Made in the Shade

The Effects of Agrivoltaics on Crops

Description

Agrivoltaics is the dual use of land for agriculture and solar energy production. One potential benefit of agrivoltaics is that it can increase shade over crops, thereby reducing the negative effects of high temperatures and reduced rainfall. In this lesson, students will use a model solar panel and spinach leaves to test the effects of shading from a solar panel on plant transpiration. They will use solar beads and a flashlight to investigate the potential effects of solar panels on photosynthesis.

Grade Level: 6-8

Objectives

Students will:

- Investigate whether solar panels can help reduce crop transpiration.
- Determine how solar panels affect photosynthesis of plants under and around the panels.

Time: 45 minutes

Common Core State Standards

ELA-LITERACY.RST.6-8.3 Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

ELA-LITERACY.RST.6-8.4 Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 6-8 texts and topics.

ELA-LITERACY.WHST.6-8.2.D Use precise language and domain-specific vocabulary to inform about or explain the topic.

Next Generation Science Standards

MS-ETS1-2 Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

Science & Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Engaging in Argument from Evidence Developing and Using Models Constructing Explanations and Designing Solutions Planning and Carrying Out Investigations	ETS1.B Developing Possible Solutions	Systems and Models Cause and Effect

Materials

- *Made in the Shade* student worksheets (1 per student)
- PowerPoint presentation and a way to show it to students
- Calculators (1 per every 2 students)*
- Dinner-sized paper plates (3)
- Dessert-sized paper plates (9)
- Dixie cups (6)
- Clip-on, reflective shop lights (6)
- Large bunch of spinach (approximately 10 leaves per group)*
- Electronic scales with 0.1 g accuracy (3)
- Multimeters (6)
- Solar panels (6)
- Solar beads - 2 strands glued onto felt-covered cardboard (6)
- UV flashlights (6)
- Task cards for transpiration activity (6)
- Task cards for photosynthesis activity (6)
- Extension cords (if needed)*

*Not included in kit

Background

High temperatures are detrimental to many crops and may reduce crop production. Excessive heat can result in wilting, scalding, and scorching of leaves and stems, sunburn on fruits and stems, leaf drop, reduction in growth, and decreased photosynthesis.

Agrivoltaics, the dual use of land for agriculture and solar energy production, has been proposed as a method to adapt to rising temperatures and decreased rainfall. Solar panels reduce the temperature for crops growing beneath them, possibly resulting in enhanced crop production with reduced irrigation.

Plants regulate temperature and gas exchange through the opening and closing of pores on their leaves called **stomata** (singular: **stoma**). When stomata are open, carbon dioxide enters, and water and oxygen escape. The release of water from plants is called **transpiration**. Transpiration helps draw up minerals and water through the roots because as water evaporates from the leaves, it is replaced by other water molecules. These water molecules move up through the plant in a continuous column from the soil, through the roots, stem, and leaves, and ultimately into the atmosphere. An important function of transpiration is to allow evaporative cooling of the plant.

Carbon dioxide (CO_2) levels in the atmosphere are increasing, which has contributed to increased global temperatures. Increased CO_2 generally causes stomata to be closed more often because stomata do not need to be open as long to take up adequate CO_2 for photosynthesis. This causes a reduction of water loss by transpiration. However, increased temperatures can result in increased transpiration because warmer air has a greater ability to hold more water. Warmer air pulls water more quickly out of the open stomata. Researchers have demonstrated that for crops growing in the warmest parts of the year, increased transpiration due to higher temperatures cannot be offset by the partial closure of stomata due to CO_2 levels. In other words, crops will experience increased transpiration as temperatures increase, and increased CO_2 will not counteract the loss of water. As a result, researchers are studying the use of solar panels to create a cooler microenvironment under the solar panels where crops could thrive.

Preparation

1. Plan to divide students into 6 teams.
2. Set up scales around the room in easily accessible locations.
3. Set up a computer and PowerPoint presentation.
4. Set up six stations for the spinach experiment.
    a. Rinse and soak spinach to remove any soil and then blot it dry.
    b. Write “under the solar panels” on the edge of three dessert plates and write “sun” on the edge of three other dessert plates.
    c. Weigh out the same amount of spinach (approximately 8-10 leaves work well) onto each plate, within approximately +/-0.2 g.
        i. Place an empty dessert plate on the scale and press the tare button.
        ii. Remove the plate, then weigh the plates of spinach, adding or removing spinach as needed to make all plates the same weight, within approximately +/-0.2 g.
        iii. If the activity will not be conducted immediately, the spinach-filled plates should be stored in the refrigerator until ready to use.
    d. At each of the six stations, set up:
        i. One lamp adjusted 4 - 6 inches (same for all treatments) above the plate with spinach.
        ii. One “Made in the Shade” task card.
        iii. The three “under the solar panel” treatments will also need a “solar panel,” modeled by a larger paper plate and two Dixie cups. For these three stations, set two Dixie cups on each side of the spinach plate. Place a dinner plate on the cups between the spinach and the light to represent solar panels. Examples are pictured below:



