How Do Plants Know Which Way to Grow?

"Tropisms"

Level

Grades 5 and higher

Definitions

Most people think of plants as passive acceptors of their environment. In fact, plants do respond to many factors in their physical surroundings—animals and insects, and even from other plants. Complex responses to stimuli such as temperature, light, and moisture enable seeds to germinate at the right time of year and trees to drop their leaves in the fall and send out new ones in the spring. Plants respond to diseases and harmful insects in many ways that limit damage, including the production of chemicals that discourage further attack and signal other plants to be "on guard."

Responses that involve definite and specific movement of the plant are called tropisms (from the Greek word for "to turn"). Any factor that elicits such a response is called a stimulus. Plants can respond by moving toward the stimulus, a positive response, away from the stimulus, a negative response, or somewhere in between, depending on the nature of the stimulus and the type of plant. Different parts of the same plant can respond differently to the same stimulus. But whatever the response, the same type of plant will always respond to same type of stimulus in a similar and predictable way. There are a number of different tropisms including chemotropism, which enables plant roots to avoid some toxins and grow toward water and nutrients; thigmotropism is response to touch, an example of which is the twining of a vine tendril around an object. Perhaps the best known and most studied tropisms are phototropism, response to light, and geotropism, response to gravity. The following activities are designed to help students explore and understand some of the basic plant responses involved in phototropism and geotropism.

Phototropism Activity

Introduction

Most plants are phototropic, that is, they grow toward the light. Probably everyone has noticed examples of positive phototropism in many different types of plants, from houseplants struggling to find a sunny spot at the window to a field of sunflowers following the path of the sun across the sky.[1] [2] This ability is very useful for the plant, enabling it to position itself, especially its leaves, to efficiently receive the light energy needed for photosynthesis, without which the plant could not grow and reproduce. (Less obviously, most plants' roots are negatively phototropic, that is, roots grow away from light. This is also a very useful trait, allowing the plant to anchor itself and find the soil, water and nutrients it needs.)

Scientists have been conducting experiments on phototropism since at least the early 1800s. One of the earliest experiments, conducted by the Swiss botanist A. de Candolle, proved that it was indeed light that caused the growth response and not "air," as had previously been thought.[3] Charles Darwin conducted several plant growth experiments involving light and found that the stimulus can be detected in one part of the plant while the response may occur somewhere else. This led to the later discovery of the class of plant hormones, known as auxins, that is responsible for the plant cell elongation involved in phototropism. [4]

The phototropic response occurs, to a greater or lesser extent, throughout a plant's life cycle, but it is in the early stages of growth that it is most prominent and easily manipulated. The following experiment uses the base of the students' Space Gardens,

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[1] Tracking the sun is properly known as heliotropism. It is a temporary change in the orientation of plant parts in relation to the position of the sun (or other light source). Heliotropism is accomplished by differential swelling and contraction of cells and can be reversed by changing the position of the light source. All responses to light were originally called heliotropism, but the term phototropism was introduced when it was discovered that artificial light also could elicit a response and to make a distinction between a temporary, heliotropic change and the permanent, non-reversible directional growth resulting from phototropism.

[2] Some research suggests that sunflowers do not actually track the sun. Rather, their daily rotation from east to west is a circadian rhythm that would occur just as well in the dark as the light. (Indiana University Moments in Science. 1/22/02)

[3] Reference 5

[4] Reference 4

seedlings, and a simple “light exclusion chamber” constructed by the students to illustrate how the direction from which a plant receives light influences the direction of the plant’s growth. This activity demonstrates the fundamental principle of phototropism. It can be used as a starting point for other experiments arising from the students’ questions and observations. For example: Does the intensity of light matter? Does the quality (color) of light matter? Do different types of seedlings respond differently? Does a young seedling respond differently from an older one of the same type? All of these questions and many others can be explored using the equipment used here.

Observations from this experiment on phototropism lead naturally to questions about geotropism. Therefore, it is best done before the exercise on geotropism.

Question

Will light from different directions affect the way seedlings grow?

Hypothesis

Seedlings will bend (change direction) and grow (increase in length) toward the light.

Design

Students will gain additional experience in plant culture as they observe, measure, and document the effects of directional light on seedling growth. They will also gain hands-on experience with equipment design and construction. Students will discuss the experiment and present their results using written narrative, graphics, and photos. Students may wish to design additional experiments related to phototropism.

