THE WATER (HYDROLOGIC) CYCLE: TRANSPIRATION

OBJECTIVES:

- Students will correctly define transpiration.
- Students will compare the rate of transpiration from plants grown in three EarthBoxes under different simulated environmental conditions by measuring the amount of water added to each box and calculating the difference.
- Students will analyze and interpret their data and formulate conclusions about the measured transpiration rates.
- Students will prepare wet mounts of bean leaves and examine them under a microscope to see stomata.

NATIONAL STANDARDS ADDRESSED:

Science (National Science Education Standards)
A.1, C.5.d, D.2
Mathematics (Principles and Standards for School Mathematics)
Numbers and Operations, Measurement, Data Analysis and Probability
Reading (Standards for the English Language Arts)
1, 3, 5

MATERIALS:

- Three EarthBox kits
- Empty 1-gallon milk container and measuring cup or other graduated measuring device for watering EarthBoxes
- Small electric fan
- Microscopes, slides, and cover slips
- Three packets of broad bean seeds (minimum 96 seeds)
- Window ledge with 6-8 hours of Eastern or Southern exposure (two grow lights may be substituted)
- Heat lamp (or halogen light)

PROCEDURE:

PART I, 45 MINUTES

STEP 1: Have students take turns reading the EarthBox instructional booklet out loud. As a class, set up the three EarthBoxes according to the instructions with the following exception:

- No fertilizer is necessary. If fertilizer is already in the three EarthBoxes, it can be left there without having any negative effect on the experiment.

STEP 2: Prepare the three EarthBoxes for planting the broad been seeds. Designate 3 students to cut 16 holes in each EarthBox plastic cover according to the instructions for bean plants. Have the remainder of the class make three piles of 32 bean seeds, selected at random from the seed packs. Have students take turns planting 2 bean seeds ¾" deep in the potting mix at each of the 16 holes in the plastic cover of each of the three EarthBoxes, for a total of 32 seeds in each EarthBox (96 seeds total). When finished planting, position each EarthBox under a grow light or in an appropriate window location. Create and post a schedule of EarthBox watering duties so that as many students as possible have the responsibility to water the EarthBoxes (a blank schedule is included at the end of this manual).

Ten Days Later – Part II

Step 3: Assign several students to thin the bean plants to one per hole, for a total of 16 bean plants in each EarthBox. To do this, have the students examine each pair of bean plants growing through each hole in the plastic cover to determine which plant looks the healthiest (based on size, color, and overall appearance). The students should then pinch off the other bean plant at its base and discard it. If only one seed germinated in a given hole, that single bean plant should be left alone.

One Week Later – Part III (length varies depending on how many days the class collects data)

Step 4: Now that the bean plants have grown sufficiently, the class is ready to begin the experiment. Have three students make sure that the water reservoirs are completely full by adding water slowly through the watering tubes until it just begins to drip out the drain holes. Next, have the class set up the simulated environmental conditions as follows:

> **Wind** – Position the fan so that it circulates air past all of the bean seedlings in the first EarthBox. Turn the fan on (medium or high setting, depending on how forceful it is) and leave it on continuously.
>
> **Heat** – Position the heat (or halogen) lamp near the bean plants in the second EarthBox. Place it in the center of the long side of the EarthBox approximately one foot from the plants. You must be careful not to position it too close to the plants or the heat may kill them.
>
> **Control** – Do nothing to the third EarthBox. It will serve as your control for the experiment.

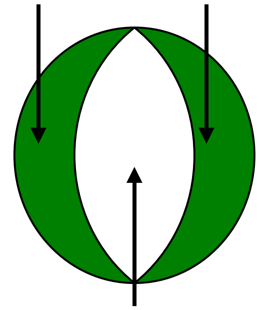
Step 5: Have the students formulate and write hypotheses in their lab manuals about how the increased air circulation from the fan and the increased heat from the heat lamp will affect the rate of transpiration in the bean plants.

Step 6: Ask the class to determine the appropriate unit of measure (cups, ounces, milliliters) to use when filling the EarthBoxes during the experiment. Once a day, at the same time each day, have students add water to the reservoirs of the three EarthBoxes in small, measured amounts using the measuring cup or other graduated measuring device. Have the students add the water slowly and stop adding water as soon as water begins dripping out of the drain hole. After students have watered the EarthBoxes, have the entire class record in their lab manuals the volume of water added to each EarthBox.