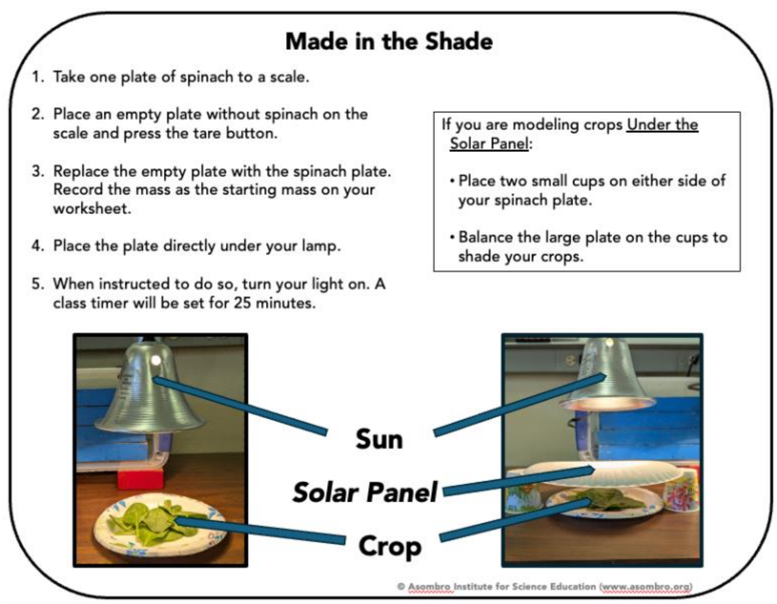
    e. Prepare materials for the Solar Panel Efficiency study, which students will do at their desks. Each of the six groups will receive:
        i. Solar Panel Efficiency task card.
        ii. Solar panel
        iii. UV flashlight
        iv. Solar beads attached to felt-covered cardboard
        v. Multimeter – Prepare by attaching cables to the multimeter as shown in the picture at right. Attach the black cable into the center plug (labeled COM) and the red cable into the right plug (labeled VΩmA). Students will attach solar panel leads to the multimeter.

Introduction (~5 minutes)

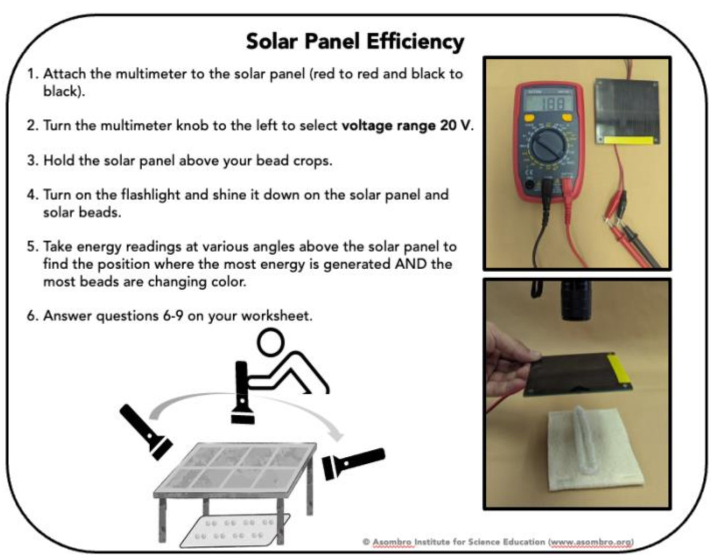
1. Give each student a *Made in the Shade* worksheet.
2. Slide 2: Define Agrivoltaics
    a. The dual use of land for both agriculture and solar energy production.
    b. Agrivoltaics is a relatively new field of study, and research is currently being done to study the advantages and disadvantages.
    c. Show the pictures of solar panels and discuss where the crops would be located.
    d. Could agrivoltaics help farmers grow more crops? In this lesson, we will investigate how the shade from solar panels affects plant transpiration and photosynthesis.
3. Slide 3: Agrivoltaics is an area of interest because climate change is causing higher temperatures and longer and more extreme droughts in the southwestern United States.
    a. This drought map was created by the U.S. Drought Monitor, which releases weekly drought maps for the entire country. You can replace this drought map with the most recent one by visiting https://droughtmonitor.unl.edu/ and clicking on the region or state of your choice.
    b. This graph shows average annual temperatures for the contiguous United States from 1895 to 2020 (orange line), along with the warming trend of 0.16˚F per decade (red line). Graph by NOAA Climate.gov, based on data from NCEI Climate at a Glance.
4. Slide 4: Using shade to help grow crops isn't a new concept. Indigenous peoples developed the Three Sisters planting method. The squash leaves provide shade, which helps keep the soil moist. The corn stalk supports the beans, which fertilize the soil.

