*Modeling an Adaptation* *to Climate Change*

# WILT IT BE PRODUCTIVE?

## DESCRIPTION

To evaluate an agricultural adaptation to climate change, students conduct an experiment to test the effectiveness of a model shade structure in reducing transpiration from spinach leaves under lights.

## PHENOMENON

Can a shade structure prevent crops from wilting?

## GRADE LEVEL
6 – 12

## OBJECTIVES

Students will:

- Explain how global change, especially increased temperatures and carbon dioxide levels, affects plant transpiration and photosynthesis
- Analyze the results of an experiment and use them to determine the feasibility of an agricultural adaptation to climate change

## TIME
60 MINUTES

## COMMON CORE STATE STANDARDS

***English Language Arts Standards » Science & Technical Subjects » Grade 6-8***

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

CCSS.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.

***English Language Arts Standards » Writing » Grade 6-8***

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

***English Language Arts Standards » Science & Technical Subjects » Grade 9-10***

CCSS.ELA-LITERACY.RST.9-10.3. Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.

CCSS.ELA-LITERACY.RST.9-10.4. 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 9-10 texts and topics.

***English Language Arts Standards » Writing » Grade 9-10***

CCSS.ELA-LITERACY.WHST.9-10.2.D. Use precise language and domain-specific vocabulary to manage the complexity of the topic and convey a style appropriate to the discipline and context as well as to the expertise of likely readers.

***English Language Arts Standards » Science & Technical Subjects » Grade 11-12***

CCSS.ELA-LITERACY.RST.11-12.3. Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.

CCSS.ELA-LITERACY.RST.11-12.4. 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 11-12 texts and topics.

***English Language Arts Standards » Writing » Grade 11-12***

CCSS.ELA-LITERACY.WHST.11-12.2.D. Use precise language, domain-specific vocabulary and techniques such as metaphor, simile, and analogy to manage the complexity of the topic; convey a knowledgeable stance in a style that responds to the discipline and context as well as to the expertise of likely readers.

***Grade 7 » Ratios & Proportional Relationships***

CCSS.MATH.CONTENT.7.RP.A.3. Use proportional relationships to solve multistep ratio and percent problems. Examples: simple interest, tax, markups and markdowns, gratuities and commissions, fees, percent increase and decrease, percent error.

## NEXT GENERATION SCIENCE STANDARDS

***Middle School Performance Expectation***

MS-LS1-6. Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms.

***High School Performance Expectation***

HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

## NEXT GENERATION SCIENCE STANDARDS

| Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts |
|---|---|---|
| Planning and Carrying Out Investigations (MS)<br>Developing and Using Models (MS, HS)<br>Using Mathematics and Computational Thinking (MS)<br>Analyzing and Interpreting Data (MS)<br>Constructing Explanations and Designing Solutions (MS) | ESS3.C Human Impacts on Earth Systems (MS, HS)<br>LS1.C Organization for Matter and Energy Flow in Organisms (MS, HS)<br>PS3.D Energy in Chemical Processes and Everyday Life (MS, HS) | Energy and Matter (MS)<br>Systems and System Models (MS, HS) |

## AGRICULTURE, FOOD, AND NATURAL RESOURCES STANDARDS

CS.01.02. Examine technologies and analyze their impact on AFNR systems.
  CS.01.02.01.a. Research technologies used in AFNR systems.
CS.04.02. Assess and explain the natural resource related trends, technologies and policies that impact AFNR systems.
  CS.04.02.01.b. Analyze natural resources trends and technologies and explain how they impact AFNR systems (e.g., climate change, green technologies, water resources, etc.).
ESS.03.01. Apply meteorology principles to environmental service systems.
  ESS.03.01.03.b. Assess the environmental, economic and social consequences of climate change.
  ESS.03.01.03.c. Evaluate the predicted impacts of global climate change on environmental service systems.
PS.01.01. Determine the influence of environmental factors on plant growth.
  PS.01.01.02.a. Identify and summarize the effects of air and temperature on plant metabolism and growth.
  PS.01.01.01.b. Analyze and describe plant responses to light color, intensity and duration.
  PS.01.01.02.c. Design, implement, and evaluate a plan to maintain optimal air and temperature conditions for plant growth.

## BACKGROUND

High temperatures are detrimental to many crops. Excessive heat can result in crop wilting, scalding and scorching of leaves and stems, sunburn on fruits and stems, leaf drop, reduction in growth, and decreased photosynthesis. Because of these complications, high temperatures will lead to reduced yields in many crops.

As climate change intensifies, it will be increasingly necessary for agricultural producers to adapt to rising temperatures. Adaptations may include changing planting locations, changing crop varieties, adjusting planting and harvesting dates, increased irrigation, and the use of shade structures. Shade structures reduce the temperature for crops growing under them, and increased crop yields with the use of shade structures have been demonstrated in tomatoes, cherries, and bell peppers.

Plants have the ability to 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 to 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 proportionally more closed 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 (relative humidity). This warmer air effectively 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 increased 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.

## MATERIALS

- *Wilt it Be Productive? and Don't Be a Loser!* handout packet [1 per student]
- Set of *Don't Be a Loser!* game cards [1 set per every 2 students]
- PowerPoint presentation
- Computer and projector
- Scissors
- Calculators [1 per every 2 students]
- Dinner-sized paper plates (thin and easily cut with scissors) [1 per every 4 students]
- Dessert-sized paper plates [2 per every 4 students, plus a few extras]
- Soda cans, empty or full [2 per every 4 students]
- Clip-on reflective shop lights [2 per every 4 students]
- Large bunch of spinach [1 per every 16 students]
- Electronic balance with 0.1g accuracy [1-5 per class]
- Kitchen timer [optional]
- Extension cords [optional]
- *Wilt it Be Productive?* instructional video, optional introduction to the experiment for the educator

## PREPARATION

1. If possible, watch the *Wilt it Be Productive?* instructional video for an introduction to the experiment.
1. Plan to divide students into teams of four. If necessary, teams of three or five would also be acceptable, as activity tasks can be combined or divided.
2. Make one shade plate for every team of four students. Make shade plates by gently folding the dinner plate in half without creasing it. Cut five narrow triangle shapes along the center fold, approximately 1-inch wide x 5-inch long. Unfold the plate and smooth it out so that it will lay flat. It should look roughly like the top plate in Figure 1.

