Natural Inquirer

FACELook!

Exploring the relationship between carbon, photosynthesis, and the roots of trees

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FACE Look! *Exploring the relationship between carbon, photosynthesis, and the roots of trees*

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Editorial Review Board

Mrs. Smith's and Mr. Slye's 7th grade class,
Transylvania County and Buncombe County, North Carolina

Comments from the Editorial Review Board

"I thought that it had a lot of good information and pictures. It was also easy to understand."

"I would like to do some things out of this about twice a month. I think some parts are confusing but over all it is fine. Also the diagrams were easy to understand."

"I definitely like the glossary but could use more words we don't understand that are in the article."

"I like most of the pictures, but did not understand some things."

"I think it's good that you give examples."

"This *Natural Inquirer* was interesting. It taught about the environment and how we can help keep it clean. Also it taught about the atmosphere."

"This holds lots of scientifical facts. The facts help me learn more about how scientists work and experiment."

Visit http://www.naturalinquirer.usda.gov ☞
for more information, articles, and resources.

NOTE TO EDUCATORS
Before using the *Natural Inquirer* in your classroom,
read the Educator Resources section beginning on page18.

FACE*Look!*

Exploring the relationship between carbon, photosynthesis, and the roots of trees

Meet the scientists

Ram Oren

My favorite science experience was as a graduate student when I “discovered” that the structure of leaves determined how they worked. Later, I found out that two Estonians had discovered this earlier than I, but I still like this experience best.

Sari Palmroth

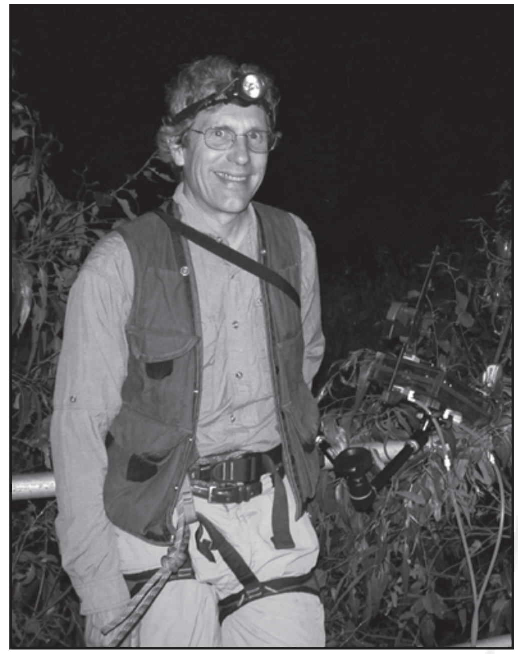
My favorite science experience is to put a green leaf in a small chamber. Then, given that there is enough light in the chamber, I like to see how the amount of carbon dioxide in the air within the chamber is reduced as the leaf *photosynthesizes*. During photosynthesis, the leaf is converting solar energy into *carbohydrates*. This photo of me was taken in Australia. Can you guess what kind of animal I’m with? If you guessed a kangaroo, you are right!

Heather McCarthy

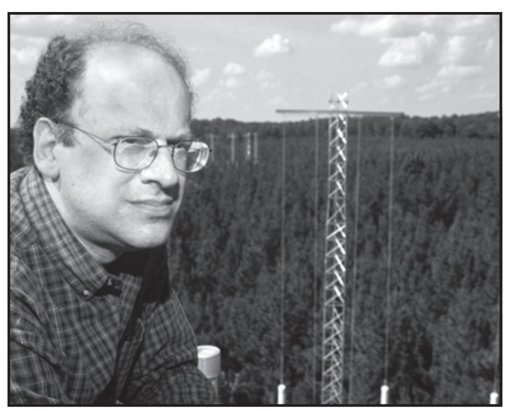
My favorite science experience was going to the Wind River Canopy Crane in Washington. I got to ride in the crane, which goes 200 feet in the air above 500 hundred year old Douglas-firs and western hemlocks.

Kurt Johnsen
My favorite science experience was collecting seed from old-growth red spruce trees in Nova Scotia.

Michael Ryan
I have two favorite science experiences! The first was my first visit to primary wet tropical forest in Costa Rica. It was like entering a different world. Very dim, green light at the bottom of the forest with incredible *diversity* of trees and animals. There were giant trees and lots of critters that could do harm, such as snakes and stinging ants. In this photo, I am getting ready to collect *data* at night from the tops of trees. My other favorite science experience was riding on the Wind River Canopy Crane in Washington State. I was in the open gondola. We could go anywhere over the tops of the trees over 2.5 acres. I never get tired of looking at trees from the top.



