Transpiration: An Inquiry-Based Adaptation of a Traditional Cookbook Lab

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Abstract: Here I present an inquiry-based adaptation of a traditional lab to plant teach transpiration, the process that supplies leaf cells with water and dissolved minerals, that cools leaves, and is an important part of the global water cycle. Students begin lab by observing stomata on both surfaces of leaves and speculate about the patterns they find. They then work in teams to determine how to use potometers to measure the rate of transpiration. They work in groups and follow a lab handout to design and execute an experiment to test the effect of environmental variables on the rate of transpiration.

Introduction

Transpiration is the process by which water moves through plants from roots to small pores on leaf surfaces, where the water then evaporates as vapor into the atmosphere. Transpiration supplies leaf mesophyll cells with the water needed for photosynthesis, cools leaves, and delivers dissolved minerals from the roots for biosynthesis within the leaf. Only about 1% of the water transported from the roots to the leaves of a plant is actually used for photosynthesis – leaving an enormous amount of water that is lost through stomata as it evaporates as water vapor, making transpiration an important part of the global water system.

Transpiration is typically taught in a cookbook-style lab in which students follow instructions to carry out a pre-designed investigation. Many versions of this traditional lab for Intro and AP Biology are easily found with an Internet search. In this inquiry-based adaptation of the traditional lab format, students figure out how to use the potometers on their lab benches and then design their own experiments. This lab emphasizes the process of scientific inquiry at the same time it demonstrates an important organismal process in action.

Instructor's Notes

Materials

Potometers

- One ring-stand with a clamp (for plant)
- One ring-stand with a ring (for funnel)
- Rubber tubing and 2 tubing clamps
- One T or Y-shaped tubing connector
- Plastic funnel and clothespin (to secure the funnel to the funnel-ring)
- Plastic pipette with 1/100 mL gradations
- Plant cuttings (wax myrtle, honeysuckle, and other shrubs work well)
- Beaker or tray to catch water overflow from the pipette
- Bucket or tub of water to store plant cuttings and make fresh cuts under water

Environmental variables

- Utility or similar light bulbs (~heat, light)
- Fans (~wind)
- Mist sprayers and plastic bags (~to create and trap humidity)
- Hair dryers (~wind or warm wind)

General Lab Outline

Prior to lab, assemble the potometers on the lab benches. Set out equipment to measure environmental variables on the lab benches; students will choose what they want to measure and how.

During lab, move around the classroom to facilitate group discussion and critical thinking as students figure out how to use the potometers. Encourage groups that figure something out to share their discoveries with classmates until all groups can use the potometers to measure transpiration. Then continue to facilitate discussion as students design their experiments, develop their protocols

and methods, and design tables to record data. Refer to the poster for details on "challenges" included in the lab handout.

Potometer assembly

Potometers can be assembled with two ring stands as shown in Figure 1 or with all clamps attached to a single ring stand. Assemble potometers in the morning before the first lab of the day starts. To get started, place a tub of water nearby and under water, make a fresh sloping cut on a branch stem, and keep the stem under water. Turning to the photometer assembly, mount the funnel on the ring stand and attach the three pieces of rubber tubing (A, B, C), plastic T-shaped connector, and pipette (see Figure 1). Apply one clamp to the B tube and then fill the funnel with water.

1. To attach the plant branch, you will need water to flow between the funnel and the rubber tubing leading to the branch. Cut off water flow to the pipette by placing a clamp on the C tube. Remove the clamp from the B tube to allow water to fill the A tube (allow it to overflow and then pinch it off). Quickly insert the recently cut branch stem into the A tube and make sure there are no air bubbles in the tubing. Firmly attach the branch to the ring stand with a clamp (see Figure 1).
2. To set the potometer to the "zero" point, unclamp water flow to the pipette (tube C) to allow water to flow through the pipette (catch the overflow in the dishpan or sink). Make sure the water in the funnel does not run out as it will introduce air bubbles into the system – you can refill it with water from a beaker.
3. To start the transpiration run, clamp off the B tube between the T connector and the funnel so that water can only flow between the pipette and branch stem.