Timeframe

Seeds should be planted 3-5 days (varies with the type of seed used) prior to the planned date of the experiment. The cotyledons should be expanded but the first true leaves not fully emerged. Discussion of the experimental concept and expectations, construction of the light exclusion chambers, and experiment set-up will take one 50-minute class period in the morning. An additional period will be needed anywhere from

4 hours later to the next day (whichever is more convenient) to observe, measure, document, and discuss the results.

Learning Objective

In this activity students will:

- Learn about plant growth by observing germination and seedling growth
- Learn about plant responses to light by observing and measuring changes
- Gain experience in constructing scientific equipment
- Gain experience in measuring - length and angles
- Use tables, graphs or other media to present data
- Gain communications skills by discussing and presenting results

Materials

Space Garden bases

Black construction paper (9 x 12 inches)

Black electrical tape

Light exclusion chamber pattern (included)

Seeds (Radish, sunflower or bean work well. Corn, a monocot, can also be used.)

Rooting medium (Arcillite or potting soil)

White tape and marking pen

De-ionized or distilled water

Fluorescent or “grow” light(s)

Metric ruler

Protractor

Camera

Paper towels

Procedure

Class 1 (several days before the day of the experiment)

1. Discuss the concept of tropism in general and phototropism in particular. Have students give examples of phototropism they've noticed in plants. Can they think of other kinds and examples of tropisms?
2. Explain the experimental design and that, by restricting the direction from which light is received, the experiment is expected to demonstrate phototropism in the seedlings.
3. Have students examine an already prepared light exclusion chamber. Note especially:
    a. The placement of the small openings will determine the direction of incoming light.
    b. The shape of the openings will allow all three seedlings to receive approximately the same amount of light from the opening.
    c. The color of the chamber (black) will absorb light and prevent light from reflecting off the inside surfaces .
    d. Black tape on the seams will further prevent entry of light from anywhere other than the opening.
4. Student groups each construct two light exclusion chambers—one with no holes, and therefore no light, and one with the appropriate opening (s) for one of the four chamber designs that will be used (opening at the top, opening on the upper side, opening on the lower side or openings on opposite upper sides). Each configuration should be represented by at least one group. A pattern and assembly instructions are included below.
5. Fill Space Garden bases with moistened rooting medium.
6. Place three seeds in a row in each base. (The row should be centered and run lengthwise, seeds equidistant from each other.) Place tape on the rim of the base in front of each seed (watering port should be facing toward the student) and number 1, 2, and 3 from left to right.
7. Cover the seeds lightly with rooting medium. (You might want to try this part before the actual experiment to get an idea of how long it will take your particular seeds to germinate and grow to the appropriate stage.)
8. Place the light exclusion chambers with no holes over the planting area of each Space

Garden (in place of the bellows), seal edges with black tape, and allow seeds to germinate and grow until seedlings are ready for the experiment. The seedlings should be between 1 and 2 inches tall. Water with de-ionized or distilled water as needed.

(End of Class 1)

Class 2

1. Arrange fluorescent or “grow” lights so that all Space Gardens can be placed equidistant from a single source of light.
2. Make sure plants are adequately hydrated.
3. Measure each plant’s height from the level of the rooting medium to the point of the top leaf attachment. Record on group data sheet.
4. Use a protractor to measure any curvature in the stems before light is excluded. For this experiment, the angle of curvature is the difference between upright (0° curvature) and the bent part of the stem. For example, a stem that is slightly bent might have an angle of curvature of 10° to 15° away from upright. One way to determine this angle is to measure the angle between the upright part of the stem and the part that curves away from the upright (in this example 165° to 170°) and subtract from 180°. Record values.
5. Note the orientation of the leaves/cotyledons in relation to the stem. Are they horizontal? Perpendicular to the stem? Twisted to one side or the other? Students can measure and/or sketch the leaf attachment.
6. Older students can use a protractor to determine the angle at which light will be reaching the growing tip of the seedlings relative to the vertical. (Light from the top will be 0° from vertical. If the seedlings are approximately 4 cm tall, light from the upper opening will be at an angle of about 60° and light from the lower opening will be at about 90°. The control plants will, of course, receive no light.)
7. Insert a metric ruler vertically in each base (for scale) and photograph the seedlings from all sides. Remove the ruler.
8. Cover the seedlings with the light exclusion chambers and seal the bottom edges with black electrical tape. The controls will consist of covers with no windows.
9. Place the units (including the control) near lights - as close as possible without actually touching the light. Make sure that all units are the same distance from the light source.
10. Don’t peek! Discuss with the students why this is important. Even a brief exposure to light from other directions could change the plants’ responses and disrupt the experiment.

