CO₂ indicator.
C. Record the color of the CO₂ indicator in each container.
   L ______________________  D ______________________

D. Seal your container. Put the L container in a sunny spot with grow lights. Put the D container in a dark closet, trash bag or box. Record the day and time. ____________________

E. Wait a day. Then, record the color of the CO₂ indicator in each container.
   L ______________________  D ______________________
   Record the day and time. ____________________

**Results and Interpretation**

13. Your teacher will give you a color chart to interpret the changes in color. For each sentence, choose the best match from the list below.
   
   For the plants in the light, the concentration of CO₂ in the surrounding air ___.
   For the plants in the dark, the concentration of CO₂ in the surrounding air ___.
   a. decreased  b. increased  c. stayed the same

14a. For the plants in the light, what caused the change in the concentration of CO₂ in the surrounding air?

14b. How is this change in CO₂ concentration related to the increase in biomass of plants that are growing in the light?

15a. For the plants in the dark, what caused the change in CO₂ concentration in the surrounding air?

15b. Based on these results, answer the following question about Experiment 1. Why did the seedlings that grew in the dark have less biomass than the seeds they spouted from?

16. In Experiment 1, the seedlings that grew in the dark had less biomass, but more total mass than the seeds they sprouted from. What caused the increase in total mass?
Effects of Photosynthesis and Cellular Respiration on Changes in Biomass

17a. For a plant to gain biomass, the number of glucose molecules produced by photosynthesis must be ______________________ the number of glucose molecules used for cellular respiration. (greater than / less than / the same as)

17b. A seed with biomass S sprouts and grows underground until time E when the seedling’s leaves emerge from the soil into the light. In the graph, show the changes in biomass before E and after E.

17c. Explain the reasons for the changes in biomass you have shown.

18. Many people get most of their daily calories from the starch that is stored in seeds such as rice, corn or wheat. Explain why it is useful to plants to include a store of starch in their seeds.

19. Draw a poster that summarizes what you have learned. Your poster should show:
   - the processes that provide energy for plant cells in the light and in the dark
   - the processes that result in increased biomass or decreased biomass
   - the inputs and outputs for each of these processes and how the outputs of each process can be inputs for another process.