MY EXPERIENCES WITH A POTOMETER

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How does water from the soil reach the farthest extremities of a plant? And how fast does it travel there? A device called potometer can be used to explore these questions. But conventional potometers are expensive & difficult to set up. How do we make a simple low-cost one to encourage student experimentation?

The movement of water from the soil to every part of the plant body is an essential aspect of plant physiology. This flow is driven by the loss of water from leaf surfaces through transpiration (see **Box 1**). The faster the transpiration, the faster is the flow of water through the plant body. Is it possible to estimate the rate of transpiration? Do environmental factors influence this rate? These questions can be explored through a special device called the **potometer**.

How does a potometer work? We know that the volume of water that a plant absorbs from the soil over a period of time is nearly equal to the volume it loses by transpiration in the same duration (see **Box 2**). A potometer estimates the rate of transpiration indirectly by measuring the rate of uptake of water by a leafy stem.

Commonly used potometers

Commonly available potometers are of three types — Darwin's, Farmer's, and Ganong's (named after the scientists who designed and used them for the first time). All three consist of glass tubes fitted with rubber corks.

(a) Darwin's potometer: This is the simplest of the three types. It has a U-tube type attachment along a straight glass tube fitted with a cork. A capillary tube is fitted with a cork at the base of the straight glass tube. A small 15 cm scale is tied over the capillary tube. The entire set-up is placed over a vessel containing water in such a way that

Box 1. Why study transpiration?

A large part of any plant is made up of water. For example, 98% of the body of an aquatic plant, 95% of the body of a fleshy land plant, and 80% of a woody land plant is composed of water. Surprisingly, observations show that only about 2-5% of water absorbed by the roots of a plant is used for life processes like synthesis of food, growth, and digestion. The remaining 95-98% is lost as water vapor, mainly from the leaves. This process of loss of water as water vapor through small pores, called **stomata**, on the surfaces of the aerial parts of plants (like the leaves) is called **transpiration**.

Transpiration replenishes resources required for other life processes. Since stomata are almost at the extremities of water-conducting tissues in plants, the constant loss of water vapour from these pores causes a vacuum in the vessel-like tissues. This leads to the rapid movement of water with dissolved minerals (some of the raw materials for photosynthesis) from the roots to all chloroplast-containing cells — even those at the extremities of the tallest of plants (see **Fig. 1**).

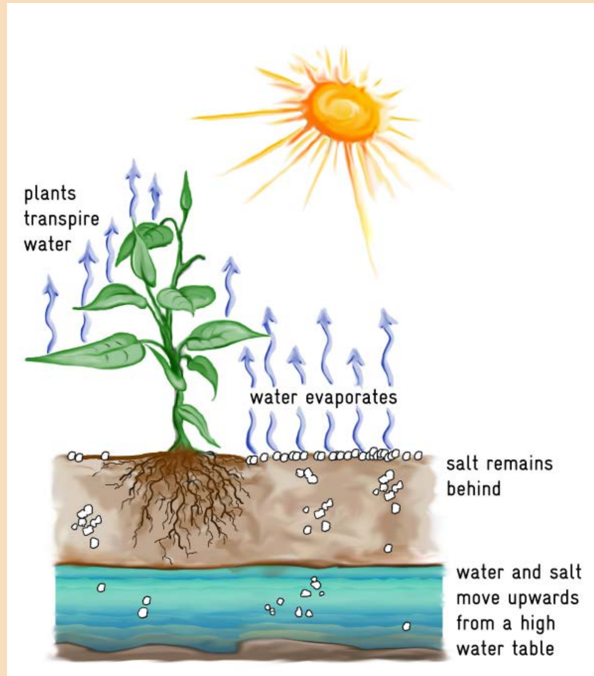

Fig. 1. Transpiration drives the movement of water through every part of the plant body.