*Figure 1. Experimental set up of shade treatment with plates and soda cans*

4. Set up scale(s) around the room in easily accessible locations.
   a. Place an empty dessert plate next to each scale.
5. Draw the whole class data table from page 3 of the handout on the board or prepare to show it with a document camera.
6. Place a calculator on each group's table or in an accessible location.
7. Set up a computer and projector and display the PowerPoint presentation.
8. Thoroughly rinse or soak the spinach to remove any soil sticking to the leaves. Blot it dry. If possible, keep it in a refrigerator or cooler when not using.
9. Label and pre-weigh two paired dessert plates of spinach for each group. Label one plate: "Shade." Label the other plate: "Open." On one of the paired plates, arrange eight spinach leaves so that there is very little overlap between leaves. Place an empty dessert plate on the scale, press the tare button, and then remove the empty plate. Take the mass of the plate of spinach, and record it in Table i. below. Then place

*Table i. Starting masses of spinach on open and shade plates for each group*

| GROUP | OPEN MASS (G) | SHADE MASS (G) |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |
| 9 | | |
| 10 | | |

eight spinach leaves, with very little overlap, on the second plate of the pair so that the starting mass of the two treatments is approximately equal (+/- 0.2g). In other words, if the starting mass of the first plate of spinach is 9.4g, be sure that the second plate is between 9.2g and 9.6g. This can be accomplished by removing the stem of one or more leaves or swapping out a leaf for a larger or smaller one. Do not forget to tare the scale with an empty dessert plate before taking the mass every time.

   a. Place the weighed spinach plates in an area near the stations for student collection, keeping the paired plates together.

Note: Time permitting, the educator may instruct students to complete this step before conducting the activity. For educators with one hour or less to conduct this activity, however, it is recommended to pre-weigh spinach for the experiment. Minimize the time that spinach is left sitting out after weighing. If not conducting the activity within 45 minutes, place spinach inside labeled plastic zipper bags and refrigerate.

## PROCEDURES

***Optional Engage Activity***

Bring in a wilted plant and ask students to hypothesize about how the plant became wilted. Elicit that the plant likely was not watered enough, and without water, the leaves and stems wilted. Pose questions to get students thinking about its ability to survive and photosynthesize, such as:

- What usually happens to plants that look like this if they do not get some water? [Answer: they usually die.]
- Why do plants need water? [Answer: for turgidity, obtaining nutrients, and to conduct the chemical reactions needed to live, such as photosynthesis. Note: there is no need to go into depth in your explanation of photosynthesis; it will be addressed later in the activity.]

## INTRODUCTION

1. Divide students into teams of four.
2. Pass out a *Wilt it Be Productive?* and *Don't Be a Loser!* handout packet to each student.
3. Give a short introduction using the PowerPoint presentation.
   a. **Slide 2**: as you probably know, crops need to be watered. Today, we are going to examine what happens to the water that plants take up.
   b. **Slide 3**: one of the things that happens to the water that plants take up is a process called transpiration. It is the loss of water from inside plants into the atmosphere. It functions to cool the plant. Also, it helps to drive water movement through the plant and bring water and nutrients up through the roots and into the stems and leaves. It is basically an invisible process, but if you cover the leaves of a plant with a bag, the bag will get foggy with the water that is being transpired.
   c. **Slide 4**: transpiration does not always happen at the same rate. 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.
   d. **Slide 5**: let's think for a moment about the climate currently and how it is changing. Since 1958, scientists at Mauna Loa, on a Hawaiian island in the North Pacific, have been collecting atmospheric data. This graph shows the concentration of carbon dioxide in the atmosphere as measured at Mauna Loa. Ask students to describe the trend of this graph [answer: carbon dioxide is increasing; some students may also notice that there is a sawtooth pattern from seasonal CO2 uptake and release in the northern hemisphere].
   e. **Slide 6**: we have recorded data on Earth temperatures since 1880. Ask students to describe the trend of this graph [answer: temperature is increasing].
   f. **Slide 7**: remember the factors that affect transpiration. We just mentioned that the concentration of carbon dioxide in the atmosphere is increasing. With this increase, we are also seeing an increase in temperature. We will focus on these two factors in our activities today. First, we will investigate the effects of temperature on plant transpiration. We are going to conduct an experiment that will serve as a model for crops in a warming climate and a way to examine a possible adaptation.
   g. **Slide 8**: farmers in many areas will need to strategize about how they will adapt to increasing temperatures. Some may shift the seasons in which they grow certain crops. Some may switch to more heat-resistant varieties of crops. Another adaptation that is being used experimentally is shade. It has been used with bell peppers, tomatoes, and cherries. The shade helps to reduce the temperature underneath. Producers have experienced increased yields in these crops with the use of shade structures.

***Set Up and Begin Experiment***

1. Explain the experiment using the PowerPoint presentation.
   a. **Slide 9**: we are going to conduct an experiment that uses a shade structure model made out of a paper plate with holes cut out of it that is resting on two soda cans. We will be comparing the water loss from two bunches of spinach placed under lights for 30 minutes. One will be placed under a paper-plate shade structure, and one will be left out in the

open under the light. Instruct students to make a prediction about which treatment will result in higher water loss and then fill in the blank of the prediction statement on page 1 of the handout.
2. Instruct students to read the team member roles on the front page of the handout and choose one role for each student in the group.
3. Once roles are chosen, explain that the materials manager in each group will collect two paired spinach plates. Ensure that students pick up a matched pair of plates.
4. Ask all team members in each group to take the spinach plates to a station with two lights.
5. Instruct the lights operator to place the spinach plates on the table under each of the lights. Ensure that they do not adjust the distance of the lights from the table and do not turn on the lights yet.
6. Tell the lights operator to set up the shade treatment by placing a soda can on each side of the spinach plate labeled "Shade." They will then balance the dinner plate with cutouts on top of the two soda cans.
7. Explain that they will leave the spinach plate un-shaded under the other light because this is the open treatment.
8. If you pre-weighed the spinach plates, ask students to take the mass again before conducting the experiment because the masses may have changed slightly since you weighed and recorded them.
9. Instruct the scale operator and data recorder to take the two paired spinach plates to the scale, along with the handout.
10. Instruct the scale operator to place an empty dessert plate on the scale, press the tare button, and then remove the empty plate.
    a. It is very important that students tare the scale to account for the mass of the dessert plate.
11. Ask the scale operator to take the mass of each of the spinach plates and the data recorder to record them in the starting mass column of the data table on page 2 of the handout.
12. Instruct the scale operator to carry the two spinach plates back to the light station.
13. Ask the lights operator to place the spinach plates back under the lights, being sure to place the plate labeled "Shade" under the shade structure and the plate labeled "Open" under the open light.
14. Once each group has placed the plates back under the lights, instruct all of the lights operators to turn both lights on at the same time. Tell students that you will give a count of three and ask them to turn on both of their lights as you say three.
15. Spinach plates should remain under the lights for at least 30 minutes to produce results that show a difference between treatments. You may set a timer for 30 minutes if you have one; otherwise, you may just watch the clock until at least 30 minutes have elapsed. It is preferable to conduct the experiment for longer if possible; in fact, a greater difference between treatments will be obtained if you are able to let the experiment run for a longer period of time.
16. While waiting for the experiment, play the *Don't Be a Loser!* game, and then students will return to their stations to measure and record ending masses.