John Butnor
My favorite science experience was mapping tree roots with ground penetrating radar near the Artic circle in Northern Sweden.



William Schlesinger
My favorite science experience was watching woodcocks at dusk in a northeastern Ohio shrub wetland.

Thinking About Science

When scientists work to solve a problem or answer a question, they often work on teams. As you can see from the scientists on pages 2 and 3, this research involved a team. This team included men and women with different skills, abilities, and interests.

Think about your experience of working on teams. Do you always agree with everyone on your team? At times during this research project, the scientists did not always agree either. It is normal for scientists to disagree with one another. They might disagree, for example, on how to collect their data. They might disagree on how to explain their findings. When scientists work together on a project, they must work out their differences. Because they respect each other's talents, they often suggest new experiments that will help them to resolve their differences.

Think about a time when you disagreed with someone on how to do something.

Were you able to continue working together?

How did you solve your disagreement?

Thinking About the Environment

The atmosphere is made up of layers of gases surrounding Earth (figure 1). The troposphere is the layer closest to Earth. About 99 percent of the troposphere is made up of nitrogen and oxygen. Of the remaining one percent, about 0.036 percent is carbon dioxide, or CO_2.

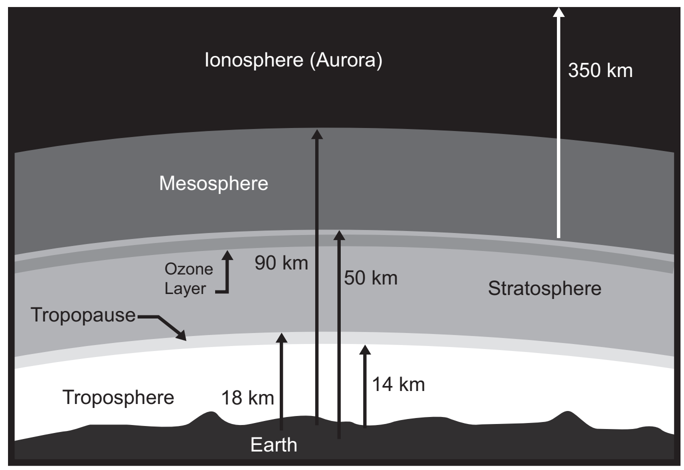


Figure 1. Earth's atmosphere. From the surface of Earth where people live, one can see clouds in the troposphere. Most of Earth's weather happens in this layer of Earth's atmosphere.

(Image courtesy of The University of Tennessee-Knoxville.)

Trees capture some of this carbon dioxide from the atmosphere through the process of photosynthesis. One product of photosynthesis is *glucose*, from which trees obtain energy. Glucose is a carbohydrate and contains carbon, hydrogen, and oxygen. You can see that through photosynthesis, trees capture carbon and use it to grow and maintain their living tissues.

Largely from burning fossil fuels such as coal and oil, Earth's troposphere is experiencing higher levels of carbon dioxide and other greenhouse gases. These gases trap the sun's warmth and are causing changes in Earth's climate. As the level of carbon dioxide rises, more carbon dioxide will be available to trees. This increase in carbon dioxide may not only change Earth's climate. It may also change the amount of photosynthesis in trees and forests world-wide.

Pronunciation Guide

a	as in ape
ä	as in car
e	as in me
i	as in ice
o	as in go
ô	as in for
u	as in use
ü	as in fur
oo	as in tool
ng	as in sing

Accented syllables are in **bold**.

Glossary

photosynthesize (**fo** to **sin** thuh siz): The formation of carbohydrates from carbon dioxide and water in the green tissues of plants when they are exposed to light.

carbohydrate (**kär** bo **hi** drat): Any of a group of substances made up of carbon, hydrogen, and oxygen, including sugars and starches.

diversity (duh **vür** suh te): A measure of the differences between the types and numbers of living things in a natural area.

data (**dat** uh): Facts or figures studied in order to make a conclusion.

glucose (**glu** kos): A form of sugar found in nature.

respiration (**res** pür **a** shun): The process by which a living thing takes in oxygen from the air and gives off carbon dioxide and other waste products.

respire (re **spir**): To carry on respiration.

emit (e **mit**): To send out or give forth.

simulate (**sim** u lat): To look or act like.

variable (**ver** e uh bul): Thing that can vary in number or amount.

inverse (**in** vürs): Exactly opposite.

proportion (pro **pôr** shun): The relation of one thing to another in size, amount, degree, etc.

saturation (**sach** ür **a** shun): The state of being saturated, completely filled or soaked.

species (**spe** sez): Groups of organisms that resemble one another in appearance, behavior, chemical processes, and genetic structure.

random (**ran** dum): Selection purely by chance, with every element having an equal chance of being selected.

erode (e **rod**): To wear away.