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In addition, this process plays an important role in the maintenance of the water cycle. It contributes about 10% of the water returning to the water cycle.[1] According to the forester Peter Wohlleben: '... cloud formation in areas far from the sea may be attributed to transpiration loss by plants...'[2] Interestingly, environmental factors like temperature, wind, light conditions and humidity can influence the rate of transpiration and, thereby, the rates of photosynthesis and water uptake. Therefore, studying the rate of transpiration has important implications in agriculture and water management.

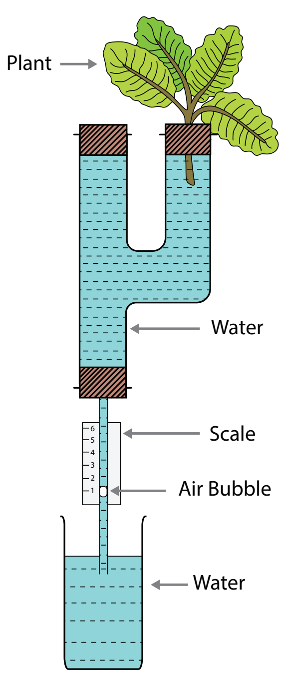

Fig. 3. The set-up of the Darwin's potometer.

Adapted from: https://www.biologydiscussion.com/experiments/top-13-experiments-on-transpiration-plants/56605.

the capillary tube just dips into the water. This set-up is ready to use once it is filled with water, and a freshly cut twig is inserted into the single hole in the cork in the side tube. The rate in transpiration can be measured by recording the upward movement of water in the capillary tube (usually visualized with an air bubble in the capillary tube or a dye added to the water) as the water gets pulled up by the twig. Since each of the corks used in this type of potometer has a single sealed hole, the risk of water-leakage is minimum. However, the apparatus requires the support of a burette stand. If a large-sized leafy twig is used for the experiment, the apparatus may still topple over (see **Fig. 3**).

(b) Farmers' potometer: This type of potometer has a large, wide-mouthed bottle fitted with a cork with three holes. A capillary tube bent in three places is fitted into one of the holes of the cork. A 15 cm scale is attached to part of this capillary tube. A funnel-like reservoir, inserted into the second hole of the cork, enables entry of water into the bottle. A freshly-cut twig is inserted into the third hole of the cork. As soon as this apparatus is filled with water, the process of transpiration starts. As soon as the volume of water in the capillary tube reduces, its open lower end is instantly placed in a small beaker. Due to this, an air bubble enters the capillary. The rate of loss of water due to transpiration is measured in terms of the rate of movement of the air bubble as the water gets pulled up by the twig. Since the bottle of water is large and heavy, it doesn't topple over and does not require a stand for support. On the other hand, the single cork with three holes makes it difficult to keep it airtight (see **Fig. 4**).

Box 2. How are the rates of uptake and loss of water by a plant related?

Leaves are the main sites of photosynthesis in most green plants. Photosynthesis occurs within clusters of cells, located between the upper and lower surfaces of a leaf, that contain (the green pigment) chlorophyll. A network of fine tubular structures, which we call **venation**, replenish these cells with minerals and water absorbed from the soil by the roots of the plant. Interspersed between these cell clusters are air spaces that allow the easy exchange of gases with the environment. These air spaces open out through thousands of stomata on the upper and lower leaf surfaces. By enabling the continuous diffusion of air and water through the leaf, each stoma allows photosynthesis, respiration, and transpiration (see **Fig. 2**).

During transpiration, water moves out from leaf cells into the environment in the form of water vapour. This causes a deficit of water in the leaf cells, which results in a transpiration pull that reaches adjoining fine veins, and through them to larger and thicker veins, finally reaching the leaf stalk. The force of this pull reaches the stems of plants, extending all the way down to the roots. This causes water to be conducted from the roots of the plant, via its stems, to its leaves.

