Transpiration Lab

What factors, including environmental variables, affect the rate of transpiration in plants?

BACKGROUND

Cells and organisms must exchange matter with the environment to grow, reproduce, and maintain organization, and the availability of resources influences responses and activities. For example, water and macronutrients are used to synthesize new molecules, and, in plants, water is essential for photosynthesis. Organisms have evolved various mechanisms for accumulating sufficient quantities of water, ions, and other nutrients and for keeping them properly balanced to maintain homeostasis.

Plants absorb and transport water, nutrients, and ions from the surrounding soil via osmosis, diffusion, and active transport. Once water and dissolved nutrients have entered the root xylem, they are transported upward to the stems and leaves as part of the process of transpiration, with a subsequent loss of water due to evaporation from the leaf surface. Too much water loss can be detrimental to plants; they can wilt and die.

The transport of water upward from the roots to shoots in the xylem is governed by differences in water (or osmotic) potential, with water molecules moving from an area of high water potential (higher free energy, more water) to an area of low water potential (lower free energy, less water). The movement of water through a plant is facilitated by osmosis, root pressure, and the physical and chemical properties of water. Transpiration creates a lower osmotic potential in the leaf, and the TACT (transpiration, adhesion, cohesion, and tension) mechanism describes the forces that move water and dissolved nutrients up the xylem.
During transpiration, water evaporating from the spaces within the leaves escapes through small pores called stomata. Although evaporation of water through open stomata is a major route of water loss in plants, the stomata must open to allow for the entry of CO\textsubscript{2} used in photosynthesis. In addition, O\textsubscript{2} produced in photosynthesis exits through open stomata. Consequently, a balance must be maintained between the transport of CO\textsubscript{2} and O\textsubscript{2} and the loss of water. Specialized cells called guard cells help regulate the opening and closing of stomata.

In this laboratory investigation, you will begin by calculating leaf surface area and then determine the average number of stomata per square centimeter. From your data, several questions emerge about the process of transpiration in plants, including the following:

- Do all plants have stomata? Is there any relationship between the number of stomata and the environment in which the plant species evolved?
- Are leaf surface area and the number of stomata related to the rate of transpiration? What might happen to the rate of transpiration if the number of leaves or the size of leaves is reduced?
- Do all parts of a plant transpire?
- Do all plants transpire at the same rate? Is there a relationship between the habitat in which plants evolved and their rate of transpiration?
• What other factors, including environmental variables, might contribute to the rate of transpiration?
• What structural features and/or physiological processes help regulate the amount of water lost through transpiration? How do plants maintain the balance between the transport of CO₂ and O₂ and the amount of water lost through transpiration?

You will then design an experiment to investigate one of these questions or a question of your own. This investigation also provides an opportunity for you to apply concepts you will be studying, including the relationship between cell structure and function; osmosis, diffusion, and active transport; the movement of molecules and ions across cell membranes; the physical and chemical properties of water; photosynthesis; and the exchange of matter between biological systems and the environment.

LEARNING OBJECTIVES
• To investigate the relationship among leaf surface area, number of stomata, and the rate of transpiration.
• To design & conduct an experiment to explore other factors, including different environmental variables, on the rate of transpiration.
• To investigate the relationship between the structure of vascular tissue (xylem & phloem) and their functions in transporting water and nutrients in plants.

THE INVESTIGATIONS

GETTING STARTED

These questions are designed to help you understand concepts related to transpiration in plants before you design and conduct your investigation(s).

1. If a plant cell has lower water potential than its surrounding environment, make a prediction about the movement of water across the cell membrane. In other words, will the cell gain water or lose water? Explain your answer in the form of a diagram with annotations.
2. In the winter, salt is sometimes spread over icy roads. In the spring, after the ice has melted, grass often dies near these roads. What causes this to happen? Explain your answer in the form of a diagram with annotations.
3. How does the difference in cellular structure between xylem and phloem reflect their differences in function?
4. If you wanted to transplant a tree, would you choose to move the tree in the winter, when it doesn’t possess leaves but it’s cold outside, or during the summer, when the tree has leaves and it’s warm and sunny? Explain your answer.

**PROCEDURE**

**MATERIALS**

- Living representative plant species available in your region/season
- Calculator, microscope, microscope slides

Investigate methods of calculating leaf surface area. (You will need to calculate leaf surface area when you conduct your experiments.) Think about and formulate answers to the following questions as you work through this activity:

a. How can you calculate the total leaf surface area expressed in cm\(^2\)? In mm\(^2\)?

b. How can you estimate the leaf surface area of the entire plant without measuring every leaf?

c. What predictions and/or hypotheses can you make about the number of stomata per mm\(^2\) and the rate of transpiration?

d. Is the leaf surface area directly related to the rate of transpiration?

e. What predictions can you make about the rate of transpiration in plants with smaller or fewer leaves?

f. Because most leaves have two sides, do you think you have to double your calculation to obtain the surface area of one leaf? Why or why not?

g. Water is transpired through stomata, but carbon dioxide also must pass through stomata into a leaf for photosynthesis to occur. There is evidence that the level of carbon dioxide in the atmosphere has not always been the same over the history of life on Earth. Explain how the presence of a higher or lower concentration of atmospheric carbon dioxide would impact the evolution of stomata density in plants.