***Don't Be a Loser! Game***

1. Prepare to divide students into teams of two for the game.
2. Give a short introduction to related concepts and the game using the PowerPoint presentation.
    a. **Slide 10**: plants have pores on their structures called stomata that allow them to exchange gases with the atmosphere. They are usually microscopic. They open and close in response to the environment. When a stoma is open, carbon dioxide needed for photosynthesis enters, and water and oxygen escape.
    b. **Slide 11**: now let's think about climate change and how it is affecting transpiration. As we saw earlier, carbon dioxide is increasing in the atmosphere. When carbon dioxide is abundant, stomata tend to close because the plant is able to take in carbon dioxide quickly, and the plant gets as much as it needs. When the stomata are closed, the plant does not lose water to the atmosphere. This can be good for farmers because less water is needed when stomata are closed. However, the global average temperature is also increasing. In warmer temperatures, stomata are usually open because warmer air tends to drive water out of the stomata. This is usually the case if plants have sufficient water and are not under water stress.
    c. **Slide 12**: we are going to play a game to examine the effects of climate change on water loss through transpiration called *Don't Be a Loser!* Our game will be dealing with the reality of our changing climate, in which carbon dioxide and temperatures are increasing. We will also include some science fiction. Imagine that you are a farmer with the ability to miniaturize. For 9 days, every day at 12:00 pm you will miniaturize and visit the same stoma on the same tomato plant. You will observe whether the stoma is open or closed. You assume that the stoma that you observe is giving you a reasonably good idea about how the rest of the stomata on the plant are behaving. You will also consider the temperature at that time each day relative to the historic temperature average of the previous 30 years.
    d. **Slide 13**: you and your partner will be given a stack of nine cards, and each card represents what you see on your daily 12:00 pm visit to the stoma on your tomato plant. You

will begin by looking at the A side of your first card. You will fill in the conditions noted on the card on your scorecard on page 6 of your handout. We will use this example to look at how to fill in the scorecard. Just follow along with me; do not write anything on your handout yet. Carbon dioxide is at an increased level on this card, which is how it will be on every card over the course of the game. We see that the temperature is 1 degree Celsius (°C) above historic level, so, on our scorecard, we will write a one in the blank for temperature and circle "above." Because it is warm, the stoma is open, and the card reads "open stoma." We will circle "open" in the stoma column on our scorecard. Now we will flip our card over to the B side. It says that we will lose two water points because our stoma is open. We will write "2" in the lost column in the water points section of our scorecard. If we were playing, we would then go on to our next card. You will now receive a stack of cards, and you will record the conditions from the A side and water points from the B side of each card over nine rounds.

   i. Note that we are using degrees Celsius (°C) in this activity since this is how scientists measure temperature. A change in the temperature in °C is equivalent to a larger number when measured in Fahrenheit (°F). Let us imagine, for example, that it is a warm summer day in the Southwest, and it is 35°C, which is 95°F. If the temperature were to increase by 2°C, or to 37°C, it would equal 98.6°F. To convert temperatures in Celsius to temperatures in Fahrenheit, we multiply by 1.8 and add 32.

3. Hand a full set of nine of cards to each team of two students. If students are currently grouped in teams of four, divide each team in half. Otherwise, students may need to be rearranged to work in pairs.
4. Once teams have had enough time to fill out their scorecards, instruct them to add up all of the water points that were gained during the game and all of the water points that were lost during the game, and record them in the last row of the scorecard.
5. Explain that students will then enter the water points gained and lost into the blanks of the subtraction problem under the scorecard on page 6 of the handout.
6. Tell students to subtract the number of water points lost from the number of water points gained to determine the net water points for the game.
7. The difference will be negative. As students solve this problem, be sure that they are being mindful of the sign.
8. Instruct students to answer the results questions on page 6 of the handout. Use the questions to elicit a discussion about the water loss of their plants during the game.
9. Go back to the PowerPoint presentation to show students the results of a related study.
   a. **Slide 14**: in the game, you saw that the amount of water transpired increased as the temperature increased. For example, you can see on your scorecard that when the temperature was 1 degree C above historic temperature, the plant lost 2 water points, and when the temperature was 2.5 degrees C above historic temperature, the plant lost 7 water points. This is what research demonstrates as well. This graph is from a research paper that shows that when temperature increases, crop transpiration also increases. The two lines show two different equations used to calculate transpiration, and they both show an increased rate with increased temperature.
10. Give an explanation of photosynthesis using the PowerPoint presentation.
    a. **Slide 15**: this is the equation for photosynthesis. Carbon dioxide and water are on the left side of the arrow. These are the reactants of the chemical reaction. Plants must obtain carbon dioxide and water from the environment to conduct photosynthesis. Remember, plants take up water through their roots and carbon dioxide through the stomata. When a stoma is open, however, water is released to the atmosphere during transpiration. Without sufficient carbon dioxide or water, plants are not able to photosynthesize. Oxygen and a sugar, called glucose, are on the right side of the arrow. These are the products of the chemical reaction. Most of the oxygen a plant produces is released through the stomata, and the sugar is used by the plant for energy or to build other carbohydrates to make structures, such as leaves, stems, and fruit.
11. Ask students to answer the conclusions questions on page 7. Time permitting, elicit a discussion about the importance of water in photosynthesis and fruit production.
12. Once it has been at least 30 minutes since turning on the lights in the experiment, announce to students that it is time to return to the experiment.

***Return to Experiment: Collect and Analyze Data***

1. Explain that students are to follow the instructions on page 2 of their handout, beginning with step 8.
2. All team members will return to their station, and then instruct the lights operator to turn off both lights at the same time.
3. Instruct the scale operator to carry the two spinach plates to the scale

and the data recorder to take the handout to the scale.