Step 7: You may let the class run this experiment for as long as you wish, although 4-5 days should be sufficient to collect enough data. After the students add water on the last day, have them record the final volume of water added in their lab manuals. Next, have the students complete the analysis and questions in their lab manuals. When they are finished, lead the class in a discussion about what they learned.

Optional After Data Collection is Complete – Part IV

Step 8: Have the students prepare wet mounts of the lower epidermis of a bean plant leaf. In order to separate the lower epidermis, remove one leaf from a bean plant and fold it in half, pressing hard enough to form a crease. Unfold the leaf, and then gently tear along the crease as if you were tearing a piece of paper in half. You will know you were successful in separating the epidermis if you look closely at the leaf and see a thin, transparent layer with ragged edges extending just past the main thickness of the leaf. It is this thin, transparent layer that you should examine under the microscope to look for stomata. The stomata will appear as a light opening between two darker, crescent-shaped cells (see picture to the right). Have the students make a sketch in their lab manuals of a stoma and the surrounding cells.



ANALYSIS & QUESTIONS:

- Which simulated environmental condition resulted in the greatest rate of transpiration?
  - Why?
- What do you think would happen to a plant if it lost more water through transpiration than it received from rainfall?
  - Why?
- How did your predictions compare to the actual results of the experiment?
- Do you think you would need to water a garden more often if it is in a location that receives a steady breeze and/or endures hot summers?

EXPLANATION: Plants need water to survive. They obtain this necessary water from the ground by absorbing it through their roots. It is then carried up to the leaves of the plants, where it is used for photosynthesis.

Plant leaves have small openings called **stomata** (singular – stoma) that allow for gas exchange with the environment. Each stoma is surrounded by two special cells called **guard cells** that regulate the opening and closing of the stoma. If water is plentiful, the guard cells are full of water and swollen, leaving them in the open position. If water is scarce, the guard cells shrink and close the stoma. Whenever the stomata are open, gases may move freely into and out of the leaf. However, these openings also allow water to be lost from the plant in the form of water vapor. This is the source of **transpiration** in plants, which is defined as the loss of water through the stomata.

Various environmental conditions can affect the rate of transpiration in plants. Humidity, wind, and heat play a crucial role in plant transpiration. High humidity reduces transpiration because the humid air around the leaf cannot take in much water vapor from the stomata. Low humidity can increase the rate of transpiration because the very dry air outside of the leaf can take in a lot of water vapor from the stomata. Air flow (wind) past stomata can pull out more water vapor, thereby increasing the rate of transpiration. Higher temperatures also increase the loss of water from plants due to evaporation.

In addition to transpiration being the source of water movement from the roots of a plant to its shoots, transpiration is also responsible for the movement of minerals and dissolved nutrients from the ground to other parts of a plant. If transpiration rates are too slow, plants may not receive adequate nutrition, whether from the ground or from the fertilizer strip as used in EarthBoxes. This could ultimately result in poor, stunted growth.

In this experiment, we were concerned with measuring the effects of wind and heat on the rate of transpiration of the bean plants. So why was it necessary to also measure the rate of transpiration in a normal, uncovered EarthBox? The uncovered EarthBox was the **control** for the experiment. In other words, it served as a comparison for the **experimental** (manipulated) **variable**. If we didn't use a control, we wouldn't be able to tell if the experimental variable (the wind or the heat) increased or decreased the rate of transpiration compared to the normal rate.

EXTENSION: You can easily simulate other environmental conditions to see how they affect the transpiration of these bean plants. In this experiment, you have already tested wind and heat, but you can also test how humidity affects transpiration by spraying the plants with water and then draping a clear plastic bag over the entire EarthBox.

RESOURCES: The following is the USGS Water Science for Schools website:

http://ga.water.usgs.gov/edu/

NAME ______________________________

THE HYDROLOGIC CYCLE: TRANSPIRATION

MATERIALS:

- Three EarthBox kits
- Empty 1-gallon milk container and measuring cup or other graduated measuring device for watering EarthBoxes
- Three packets of broad bean seeds (minimum 96 seeds)
- Window ledge with 6-8 hours of Eastern or Southern exposure (two grow lights may be substituted)
- Heat lamp (or halogen light)
- Small electric fan
- Microscopes, slides, and cover slips

INTRODUCTION

Plants need water to survive. They obtain this necessary water from the ground by absorbing it through their roots. It is then carried up to the leaves of the plants, where it is used for photosynthesis.