3-4 hours later or the next day…

1. Remove the light exclusion chambers.
2. Reinsert the ruler and quickly photograph the seedlings from each side. The photographs can be used to document results and to confirm measurements made on the fresh material.
3. Remove the seedlings from the rooting medium and carefully lay them flat on paper towels. Try not to disturb the curvatures. Take another photograph (be sure to include a scale marker).
4. Measure new angle of curvature in the stem. Record on group data sheet.
5. Note the orientation of the leaves. Have they changed position? Measure and/or draw a new sketch.
6. Before they manipulate the seedlings, have students look at and think a bit about the roots as a prelude to the activity on geotropism. Are the roots all going in the same direction? If so (or not), what are some possible reasons?
7. Carefully straighten seedlings and measure length from the original point of insertion in the rooting medium to the point of attachment of the top leaves. Record on group data sheet.
8. Calculate average height before and after each treatment and calculate the average change in height for that treatment.
9. Calculate the average stem curvature before and after each treatment and calculate the average change in curvature for that treatment.
10. Calculate, describe, and/or sketch changes in leaf/cotyledon orientation.
11. Look at the photos to confirm that the measurements are a reasonably accurate reflection of the seedlings as they first emerged from the light exclusion chambers and not the result of changes that occurred during their handling and removal from the rooting medium.
12. Enter information on the class data sheet and discuss answers to the questions below.
13. Make a display stating the hypothesis and briefly explaining the experimental design. Present collected data in tables or graphs. Explain results in narrative form. Use selected photographs and sketches to illustrate the results.

Concluding activities and further questions

- Did the plants bend (change direction) toward the light?
- Did they all bend by the same amount?
- Did some plants not bend? If so, which ones? Why?[5]
- For the plants that did bend, did they face exactly to the light? For example, if the angle of the light reaching the plant was 60°, is the angle of curvature 60°?
- Did the plants grow (increase in length) toward the light? Did they all grow by the same amount?
- Did the leaves turn toward the light? Did they all turn by the same amount?
- If more than one base was used for each treatment, were the measurements similar for each unit of the same treatment?
- Control plants received no light but they continued to grow upward. How might this be explained? (Geotropism is one possible explanation, but there could be other testable hypothesis, such as "plants only grow in a straight line in the absence of light.")
- Can we accept the hypothesis? (Seedlings will bend and grow toward the light.)
- Are there other possible explanations (e.g., air or even sound)?