4. Once at the scale, the scale operator will tare the scale with an empty dessert plate, and then remove it.
5. Instruct the scale operator to take the mass of each of the spinach plates and the data recorder to record each mass in the ending mass column of the "Your Group" table on page 2 of the handout.
6. Ensure that each team has access to a calculator.
7. Once the data are collected, all team members will calculate the percent change of each treatment, which puts the measurements of each treatment on "equal ground" so that a fair comparison can be made.
    a. Explain that students will first calculate the percent change of the shade treatment. Instruct students to use the formula at the bottom of page 2. They will subtract the starting mass from the ending mass, divide the difference by the starting mass, and then multiply it by 100.
    b. Next, instruct students to follow the same procedure to calculate the percent change of the open treatment using the formula at the bottom of page 2.
    c. The percent change values should be **negative** because the mass should have decreased during the experiment. As students solve these problems, be sure that they are being mindful of the signs.
8. Fill in the "Whole Class" table written on the board or projected with the document camera from page 3 of the handout.
    a. Either ask each team to call out their values and record them in the table, or have one representative from each team come up and write their values in the table.
9. Ask students to fill in the "Whole Class" table on page 3 of their handout using the data from the table on the board (or projected with the document camera).
    a. Instruct students to calculate the mean percent change for the shade treatment and the mean percent change for the open treatment, and enter them in the bottom of the Whole Class table.

## *RESULTS AND CONCLUSIONS*

1. Go over the results questions with students to ensure that they understand them well enough to answer the conclusion questions.
    a. Emphasize the answer to results question 1; calculations were negative because the mass of the spinach declined over the course of the experiment, and the negative value denotes a decrease.
2. Direct students to answer the conclusions questions.
    a. For conclusions question 4, ensure that students use the answer to results question 3, considering the mean percent change for the whole class, not simply their own results.
    b. For conclusions question 7, use the PowerPoint presentation to show students a photo of large agricultural fields.
        i. **Slide 16**: this is a photo of lettuce growing in California. Can you think of some of the challenges of using shade structures on these agricultural fields? [Answer: these fields are very large, so constructing shade structures over them would be very costly and require a great deal of labor, materials, and time.] Now answer question 7 on page 4 of your handout.

## EXTENSIONS

1. After conducting the experiment, students may have their own ideas about how a model shade structure could be designed. Encourage students to bring in materials from home to construct a model shade structure and then conduct the experiment again. Note: Ideally, students will be able to replicate their design at least 4-10 times by constructing a number of duplicate structures or by repeating the trials several times.

## ADDITIONAL RESOURCES

Websites with background information about transpiration:

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>

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>.

Articles about using shade structures with crops:

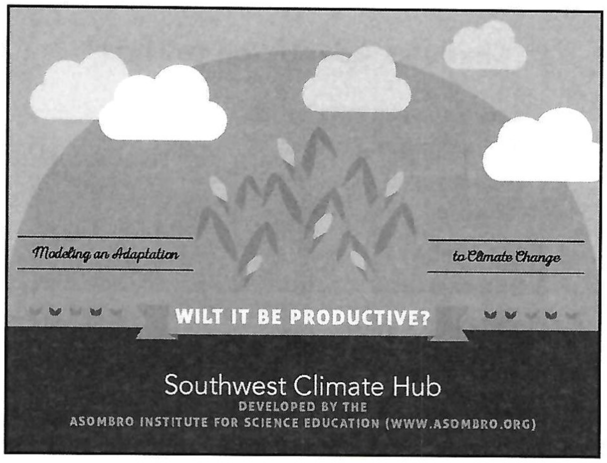
California Department of Food and Agriculture (CDFA). 2013. Climate Change Consortium for Specialty Crops: Impacts and Strategies for Resilience Report. Accessed online. 26 Apr. 2016. <https://www.cdfa.ca.gov/environmentalstewardship/pdfs/ccc-report.pdf>

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. 26 Apr. 2016. <https://edis.ifas.ufl.edu/hs368>.

Article with helpful information about how carbon dioxide affects crops:

Lovelli, S, Perniola, M, Di Tommaso, T, Ventrella, D, Moriondo, M., Amato, M. 2010. Effects of rising atmospheric CO2 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>



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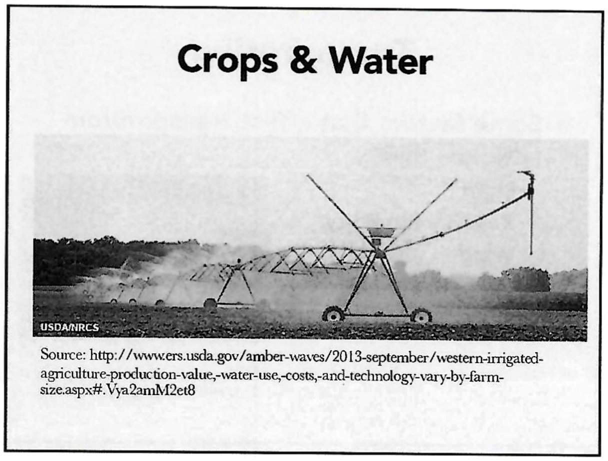
*to Climate Change*

WILT IT BE PRODUCTIVE?

Southwest Climate Hub

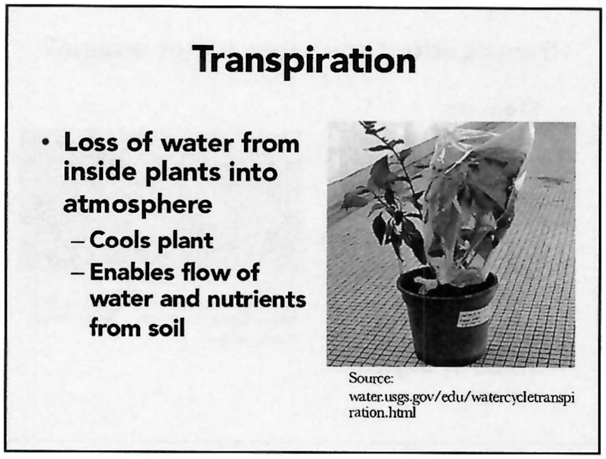
DEVELOPED BY THE

ASOMBRO INSTITUTE FOR SCIENCE EDUCATION (WWW.ASOMBRO.ORG)



# Crops & Water

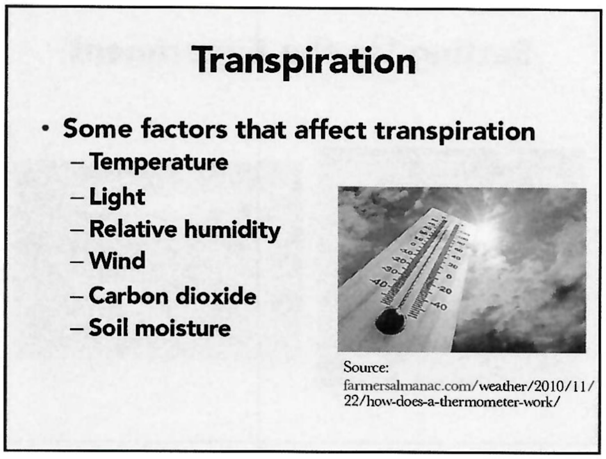
Source: http://www.ers.usda.gov/amber-waves/2013-september/western-irrigated-agriculture-production-value,-water-use,-costs,-and-technology-vary-by-farm-size.aspx#.Vya2amM2et8