Activity Stations: Made in the Shade and Solar Panel Efficiency (~25 minutes)

1. Slide 5: Today, we will conduct an experiment that measures the water loss of spinach "in the sun" versus spinach shaded by a plate that represents solar panels. Show pictures of the experiment and explain how we are modeling the solar panels.
    a. The lamps represent the sun, and the paper dinner plate represents solar panels. The "sun" treatment is shown on the left; there is nothing to block the light. The "under the solar panels" treatment is shown on the right; a paper dinner plate represents a solar panel in an agrivoltaics system. Note that the spinach is the same distance from the light in both treatments.
    b. Which spinach will lose more water (under the solar panel or in the sun)?
    c. Have students record their predictions on their worksheets.
2. Slide 6: Show students the task card (shown at right) and read the instructions. Three groups will set up the "sun" treatment, and three groups will set up the "under the solar panels" treatment. Emphasize how to tare the scale; this allows us to record the starting mass of the spinach alone, not the plate and spinach.



3. Slide 7: Divide students into six groups, assign each group to a station, and have them follow the instructions on the task cards.
    a. After all groups have their treatments ready, have everyone turn on the light and set a timer for 25 minutes (Note: if you have time, 30 minutes also works well).
    b. Have students return to their seats and continue the slide presentation and Solar Panel Efficiency activity while the spinach experiment is running.
4. Slide 8: Today we are investigating the phenomenon of how solar panels affect transpiration and photosynthesis in crops, two vital processes that plants must do to survive.
5. Slide 9: **Transpiration** is the loss of water from inside plants into the atmosphere. It cools the plant and helps drive water movement through the plant and bring water and nutrients up through the roots and into the stems and leaves. It is an invisible process. If you cover a plant with a bag (like the one shown in the picture), the bag will get foggy with the water that is being transpired.
6. Slide 10: Plants have pores on their leaves called **stomata** that allow them to exchange gases, including water vapor, with the atmosphere. Typically microscopic, these pores open and close in response to environmental conditions. When a stoma opens, carbon dioxide (necessary for photosynthesis) enters, while water and oxygen are released. Roots absorb water from the soil, and leaves release water vapor into the air through their stomata.
7. Slide 11: Environmental variables affect transpiration rates, and here are some of the factors that can slow down or speed up transpiration: temperature, light, relative humidity, wind, carbon dioxide, and soil moisture. In our experiment, we are changing temperature and light.
8. Slide 12: Give each group a UV flashlight and beads on felt, but don't tell them what they are. Ask students to explore for approximately five minutes. What happens to the beads when you shine a flashlight on them? How long do the beads stay colored? What happens when you stop shining the flashlight onto the beads?
9. Slide 13: Ask students to put down their UV flashlights and beads for a moment while you give them a few more instructions for the next activity. **Photosynthesis** is the process through which plants use the energy from the sun to create food. We will be modeling photosynthesis with the use of the solar beads and a flashlight in the next activity.
10. Slide 14: We are going to use solar beads to determine how solar panels affect photosynthesis.
11. Slide 15: Show students the photo of the materials they will use for the next activity. Each group will get a mini solar panel, a multimeter, solar beads, a flashlight, and a task card. The beads represent two rows of crops in your field, and the flashlight represents the sun. As students already discovered, when the UV light shines on the beads, they change color.
12. Slide 16: Show students how they will attach the multimeters to the solar panels (red to red and black to black – demonstrate). Turn the knob left to voltage range 20 V.
13. Slide 17: Show students the task card for this activity (shown at right) and briefly explain the instructions. Students will measure the electricity generated by a flashlight at different angles. They will also monitor the solar beads at each angle to determine when photosynthesis is being maximized (beads will turn darker with more sun). Demonstrate this using the flashlight. Students will answer questions 6 – 9 on their worksheet.