Introduction

Can you see an entire tree just by looking at it? Of course not! A tree's roots reach underground and cannot be seen. Roots absorb water and nutrients from the soil to be used by the tree to grow and survive. (figure 2). Roots are necessary to keep a tree from falling over. Although most of a tree's living tissue is visible above ground, its unseen root system is also alive.

In ***"Thinking About the Environment,"*** you learned that carbon is captured by trees during photosynthesis. Carbon is found aboveground in the trunk, branches, and leaves, and belowground in the roots of trees.

When a tree is cut down to be used for products, some of the carbon can last in solid form for many years. This is particularly true if the tree is used to build homes or furniture. If a tree is not cut down, most of the carbon stays in the tree until it dies and decays or is burned in a fire. During decay or a fire, the tree's aboveground carbon is released back into the troposphere. Because roots are better protected underground, they decay at a slower rate. Across a tree's life span, a large amount of carbon is also released during *respiration* **(figure 3)**. Respiration happens both aboveground and belowground.

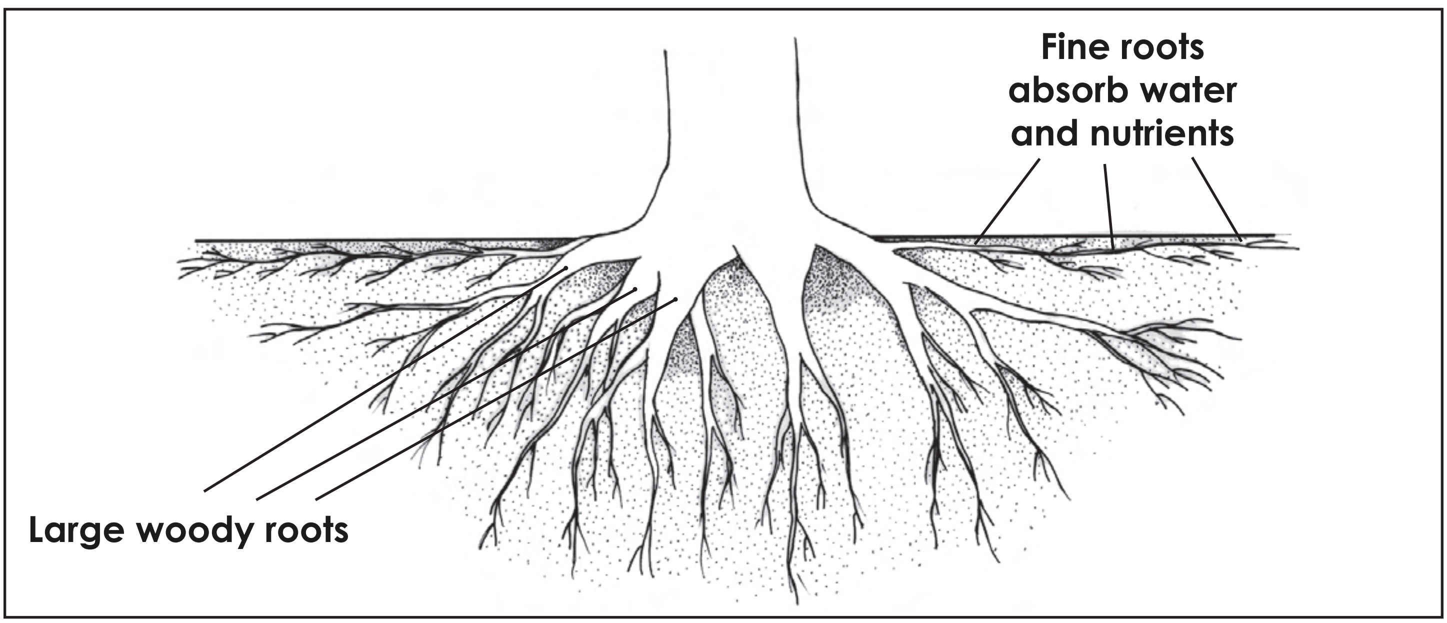


Figure 2. Trees have living tissue belowground.