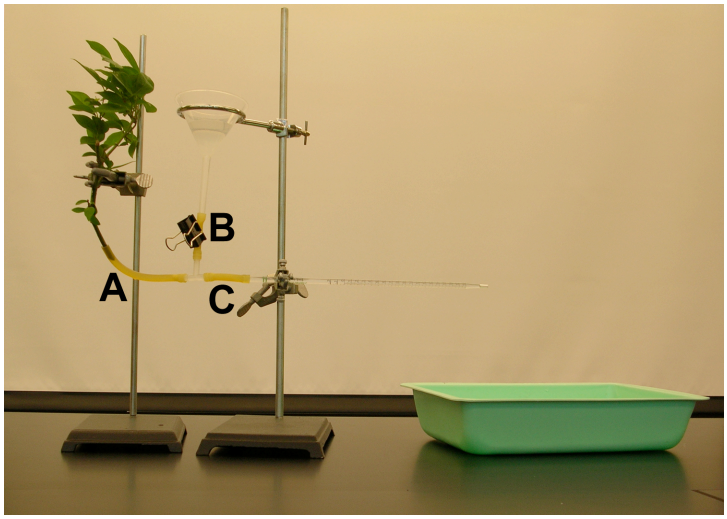

Figure 1. Potometer assembly with two ring-stands, one clamp to hold the plant branch, and one clamp for a funnel holder. A plastic funnel, the plant branch, and the pipette are connected via rubber tubing with a plastic T-shaped tubing connector (three pieces of rubber tubing are marked A, B, C). Tubing clamps are placed on tubes A, B, and C to control water flow to start and stop measuring transpiration. The funnel is used to allow water through the pipette to "reset" the water to the "zero" mark. A tray can be used to catch water overflow from the pipette.

Air bubbles in the potometer systems will cause problems as will embolisms in the xylem of the branches. If a potometer is not working well, try recutting the stems underwater and putting the system back together keeping the cut stem underwater as long as possible. After inserting the plant branch, petroleum jelly can be applied to the tubing around the branch stem to prevent water leakage.

Students should record increased transpiration rates with the light and wind, but may get low transpiration rates instead if the plants are abused by too much heat or wind. The plants should be kept in dim light between labs so that the baseline (normal room conditions) rate is lower than the

rate with the spotlight. If plants are used on multiple days throughout the week, leave the plant stem open to the funnel overnight and between labs so it can have a water supply.

Comparing rates of transpiration

Use instructor-led discussion to guide students to figure out how to compare rates of transpiration among branches. They should arrive at a method that basically allows them standardize plants for the number of stomata/leaf surface area. You can choose to have them actually carry out the comparison (and compare rates among groups) based on the time available and the number of cut plant branches available (sampling leaves is destructive so the number of plant branches you have may dictate if branches need to be used for multiple lab sections).

The rate of transpiration is measured as the amount of water lost/m^2/ minute. Because water evaporates through the many stomata on the leaf surface, the rate of transpiration is directly related to the surface area. To arrive at the rate of transpiration, therefore, you must calculate the leaf surface area of each plant: Cut of all the leaves on the plant branch. Calculate the total surface area of all the leaves using the leaf trace or leaf mass method.

1) Leaf Trace Method: Arrange all the cut-off leaves on a 1 cm grid and then trace the edge pattern directly on to the grid. Count all of the grid cells that are completely within the tracing and estimate the number of grids that lie partially within the tracing to sum the total leaf area.
2) Leaf Mass Method: Cut a 1 cm^2 section of one leaf and mass the section. Multiply the section's mass by 10,000 to calculate the mass per square meter of the leaf. (g/m^2). Mass all the leaves and then divide the total mass of the leaves by the mass per square meter. This value is the leaf surface area.

To calculate the water loss per square meter of leaf surface, divide the water loss at each time interval by the leaf surface area you calculated.

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About the Author

Eleanor Pardini is a postdoctoral research associate at Washington University in St. Louis. She earned her Ph.D. in Plant Biology from the University of Georgia in 2006. While at Georgia she served as a teaching assistant and lab coordinator in Plant Biology where she taught plant taxonomy and helped to revise the curriculum and lab manual for introductory plant biology labs. She was also an instructor for a “learning in biology” seminar offered through Academic Enhancement. She served as a university-wide TA Mentor and received the Outstanding TA and Excellence in Teaching awards at University of Georgia.