Results and Conclusions (~10 minutes)

1. Slide 18: Photosynthesis results
    a. Ask students to explain what they found. Refer to the picture and ask students to demonstrate the location of the flashlight when they saw maximum photosynthesis and maximum energy. Was it in the same location?
    b. Did the solar panel reduce photosynthesis?
2. Slide 19: Transpiration results
    a. Assuming the timer has gone off and at least 25 minutes has passed since the lights were turned on for the spinach experiment, ask students to go weigh their spinach plates again. Make sure they tare the scales again with an empty plate, so they are only recording the weight of the spinach, not the spinach and the plate.
    b. Instruct students to record the ending mass in their data table and calculate the change in mass. Note that this is the ending mass minus the starting mass.
    c. Have students calculate the percent change in mass for their group's spinach using the formula in question 2.
    d. Collect each group's data, and have students fill out the Class Data Table on question 3.
3. Slide 20: Transpiration results continued
    a. Did solar panels decrease transpiration and help the spinach save water?
    b. Have students answer questions 4 and 5. Discuss their answers.

Claim Evidence Reasoning (~5 minutes)

1. Slide 21: Have students answer question 10 on page 2 of their worksheet: "Based on your experiments, would solar panels be beneficial to farmers? Give evidence from the experiments to back up your claim and explain your reasoning."
2. Slide 22: Recap transpiration and photosynthesis and the possible benefits of using solar panels.
3. Slide 23: Solar panels can be installed in various ways in an agrivoltaics system. The examples shown on this slide will have different effects on photosynthesis of the crops growing under and around the solar panels. However, the more complicated designs can take up more space and be more costly to install and maintain.
4. Slide 24: If there is time, ask students to think about how solar panels might benefit livestock. This lesson focused on growing crops, but could agrivoltaics also work with animals?

Possible Extensions

- If your students completed the Agrivoltaics Scenarios lesson, have them discuss the pros and cons they already listed for their farm. Do any of these pros and cons change now that students have a better understanding of photosynthesis and transpiration in crops?

Additional Resources

1. Background information about transpiration and carbon dioxide effects:

Johnson, G. How High Heat Affects Vegetables and Other Crop Plants. Weekly Crop Update. University of Delaware Cooperative Extension. Published 17 Jun. 2011. Web. Accessed 24 October 2016. <https://agdev.anr.udel.edu/weeklycropupdate/?p=3203>

Lovelli, S, Perniola, M, Di Tommaso, T, Ventrella, D, Moriondo, M., Amato, M. 2010. Effects of rising atmospheric CO_2 on crop evapotranspiration in a Mediterranean area. Agricultural Water Management 97: 1287-1292. Accessed online. 26 Apr. 2016. <http://www.sciencedirect.com/science/article/pii/S0378377410001022>

United States Geological Survey (USGS). Transpiration – the Water Cycle. Published 15 Apr. 2014. Web. Accessed 1 May 2016. http://water.usgs.gov/edu/watercycletranspiration.html

2. Articles about using shade structures with crops and agrivoltaics:
Bryce, 2023. Solar panels perform better in heat when paired with crops. <https://www.anthropocenemagazine.org/2023/03/solar-panels-handle-heat-better-when-theyre-combined-with-crops/>
California Department of Food and Agriculture (CDFA). 2013. Climate Change Consortium for Specialty Crops: Impacts and Strategies for Resilience Report. Accessed online. 26 Apr. 2016. <https://www.cdfa.ca.gov/environmentalstewardship/pdfs/ccc-report.pdf>
Emerging Opportunities for Agrivoltaics in New Mexico: <https://www.nmhealthysoil.org/2024/05/28/emerging-opportunities-for-agrivoltaics-in-new-mexico/>
Gent, MPN. 2007. Effect of degree and duration of shade on quality of greenhouse tomato. HortScience 42: 514-520. Accessed online 26 Apr. 2016. <http://hortsci.ashspublications.org/content/42/3/514.short>
Hochmuth, RC, Treadwell, DD, Simonne, EH, Landrum, LB, Laughlin, WL, Davis, LL. 2015. Growing bell peppers in soilless culture under open shade structures. University of Florida, IFAS Extension Report HS-1113. Accessed online April 26, 2016. <https://edis.ifas.ufl.edu/hs368>