# Transpiration

- Loss of water from inside plants into atmosphere
  - Cools plant
  - Enables flow of water and nutrients from soil

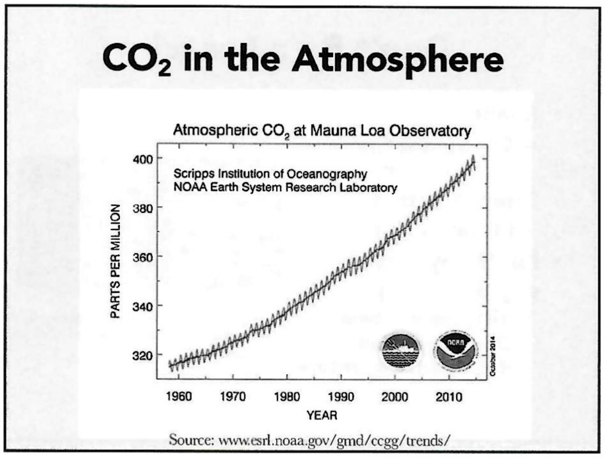
Source: water.usgs.gov/edu/watercycletranspiration.html



# Transpiration

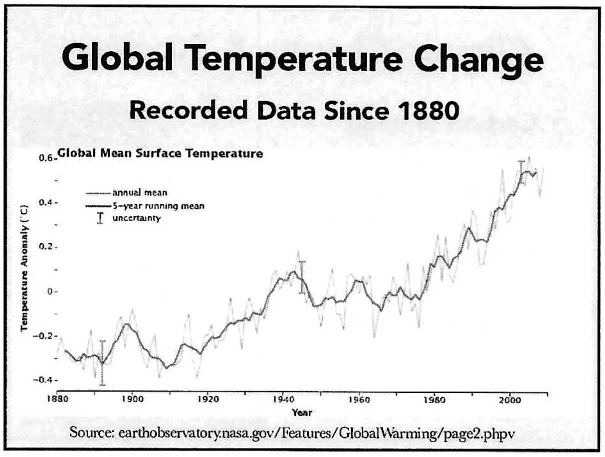
- Some factors that affect transpiration
  - Temperature
  - Light
  - Relative humidity
  - Wind
  - Carbon dioxide
  - Soil moisture

Source: farmersalmanac.com/weather/2010/11/22/how-does-a-thermometer-work/



# $CO_2$ in the Atmosphere

Source: www.esrl.noaa.gov/gmd/ccgg/trends/



# Global Temperature Change

## Recorded Data Since 1880

Source: earthobservatory.nasa.gov/Features/GlobalWarming/page2.phpv

## Transpiration

- Some factors that affect transpiration
  - Temperature
  - Light
  - Relative humidity
  - Wind
  - Carbon dioxide
  - Soil moisture

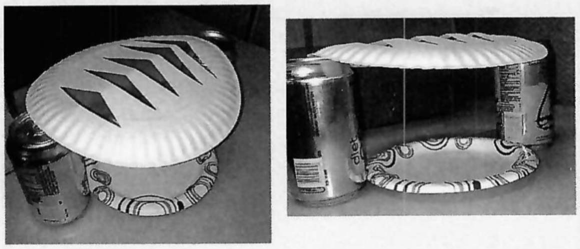
Source: farmersalmanac.com/weather/2010/11/22/how-does-a-thermometer-work/

## Shade as Adaptation to Heat

- Used experimentally in:
  - Bell peppers
  - Tomatoes
  - Cherries
- Decreased temperature
- Increased yield

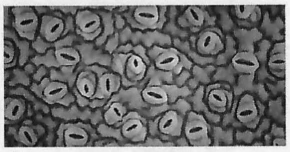
Source: edis.ifas.ufl.edu/hs368

## Setting Up the Experiment



## Transpiration: how does water escape?

- Stomata
  - Singular: stoma
- Pores on plant structures
  - Usually microscopic
  - Open and close
- Carbon dioxide enters
- Water & oxygen escape



Source: biology.anu.edu.au/research/projects/electrophysiology-and-molecular-studies-stomata-during-drought

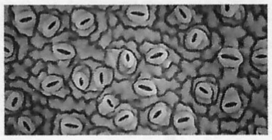
## Climate Change & Stomata

- Carbon dioxide
  - Increasing
  - Stomata: closed
    - Plant takes in $CO_2$ more quickly
- Temperature
  - Increasing
  - Stomata: open
    - Warmer air increases driving of water out of stomata

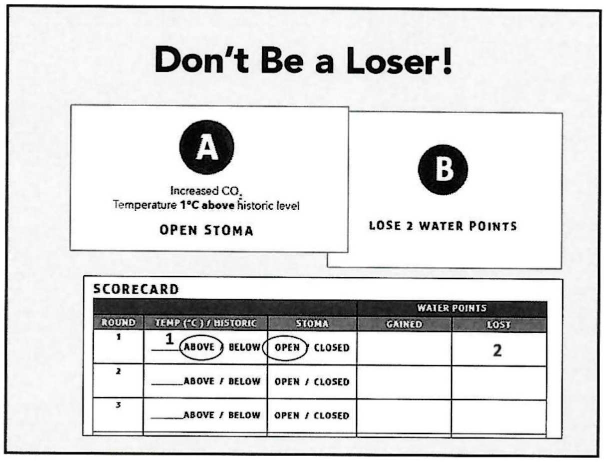
Source: www.nature.com/news/2004/040121/full/news040119-5.html

## Don't Be a Loser!

- Reality
  - Climate change
    - ⇧$CO_2$, ⇧temp
- Science fiction
  - Miniature farmer
- For 9 days, every day at 12:00 pm
  - Visit same stoma
  - Open or closed?
  - Relative temperature



Source: biology.anu.edu.au/research/projects/electrophysiology-and-molecular-studies-stomata-during-drought



## Don't Be a Loser!

**A**

Increased CO2
Temperature **1°C above** historic level

**OPEN STOMA**

**B**

**LOSE 2 WATER POINTS**

**SCORECARD**

| | | | WATER POINTS | |
|---|---|---|---|---|
| ROUND | TEMP (°C) / HISTORIC | STOMA | GAINED | LOST |
| 1 | 1 [✓ ABOVE] / BELOW | [✓ OPEN] / CLOSED | | 2 |
| 2 | ____ABOVE / BELOW | OPEN / CLOSED | | |
| 3 | ____ABOVE / BELOW | OPEN / CLOSED | | |