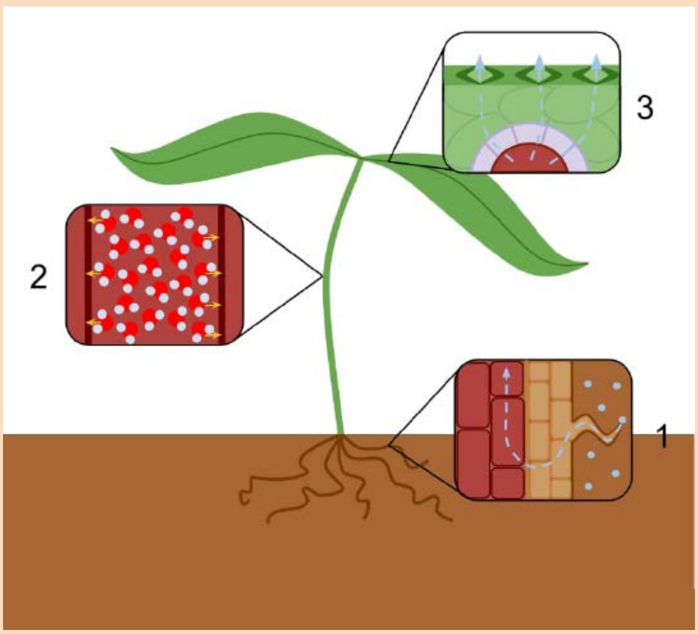

Fig. 2. The rate of water uptake by plant roots is nearly the same as that of water loss by its leaves. 1) Water molecules enter the roots passively and are guided to the xylem tissue (the water-conducting vessels in plants). 2) Once the water (red circle with two blue dots, representing H_2O) has entered the xylem, the interactions of the water molecules with the sides of the vessel (adhesion) and with each other (cohesion) leads to the formation of a column of water that extends from the roots to the top of the plant. 3) Water from the xylem is let into the spongy tissue in the leaves, where it can come into contact with stomata. When the stomata are open, the cells in this layer are exposed to the outside air, and evaporation occurs. When water molecules evaporate out of the stomata, they create tension in the water column as the forces of cohesion pull nearby molecules up with them. This creates a pulling force down the length of the xylem, causing the water in the soil to be pulled up.

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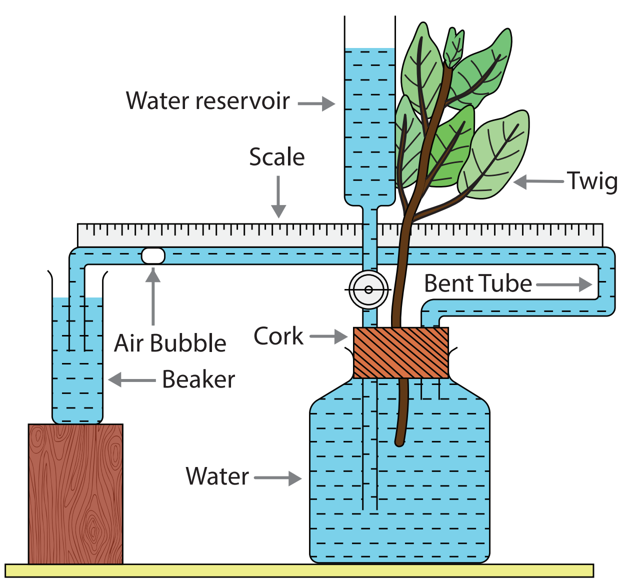

Fig. 4. The set-up of the Farmers' potometer.

Adapted from: https://www.biologydiscussion.com/experiments/top-13-experiments-on-transpiration-plants/56605.