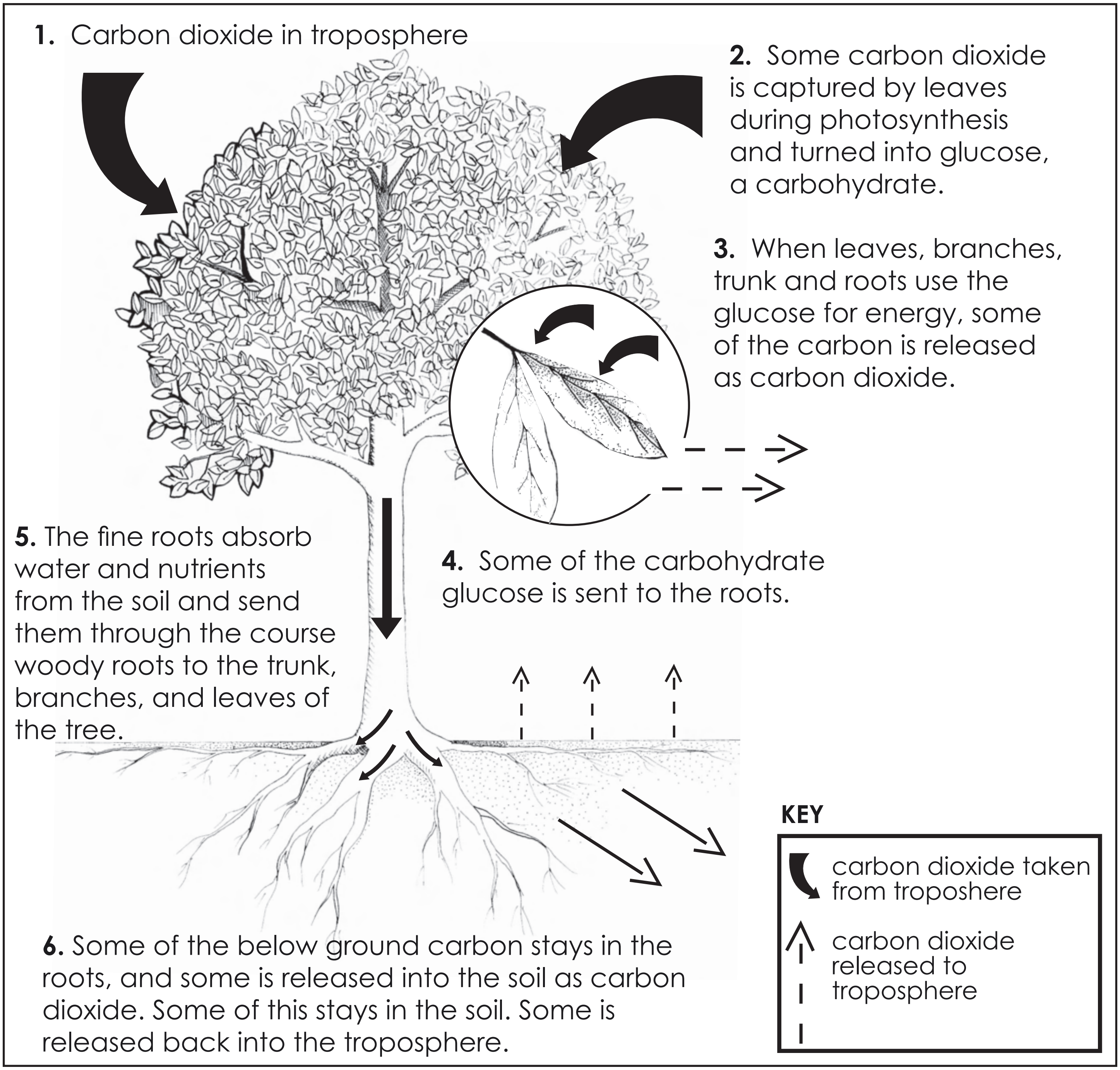


Figure 3. The movement or cycling of carbon by trees.

Climate change is caused in part by a rising amount of carbon dioxide in the troposphere. Scientists are becoming increasingly interested in how global climate change might affect life on Earth. As a part of this, some scientists want to predict what might happen to trees as the climate changes. To do this, scientists need to understand how much carbon dioxide trees capture, how much carbon they hold, and how much they *respire* back to the troposphere. To understand the total amount of carbon captured, held, and respired by a tree, scientists need to know how much carbon is kept aboveground and how much is sent belowground to a tree's root system.