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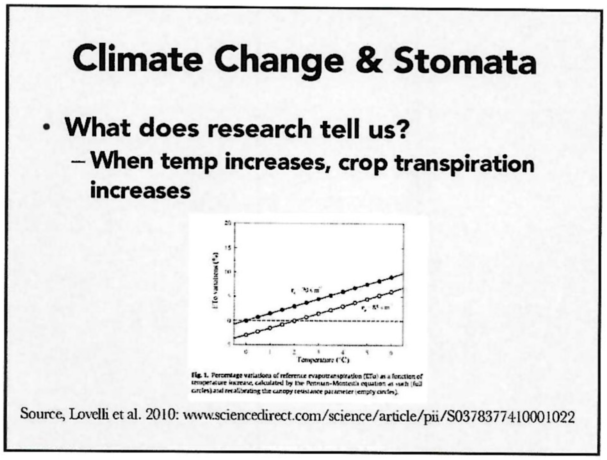

## Climate Change & Stomata

- What does research tell us?
  - When temp increases, crop transpiration increases

Fig. 1. Percentage variations of reference evapotranspiration (ETo) as a function of temperature increase, calculated by the Penman-Monteith equation as such (full circles) and recalibrating the canopy resistance parameter (empty circles).

Source, Lovelli et al. 2010: www.sciencedirect.com/science/article/pii/S0378377410001022

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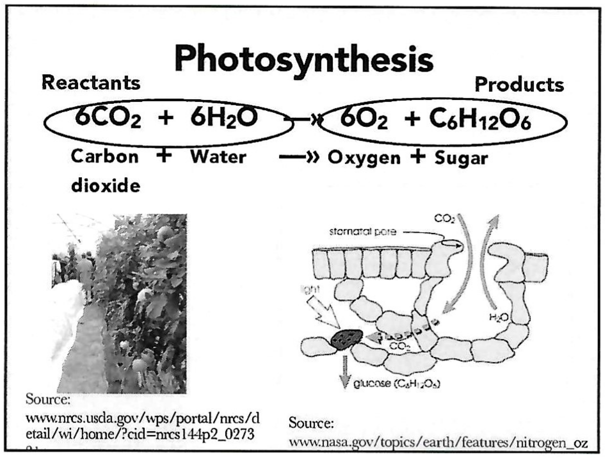

## Photosynthesis

**Reactants** **Products**

$6CO_2 + 6H_2O \rightarrow 6O_2 + C_6H_{12}O_6$

**Carbon dioxide + Water —» Oxygen + Sugar**

Source:
www.nrcs.usda.gov/wps/portal/nrcs/detail/wi/home/?cid=nrcs144p2_0273

Source:
www.nasa.gov/topics/earth/features/nitrogen_oz

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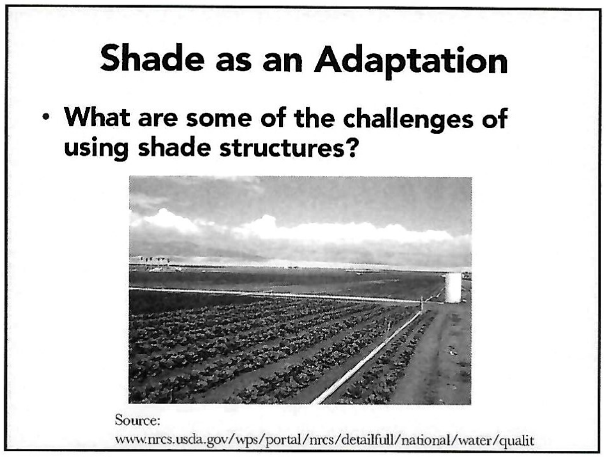

## Shade as an Adaptation

- What are some of the challenges of using shade structures?

Source:
www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/qualit

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Name ______________________________________________ Date ________________

# Modeling an Adaptation to Climate Change

# WILT IT BE PRODUCTIVE?

**TEAM MEMBER ROLES**

**MATERIALS MANAGER**
**SCALE OPERATOR**
**LIGHTS OPERATOR**
**DATA RECORDER**

*Figure 1. Experimental set up of shade treatment with plates and soda cans*

## MATERIALS

- 2 dessert-sized paper plates containing spinach leaves
- Calculator

## EXPERIMENT SET UP

1. Please work with your instructor to assemble into teams of 4.
2. Complete the prediction below.
3. Each team member will choose a role from the list of team member roles.
4. Materials manager, collect two paired spinach plates.
5. All team members, take the plates and spinach to a station with two lights.
6. Lights operator, place the spinach plates on the table under each of the lights. Do not adjust the distance of the lights from the table, and do not turn the lights on.
7. Lights operator, set up the shade treatment by placing a soda can on each side of the spinach plate labeled "Shade." Balance the dinner plate with cutouts on top of the two soda cans (Figure 1).
8. Lights operator, under the other light, leave the spinach plate un-shaded; this is the open treatment.
9. All team members, follow the procedures on page 2.

## PREDICTION

I predict that the water loss of the ____________________________ treatment will be **higher**.

**A. SHADE** **B. OPEN** **C. NEITHER (THEY WILL BE THE SAME)**

## PROCEDURES

1. Scale operator, carry the two spinach plates to the scale, and data recorder, take this handout to the scale.
2. Scale operator, place an empty dessert plate on the scale, press the tare button, and then remove the empty plate.
3. Scale operator, take the mass of each of the spinach plates, and data recorder, record it in the starting mass column of the data table on page 2 of this handout.
4. Scale operator, carry the two spinach plates to the light station.
5. Lights operator, place the spinach plates back under the lights, being sure to place the plate labeled "Shade" under the shade structure and the plate labeled "Open" under the open light.
6. Lights operator, when instructed by your teacher, turn both lights on at the same time.
7. Leave the spinach under the lights for 30 minutes.
8. All team members, after 30 minutes, return to the station, and lights operator, turn off both lights at the same time.
9. Scale operator, carry the two spinach plates to the scale and data recorder, take this handout to the scale.
10. Scale operator, tare the scale with an empty dessert plate, and then remove it.
11. Scale operator, take the mass of each of the spinach plates, and data recorder, record it in the ending mass column of the "Your Group" table below.
12. All team members, calculate the percent change of each treatment, fill in the "Whole Class" table on page 3 of this handout, and answer the results and conclusions questions.

## DATA & ANALYSIS

| YOUR GROUP | | |
|---|---|---|
| | STARTING MASS (G) | ENDING MASS (G) |
| SHADE | | |
| OPEN | | |

Calculate the percent change in order to make a fair comparison. Value may be negative.