(c) Ganongs' potometer: This is the most well-designed type of potometer. It consists of a glass tube bent at two places, with calibrations on the lower horizontal part. The upper portion of this tube has a broad opening, fitted with a single-holed rubber cork. A freshly-cut twig can be inserted into the cork. A reservoir fitted with a stopper is attached to the upper horizontal part, just before the calibrated tube. This can be used to control the movement of an air bubble inserted into the horizontal part of the tube. Like the Darwin's and the Farmer's potometers, the rate of loss of water due to transpiration is measured in terms of the rate of movement of the air bubble as the water gets pulled by the twig. The calibrated capillary tube eliminates the need to attach a scale to the device. However, the device is so fragile that it often breaks even while it is being set up. Its small base increases the probability of the apparatus toppling over (see **Fig. 5**).

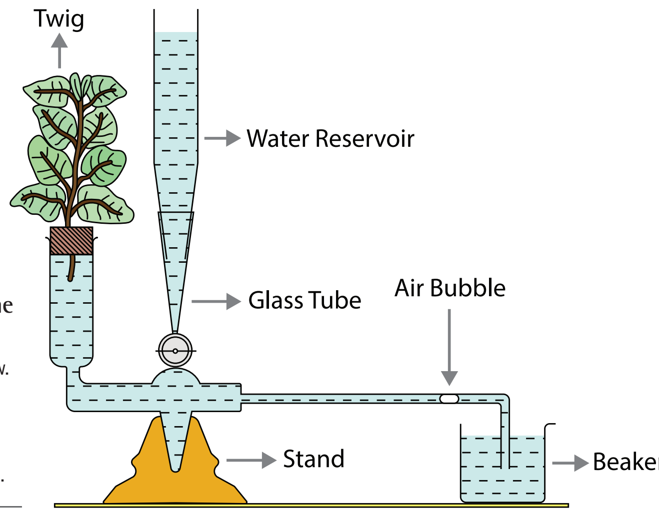

Fig. 5. The set-up of the Ganong's potometer.

Adapted from: https://www.biologydiscussion.com/experiments/top-13-experiments-on-transpiration-plants/56605.

Designing a low-cost, water-tight potometer

Potometers can be very useful in encouraging student-led investigations into the concept of transpiration and factors, like temperature or light conditions, that can influence its rate (see **Fig. 6**). But conventional potometers do not lend themselves to handling by students — they are quite expensive, difficult to set-up, unreliable, and prone to breakage.

Many of the challenges of commonly used potometers can be bypassed by using a simple, low-cost potometer (see **Fig. 7**). This can be designed using an empty plastic bottle (that would otherwise go waste) and plastic tubes instead of glass bottles, glass tubes, and rubber corks. How do we build such a device? Carve two circular holes into a plastic bottle cap with a large thick needle or knife. Into these holes, insert two 5 cm long tubes, like the water tubes used in an aquarium or the petrol tube used in a scooter or motorbike. This insertion is to be done in such a manner that half of each tube is inside the bottle, while the other half is outside. Fill the bottle to the top with water and close the cap tightly. This will cause the water to rise to the top in both tubes. If it doesn't rise, then the tubes need to be filled to the brim with the help of a syringe. Once this is done, insert the leafy stem of a berry, guava, peepal, or gerbera plant (with its petiole cut under water) into one of the tubes. Attach a scale to the bottle, close to the tube with the stem, to measure the movement of water (visualized by an air bubble) up the tube. The potometer is now ready to use (see **Fig. 7**). Do keep in mind that the lumen of the tube in which plant material is to be inserted should be selected according to the