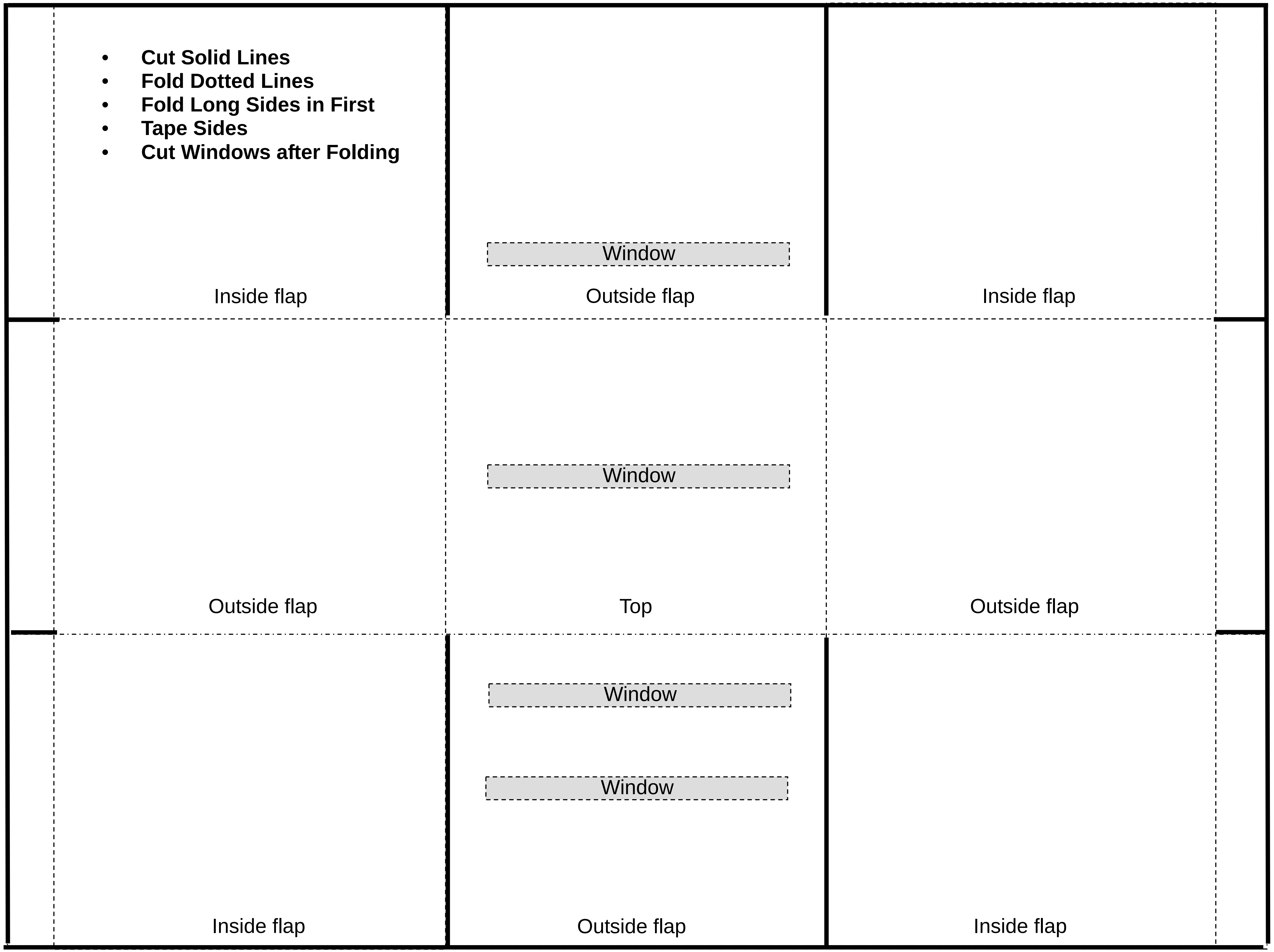
Extension - extra

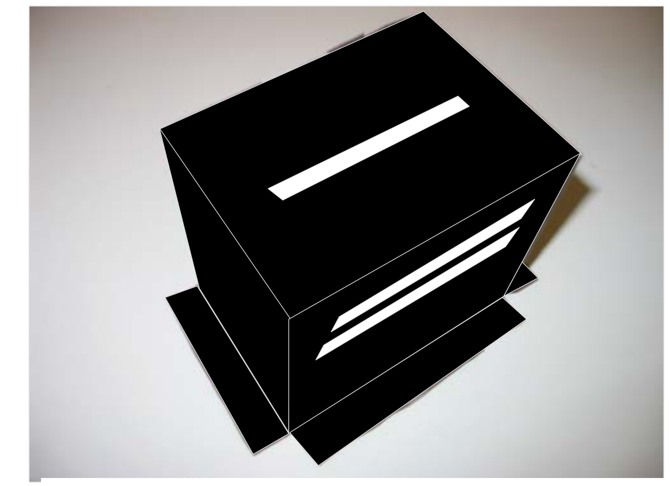
There are many experiments that can be designed to explore various aspects of phototropism. Here are a few examples.

- How does light color affect bending and rate of growth? Do red, green and blue lights have different effects? Filters of various colors can be made from colored view graph acetate (available at most office supply stores) and slipped into the light exclusion chamber to cover the openings.
- How little light is needed to produce the bending response?

[5] Plants from group 2 and group 3, with light from one side, should have bent toward the light. The plants with light from the upper opening (group 2) should have bent less than the plants with light from the lower opening (group 3). Plants with light from above (group 1) should not have bent, but they will, we hope, have grown upward toward the light. Control plants should also not have bent, but may have grown more than the plants with light from above. Plants with light from both sides (group 4) should also be straight if the light intensity was equal from both sides.

- Is it possible to have too much light? Will there be no response or a negative response?
- How little time is needed to produce the response?
- How far (how great an angle of curvature) can the seedlings be made to bend?
- Does the age of the seedling make a difference in how it responds?
- Does prior treatment of the seedling (e.g., germinated in light or dark) make a difference in how it responds?
- Where in the plant is the phototropic stimulus received?
- Where in the plant is the phototropic response expressed?
- Does light influence how roots grow?





When done, the light exclusion chamber should look like this.