### SHADE TREATMENT

(____________g – ____________g)
**Ending Mass** **Starting Mass**
______________________________ X 100 = ____________% **Change in Mass**
____________g
**Starting Mass**

### OPEN TREATMENT

(____________g – ____________g)
**Ending Mass** **Starting Mass**
______________________________ X 100 = ____________% **Change in Mass**
____________g
**Starting Mass**

| WHOLE CLASS – CHANGE IN MASS OF SPINACH | | |
|---|---|---|
| **GROUP** | **SHADE (%)** | **OPEN (%)** |
| **GROUP 1** | | |
| **GROUP 2** | | |
| **GROUP 3** | | |
| **GROUP 4** | | |
| **GROUP 5** | | |
| **GROUP 6** | | |
| **GROUP 7** | | |
| **GROUP 8** | | |
| **MEAN** | | |

## RESULTS

1. In **your group**, the percent changes in the mass of spinach that you calculated were:

**A. POSITIVE** **B. NEGATIVE**

Why were your calculations positive or negative?

2. In **your group**, which treatment had a **greater percent change in mass**? In other words, which treatment lost a larger percentage of water?

**A. SHADE TREATMENT** **B. OPEN TREATMENT**

3. In the **whole class**, the ________________ treatment had a **greater mean percent change**.

**A. SHADE** **B. OPEN**

## CONCLUSIONS

4. Turn back to the first page and review your prediction. Was your prediction correct? Use your answer to question 3 above regarding greater mean percent change.

**A. YES** **B. NO**

5. Considering the results of this experiment, does shading tend to reduce the amount of water lost from plant leaves?

**A. YES** **B. NO**

6. Imagine that the spinach leaves in this experiment are a model for the leaves of a tomato plant. Under climate change conditions, in which treatment would you expect a tomato plant to produce more tomatoes?

**A. SHADE TREATMENT** **B. OPEN TREATMENT**

7. List one or more challenges to using shade structures for crops as an adaptation to heat.

# DON'T BE A LOSER!

## MATERIALS

- Set of game cards
- Calculator

## SCENARIO

Reality: the climate is changing due to increasing levels of atmospheric carbon dioxide.

Science fiction: you are a farmer that has the ability to miniaturize and monitor the microscopic stomata on your tomato leaves. Your hope is that your tomato plants are conserving enough water that they will not wilt.

Over a 9-day period, every day at 12:00 pm, you visit the same stoma on the same tomato leaf to determine whether it is open or closed and how much water is being conserved or lost. You assume that the stoma that you observe is giving you a reasonably good idea about how the rest of the stomata on the plant are behaving and how much water the plant is conserving or losing. You also consider the temperature at that time each day relative to the historic temperature average of the previous 30 years.

## GAME INSTRUCTIONS

1. Shuffle the game cards and place them in a pile with the A side up.

2. Begin by drawing a game card to play round 1.

3. Read the A side of the card to determine the climatic conditions and the position of the stoma. The card will indicate the carbon dioxide level and temperature (°C) relative to the historic level.

4. Turn the game card over to the B side, and read how many water points you gained or lost in this round.

5. On your scorecard on page 6 of this handout, for this round, record the relative temperature (°C) and whether it was above or below the historic level, the position of the stoma (open or closed), and how many water points were gained or lost.

6. Play rounds 2-9 by repeating steps 2-6.

7. Add up all of the water points that were gained during the game and all of the water points that were lost during the game, and record them in the last row of the scorecard.

8. Subtract the number of water points lost from the number of water points gained to determine the net water points for the game.

9. Answer the results and conclusion questions.

## SCORECARD

| | | | WATER POINTS | |
|---|---|---|---|---|
| **ROUND** | **TEMP (°C ) / HISTORIC** | **STOMA** | **GAINED** | **LOST** |
| 1 | ______ABOVE / BELOW | OPEN / CLOSED | | |
| 2 | ______ABOVE / BELOW | OPEN / CLOSED | | |
| 3 | ______ABOVE / BELOW | OPEN / CLOSED | | |
| 4 | ______ABOVE / BELOW | OPEN / CLOSED | | |
| 5 | ______ABOVE / BELOW | OPEN / CLOSED | | |
| 6 | ______ABOVE / BELOW | OPEN / CLOSED | | |
| 7 | ______ABOVE / BELOW | OPEN / CLOSED | | |
| 8 | ______ABOVE / BELOW | OPEN / CLOSED | | |
| 9 | ______ABOVE / BELOW | OPEN / CLOSED | | |
| | | TOTAL | | |

## ANALYSIS: WATER POINTS DIFFERENCE

______________ – ______________ = ______________

Gained Lost Net

## RESULTS

1. In your analysis, did you find that the net water points result was positive or negative?

**A. POSITIVE** **B. NEGATIVE**

2. Over the 9-day observation period, did your tomato leaf conserve more water than it lost or lose more water than it conserved?

**A. CONSERVED MORE WATER THAN IT LOST** **B. LOST MORE WATER THAN IT CONSERVED**

## CONCLUSIONS

Consider the equation for **photosynthesis** to answer the following questions.

| | | | | | | |
|---|---|---|---|---|---|---|
| $6CO_2$ | + | $6H_2O$ | → | $6O_2$ | + | $C6H1_2O6$ |
| Carbon dioxide | + | Water | → | Oxygen | + | Sugar |

3. What two chemical compounds do plants need to undergo photosynthesis? In other words, what are the two reactants in this chemical reaction?

   a. Which of the two chemical compounds listed above is available in increased abundance under climate change conditions?

4. Given your answer to question 2 regarding the amount of water conserved or lost by your tomato leaf, do you think that your tomato plant had enough water to photosynthesize efficiently?

5. One of the products of photosynthesis is sugar, which is used as energy for the plant or to build other carbohydrates that make up plant structures such as leaves, stems, and fruit. If your tomato plant is not photosynthesizing efficiently, will it be able to build carbohydrates to produce tomatoes (the fruit of the plant)?

**A. YES** **B. NO**

Why or why not?

# ANSWER KEY

# *Modeling an Adaptation* WILT IT BE PRODUCTIVE? *to Climate Change*

### TEAM MEMBER ROLES

**MATERIALS MANAGER**
**SCALE OPERATOR**
**LIGHTS OPERATOR**
**DATA RECORDER**

*Figure 1. Experimental set up of shade treatment with plates and soda cans*

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7. Lights operator, set up the shade treatment by placing a soda can on each side of the spinach plate labeled "Shade." Balance the dinner plate with cutouts on top of the two soda cans (Figure 1).
8. Lights operator, under the other light, leave the spinach plate un-shaded; this is the open treatment.
9. All team members, follow the procedures on page 2.

## PREDICTION

I predict that the water loss of the *student answers will vary* treatment will be **higher**.