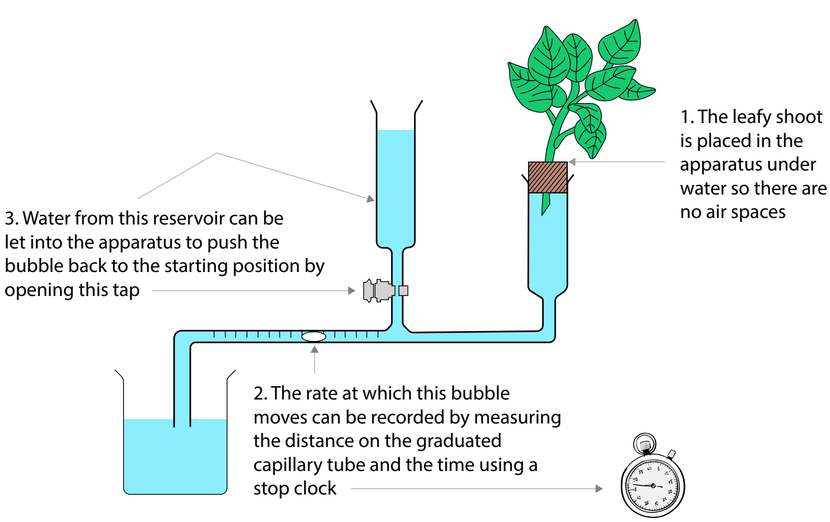

Fig. 6. Measuring the rate of transpiration.

Adapted from: Ms Cooper's IGCSE Biology. URL: https://www.youtube.com/watch?v=I510WIjaAZk.

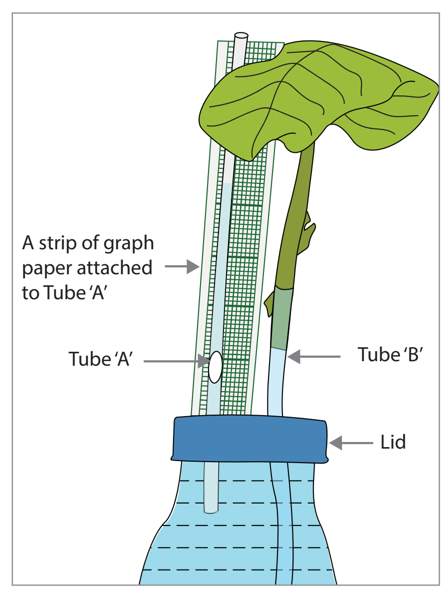

Fig. 7. A simple low-cost potometer made with a plastic bottle. In order to measure the rate of transpiration by this instrument, a strip of graph paper or a small part of a plastic scale (about 2 cm) can be attached behind tube A with cello tape. This can be used to measure the rate of movement of the air bubble in tube B.

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thickness of the stem or the petiole of the leaf.

How do we keep this device water-tight? Books often suggest the use of plasticine or grease to seal all openings from which water could leak. However, our experience suggests that grease does not stick to a wet surface. Instead, the tube end with a freshly-cut stem can be made water-tight by simply choosing a stem that is slightly thicker than the diameter of the opening in which it should be pushed through and fitted.

Parting thoughts

Exploring the concept of transpiration through experiments involving measurements of the rate of uptake of water by a leafy plant is an important part of the science syllabus at the higher secondary level. Due to challenges in setting up and using the three commonly available types of potometers in the science classroom, this experiment is often demonstrated by a teacher rather than performed by students. By using a simple, low-cost potometer, teachers can bypass these challenges and offer their students the opportunity to perform these experiments themselves.

Key takeaways

- Water uptake by plants is driven by the loss of water from its leaf surfaces through a process called transpiration.
- The rate at which a plant absorbs water from the soil is nearly equal to the rate at which it loses water by transpiration. This rate is influenced by environmental factors like temperature, light conditions, wind speed, and humidity.
- Potometers are special devices used to estimate the rate of transpiration by measuring the rate of water uptake through a leafy stem.
- Commercial potometers are expensive, cumbersome to use, and involve glass components that break easily, making them unsuitable for handling by students in a classroom.
- Making a simpler and cheaper potometer using plastic bottles and tubes makes it easier for students to use these devices for experiments around transpiration.

Note: Source of the image used in the background of the article title: https://pixabay.com/photos/drop-of-water-drip-water-macro-2356282/. Credits: Pitsch, Pixabay. License: CC0.

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