Plant leaves have small openings called **stomata** (singular – stoma) that allow for gas exchange with the environment. Each stoma is surrounded by two special cells called **guard cells** that regulate the opening and closing of the stoma. If water is plentiful, the guard cells are full of water and swollen, leaving them in the open position. If water is scarce, the guard cells shrink and close the stoma. Whenever the stomata are open, gases may move freely into and out of the leaf. However, these openings also allow water to be lost from the plant in the form of water vapor. This is the source of **transpiration** in plants, which is defined as the loss of water through the stomata.

Various environmental conditions can affect the rate of transpiration in plants. Humidity, wind, and heat play a crucial role in plant transpiration. High humidity reduces transpiration because the humid air around the leaf cannot take in much water vapor from the stomata. Low humidity can increase the rate of transpiration because the very dry air outside of the leaf can take in a lot of water vapor from the stomata. Air flow (wind) past stomata can pull out more water vapor, thereby increasing the rate of transpiration. Higher temperatures also increase the loss of water from plants.

In addition to transpiration being the source of water movement from the roots of a plant to its shoots, transpiration is also responsible for the movement of minerals and dissolved nutrients from the ground to other parts of a plant. If transpiration rates are too slow, plants may not receive adequate nutrition, whether from the ground or from the fertilizer strip as used in EarthBoxes. This could ultimately result in poor, stunted growth.

PROCEDURE

Part I

1. Set up three EarthBoxes according to the instructions except that no fertilizer is needed.
2. Cut 16 holes in each EarthBox plastic cover according to the instructions for beans.

3. Make three piles of 32 bean seeds, selected at random from the seed packs. Plant 2 bean seeds ¾" deep in the potting mix at each of the 16 holes in the plastic cover of each of the three EarthBoxes, for a total of 32 seeds in each EarthBox (96 seeds total)
4. Position each EarthBox under a grow light or in an appropriate window location as directed by your teacher.
5. Add water to the EarthBox reservoirs every other day for the next two weeks.

Ten Days Later – Part II

6. Thin the bean plants to one per hole, for a total of 16 bean plants in each EarthBox. To do this, examine each pair of bean plants growing through each hole in the plastic cover to determine which plant looks the healthiest (based on size, color, and overall appearance). Pinch off the other bean plant at its base and discard it. If only one seed germinated in a given hole, that single bean plant should be left alone.
7. Continue adding water to all of the EarthBoxes every other day.

One Week Later – Part III

8. Now that the bean plants have grown sufficiently, you are ready to begin the experiment. Make sure that the water reservoirs of all three EarthBoxes are completely full by adding water slowly through the watering tubes until it just begins to drip out the drain holes.
9. Set up the simulated environmental conditions as follows:

   Wind – Position the fan so that it circulates air past all of the bean seedlings in the first EarthBox. Turn the fan on (medium or high setting, depending on how forceful it is) and leave it on continuously.

   Heat – Position the heat (or halogen) lamp near the bean plants in the second EarthBox. Place it in the center of the long side of the EarthBox approximately one foot from the plants. You must be careful not to position the light too closely or the heat may kill some plants.

   Control – Do nothing to the third EarthBox. It will serve as your control for the experiment.

10. Write your hypotheses in the spaces below:

How do you think the increased air flow from the fan will affect the rate of transpiration of the bean plants? Why? ____

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How do you think the higher temperature will affect the rate of transpiration of the bean plants? Why? ____

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11. Determine the appropriate unit of measure (cups, ounces, milliliters) to use when filling the EarthBoxes during the experiment. Once a day, at the same time each day, add water to the reservoirs of the three EarthBoxes in small, measured amounts using a graduated measuring device. Add the water slowly and stop adding water as soon as water begins dripping out of the drain hole. Record in the data collection section of your lab manual the volume of water added to each EarthBox.
12. Allow the experiment to run for 4-5 days, recording the amount of water added each day to the three EarthBoxes on your worksheet.
13. Prepare a wet mount of the lower epidermis of a leaf from one of the bean plants. In order to separate the lower epidermis, remove one leaf from a bean plant and fold it in half, pressing hard enough to form a crease. Unfold the leaf, and then gently tear along the crease as if you were tearing a piece of paper in half. You will know you were successful in separating the epidermis if you look closely at the leaf and see a thin, transparent layer with ragged edges extending just past the main thickness of the leaf. It is this thin, transparent layer that you should examine under the microscope to look for stomata. The stomata will appear as a light opening between two darker, crescent-shaped cells. Make a sketch on your worksheet of a stoma and the surrounding cells.