**A. SHADE** **B. OPEN** **C. NEITHER (THEY WILL BE THE SAME)**

## PROCEDURES

1. Scale operator, carry the two spinach plates to the scale, and data recorder, take this handout to the scale.
2. Scale operator, place an empty dessert plate on the scale, press the tare button, and then remove the empty plate.
3. Scale operator, take the mass of each of the spinach plates, and data recorder, record it in the starting mass column of the data table on page 2 of this handout.
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12. All team members, calculate the percent change of each treatment, fill in the "Whole Class" table on page 3 of this handout, and answer the results and conclusions questions.

## DATA & ANALYSIS

| YOUR GROUP | | |
|---|---|---|
| | **STARTING MASS (G)** | **ENDING MASS (G)** |
| **SHADE** | | |
| **OPEN** | | |

*student answers will vary*

Calculate the percent change in order to make a fair comparison. Value may be negative.

### SHADE TREATMENT

(____________g – ____________g)

**Ending Mass** **Starting Mass**

________________________________________ X 100 = *will vary* % **Change in Mass**

____________g

**Starting Mass**

### OPEN TREATMENT

(____________g – ____________g)

**Ending Mass** **Starting Mass**

________________________________________ X 100 = *will vary* % **Change in Mass**

____________g

**Starting Mass**

**WHOLE CLASS – CHANGE IN MASS OF SPINACH**

| GROUP | SHADE (%) | OPEN (%) |
|---|---|---|
| GROUP 1 | | |
| GROUP 2 | | |
| GROUP 3 | | |
| GROUP 4 | | |
| GROUP 5 | | |
| GROUP 6 | | |
| GROUP 7 | | |
| GROUP 8 | | |
| MEAN | | |

*student answers will vary*

## RESULTS

1. In **your group**, the percent changes in the mass of spinach that you calculated were:

   **A. POSITIVE** [✓ **B. NEGATIVE**]

   Why were your calculations positive or negative?

   *The mass of the spinach declined over the experiment, and the negative value denotes a decrease.*

2. In **your group**, which treatment had a **greater percent change in mass**? In other words, which treatment lost a larger percentage of water?

   *This is usually the case*

   **A. SHADE TREATMENT** [✓ **B. OPEN TREATMENT**]

3. In the **whole class**, the ________________ treatment had a **greater mean percent change**.

   *This is usually the case*

   **A. SHADE** [✓ **B. OPEN**]

## CONCLUSIONS

4. Turn back to the first page and review your prediction. Was your prediction correct? Use your answer to question 3 above regarding greater mean percent change.

*student answers will vary*

B. NO

5. Considering the results of this experiment, does shading tend to reduce the amount of water lost from plant leaves?

*This is usually the case*

[✓ A. YES] B. NO

6. Imagine that the spinach leaves in this experiment are a model for the leaves of a tomato plant. Under climate change conditions, in which treatment would you expect a tomato plant to produce more tomatoes?

*This is usually the case*

[✓ A. SHADE TREATMENT] B. OPEN TREATMENT

7. List one or more challenges to using shade structures for crops as an adaptation to heat.

*Student responses may include any of the following or any other valid ideas:*
*Agricultural fields tend to be very large. Constructing shade structures over them would be very costly and require a great deal of labor, materials, and time.*

# DON'T BE A LOSER!

## MATERIALS

- Set of game cards
- Calculator

## SCENARIO

Reality: the climate is changing due to increasing levels of atmospheric carbon dioxide.

Science fiction: you are a farmer that has the ability to miniaturize and monitor the microscopic stomata on your tomato leaves. Your hope is that your tomato plants are conserving enough water that they will not wilt.

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7. Add up all of the water points that were gained during the game and all of the water points that were lost during the game, and record them in the last row of the scorecard.

8. Subtract the number of water points lost from the number of water points gained to determine the net water points for the game.

9. Answer the results and conclusion questions.

## SCORECA

student answers may be in different order

| | | | WATER POINTS | |
|---|---|---|---|---|
| | EMP (°C ) / HISTORIC | STOMA | GAINED | LOST |
| | 0.5 [✓ ABOVE] / BELOW | [✓ OPEN] / CLOSED | | 1 |
| 2 | 1 [✓ ABOVE] / BELOW | [✓ OPEN] / CLOSED | | 2 |
| 3 | 1.5 [✓ ABOVE] / BELOW | [✓ OPEN] / CLOSED | | 3 |
| 4 | 2 [✓ ABOVE] / BELOW | [✓ OPEN] / CLOSED | | 5 |
| 5 | 2.5 [✓ ABOVE] / BELOW | [✓ OPEN] / CLOSED | | 7 |
| 6 | 0.5 [✓ ABOVE] / BELOW | [✓ OPEN] / CLOSED | | 1 |
| 7 | 1 ABOVE / [✓ BELOW] | OPEN / [✓ CLOSED] | 2 | |
| 8 | 1.5 ABOVE / [✓ BELOW] | OPEN / [✓ CLOSED] | 3 | |
| 9 | 2 ABOVE / [✓ BELOW] | OPEN / [✓ CLOSED] | 4 | |
| | | TOTAL | 9 | 19 |

## ANALYSIS: WATER POINTS DIFFERENCE

9 (Gained) – 19 (Lost) = -10 (Net)

## RESULTS

1. In your analysis, did you find that the net water points result was positive or negative?

A. POSITIVE [✓ B. NEGATIVE]

2. Over the 9-day observation period, did your tomato leaf conserve more water than it lost or lose more water than it conserved?

A. CONSERVED MORE WATER THAN IT LOST [✓ B. LOST MORE WATER THAN IT CONSERVED]

## CONCLUSIONS

Consider the equation for **photosynthesis** to answer the following questions.

$6CO_2$ + $6H_2O$ → $6O_2$ + $C6H1_2O6$

Carbon dioxide + Water → Oxygen + Sugar

3. What two chemical compounds do plants need to undergo photosynthesis? In other words, what are the two reactants in this chemical reaction?

   Carbon dioxide ($CO_2$) and water ($H_2O$)

   a. Which of the two chemical compounds listed above is available in increased abundance under climate change conditions?

      Carbon dioxide ($CO_2$)

4. Given your answer to question 2 regarding the amount of water conserved or lost by your tomato leaf, do you think that your tomato plant had enough water to photosynthesize efficiently?

   No

5. One of the products of photosynthesis is sugar, which is used as energy for the plant or to build other carbohydrates that make up plant structures such as leaves, stems, and fruit. If your tomato plant is not photosynthesizing efficiently, will it be able to build carbohydrates to produce tomatoes (the fruit of the plant)?

   **A. YES** [✓ **B. NO**]

   Why or why not?

   If the plant has insufficient water for photosynthesis, it will not be able to produce the sugars that are used as building blocks to make fruits and other structures.