h. Based on the data in the following table, is there a relationship between the habitat (in terms of moisture) to which the plants are adapted and the density of stomata in their leaves? What evidence from the data supports your answer?
Table 1. Average Number of Stomata per Square Millimeter (mm²) of Leaf Surface Area

<table>
<thead>
<tr>
<th>Plant</th>
<th>In Upper Epidermis</th>
<th>In Lower Epidermis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anacharis</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Coleus</td>
<td>0</td>
<td>141</td>
</tr>
<tr>
<td>Black Walnut</td>
<td>0</td>
<td>160</td>
</tr>
<tr>
<td>Kidney Bean</td>
<td>40</td>
<td>176</td>
</tr>
<tr>
<td>Nasturtium</td>
<td>0</td>
<td>130</td>
</tr>
<tr>
<td>Sunflower</td>
<td>85</td>
<td>156</td>
</tr>
<tr>
<td>Oats</td>
<td>25</td>
<td>23</td>
</tr>
<tr>
<td>Corn</td>
<td>70</td>
<td>88</td>
</tr>
<tr>
<td>Tomato</td>
<td>12</td>
<td>130</td>
</tr>
<tr>
<td>Water Lily</td>
<td>460</td>
<td>0</td>
</tr>
</tbody>
</table>

DESIGNING AND CONDUCTING YOUR INVESTIGATION

The procedure should have raised several questions about factors that relate to the rate of transpiration in plants. Some possible questions are listed below, but you may have others.

- What environmental variables might affect the rate of transpiration?
- Do all parts of a plant transpire?
- Do all plants transpire at the same rate?
- Is there a relationship between the habitat in which plants evolved to their rate of transpiration?

Rate of transpiration can be measured by a variety of methods, including the use of a potometer or the use of the whole plant method.

STEP 1 Design an experiment to investigate one of the aforementioned questions or one of your own questions to determine the effect of an environmental variable(s) on the rate of transpiration in plants. When identifying your design, be sure to address the following questions:

- What is the essential question being addressed?
- What assumptions are made about the questions being addressed?
- Can those assumptions be easily verified?
- Will the measurement(s) provide the necessary data to answer the question under study?
- Did you include a control in your experiment?
**STEP 2** Make a hypothesis/prediction about which environmental factors will have the greatest effect on transpiration rates. Be sure to explain your hypothesis.

**STEP 3** Conduct your experiment(s) and record data and any answers to your questions. Write down any additional questions that arose during this study that might lead to other investigations that you can conduct.

**WHOLE PLANT METHOD**

**MATERIALS**

- Small potted plant with many leaves & few flowers
- One-gallon size plastic food storage bag without zipper
- String

**STEP 1** Carefully remove a plant from the soil/pot, making sure to retain as much of the root system and keeping soil particles attached to the roots. Wrap the root ball of the plant in a plastic bag and tie the bag around the base so that only the leaves are exposed. (Be sure to remove all flowers & buds). Do not water your plant any more until you finish your experiment! You can also keep the plant in the plastic pot and place it in the plastic bag.

**STEP 2** Determine the mass of your plant and then its mass for several days under your environmental condition.

**STEP 3** Record your data in a table

**CALCULATIONS:** Determining Surface Area and Transpiration Rates

**STEP 1** In the first part of this lab, you were asked to investigate methods to calculate leaf surface area of all the leaves on a plant. Choose a method, calculate, and record the value.

**STEP 2** Calculate the rate of transpiration/surface area. To do this, first determine the mass of water lost over the five days and divide this by the amount of time, in minutes, that the plant transpired. Then divide this value by the surface area calculated in Step 1.
**STEP 3** After the entire class agrees upon the appropriate control group, subtract the control value from your experimental value. Record this adjusted rate.

**STEP 4** Record the adjusted rate for your experimental test on the board to share with the other lab groups. Record the class results for each of the environmental variables investigated.

**STEP 5** Graph the class results to show the effects of different environmental variables on the rate of transpiration. You may need to convert data to scientific notation with all numbers reported to the same power of ten for graphing purposes.

**ANALYZING RESULTS**

1. How was the rate of transpiration affected by your choice of experimental variable as compared to the control?
2. By comparing results & conclusions with the other lab groups, explain how changes or variables in environmental conditions affect transpiration rates.
3. Based on data collected from different lab groups, which environmental variable(s) resulted in the greatest rate of water loss through transpiration? Explain why this factor might increase water loss when compared to other factors.
4. Why did you need to calculate leaf surface area to determine the rate(s) of transpiration?
5. What structural or physiological adaptations enable plants to control water loss? How might each adaptation affect transpiration?
6. Make a prediction about the number of stomata in a leaf and the rate of transpiration. What type(s) of experiments could you conduct to determine the relationship between the number of stomata and the rate of transpiration?
7. Create a diagram with annotation to explain how the TACT (transpiration, adhesion, cohesion, tension) mechanism enables water and nutrients to travel up a 100-ft tree. Predict how a significant increase on environmental temperature might affect the rate of transpiration in this tree.

**EVALUATING RESULTS**

1. Was your initial hypothesis about the effect of your environmental variable on the rate of transpiration supported by the data collected? Why or why not?
2. What were some challenges you had in performing your experiment? Did you make any incorrect assumptions about the effect of environmental variables on the rate(s) of transpiration?