DATA COLLECTION

In the table below, record the amount of water added to the EarthBoxes each day. Be sure to indicate units (e.g. cups, ounces, milliliters). Leave spaces blank if you did not add water that day.

DAY	DATE	CONTROL	WIND	HEAT
1				
2				
3				
4				
5				

CALCULATIONS

	CONTROL	WIND	HEAT
Calculate the total amount of water added to each EarthBox	________	________	________
Calculate the average daily rate of transpiration $\frac{\text{(the total amount of water)}}{\text{(total number of days)}}$	________	________	________

GRAPHING

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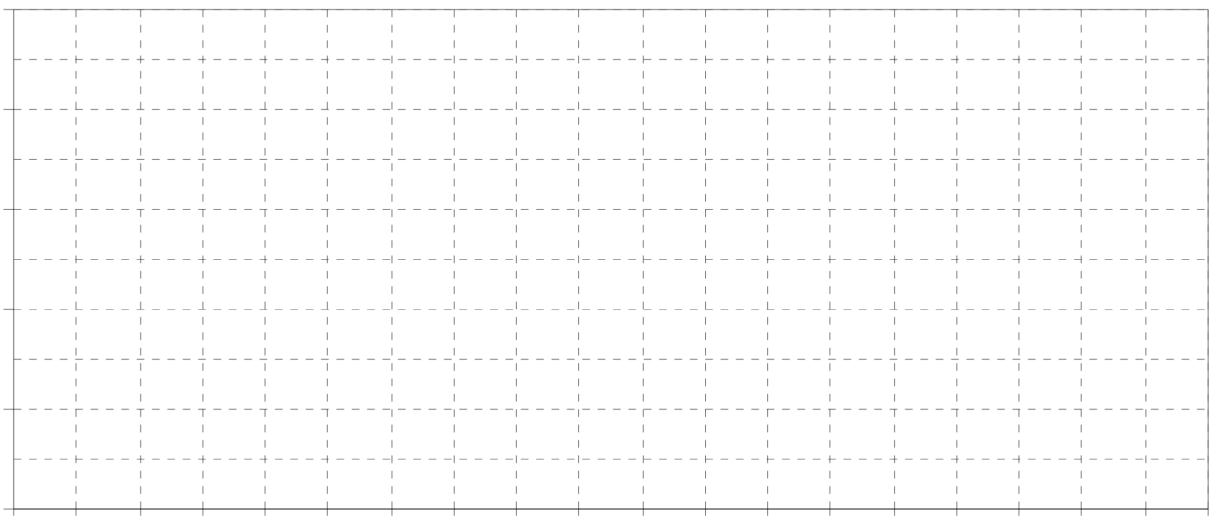

Directions: Create a graph showing the amount of water added to each EarthBox every day. In order to do this:

- Give your graph a descriptive title.
- Set up and label the two axes, giving each a title and units.
- For each day of the experiment, plot one point showing the amount of water added to each of the three EarthBoxes. Use different colors to distinguish between the three simulated environmental conditions used in the experiment.
- Connect the points in each of the three series, and then add a line showing the average daily rate of transpiration for each simulated environmental condition (as determined by your calculations).

DRAWINGS

In the circle provided, draw what you see through the microscope eyepiece when you are looking at the wet mount of the leaf. Label a stoma and guard cells as well as the total magnification you are viewing them at.

ANALYSIS AND QUESTIONS

1. Describe in a few sentences the structures of a plant that are involved in transpiration.

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2. Which simulated environmental condition resulted in the highest rate of transpiration?

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3. In your own words, describe why the fan affected transpiration in the way it did. _____

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4. In your own words, describe why the increased temperature affected transpiration in the way it did: ____

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5. In this experiment, you did not apply any simulated environmental conditions to one of the three EarthBoxes. Why was this necessary? ______________________________

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6. How close were your hypotheses to the actual results of the experiment? __________

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THOUGHT QUESTIONS

7. Which EarthBox farmer would need to add water more often to their EarthBox, one who lived near a tropical rainforest or one who lived in the desert southwest of the United States? Why? ____

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8. What do you think would happen to a plant that lost more water through transpiration than it took in from rainfall? ____

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