Scientists can estimate the amount of carbon found aboveground in a tree. The amount of carbon is about equal to one-half of the tree's weight, after all water has been removed. Belowground, however, it is a different story! Because roots are underground, it is difficult to measure the amount of carbon they hold and how much carbon is lost during respiration. If a scientist digs up a root, the roots may be destroyed and the tree may be damaged or killed. Some scientists are now using technology such as radar to estimate the amount of carbon in roots.

The scientists in this study wanted to know how rising levels of carbon dioxide in the troposphere might affect the amount of carbon sent belowground by trees and made available for tree root growth and maintenance.

- State in your own words why it is important to be able to estimate the amount of carbon sent belowground by trees.
- Do you think more of a tree's carbon is kept aboveground or sent belowground? Why?

Method

The scientists used data from four special research areas. In these areas, trees were planted on an area of land and allowed to grow. When the trees were ten years old, large towers were constructed in circles within the trees **(figure 4)**. The towers *emit* carbon dioxide into the air surrounding trees in the forest **(figure 5)**. Using technology in this way, the scientists could *simulate* rising levels of carbon dioxide on trees in the out-of-doors. These areas and the research done within them are called **FACE. FACE stands for Free-Air Carbon Enrichment**. Data from trees growing in four **FACE** areas were used. These areas are in North Carolina, Wisconsin, Tennessee, and Italy **(figure 6)**.

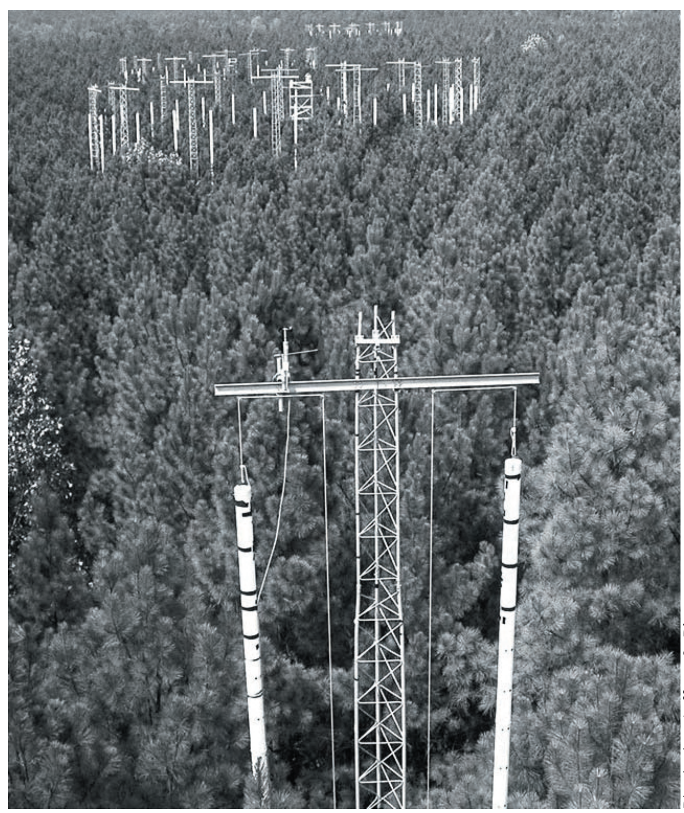


Photo by Jeffrey S. Pippen.

Figure 4. The Duke FACE research area near Durham, North Carolina. These towers spray carbon dioxide gas into the trees.

Photo by Jeffrey S. Pippen.

Figure 5. Liquid carbon dioxide is driven to the site and stored in tanks. The liquid carbon dioxide flows through a large series of pipes, where it is heated enough to turn it into gas. The gas is then piped to the towers.

Remember that carbon is captured during the process of photosynthesis. The amount of photosynthesis happening in a tree is partly dependent on the amount of leaf area exposed to sunlight **(figure 7)**. You can see that the amount of carbon a tree captures is related to its ability to photosynthesize. When carbon is captured during photosynthesis, it flows to different areas of the tree. Some of the carbon flows underground to the roots. Some of the carbon stays aboveground in the trunk, branches, and leaves of the tree. Aboveground and belowground, much of the carbon is released during respiration.

Free-Air Carbon Enrichment (FACE) Experimental Sites

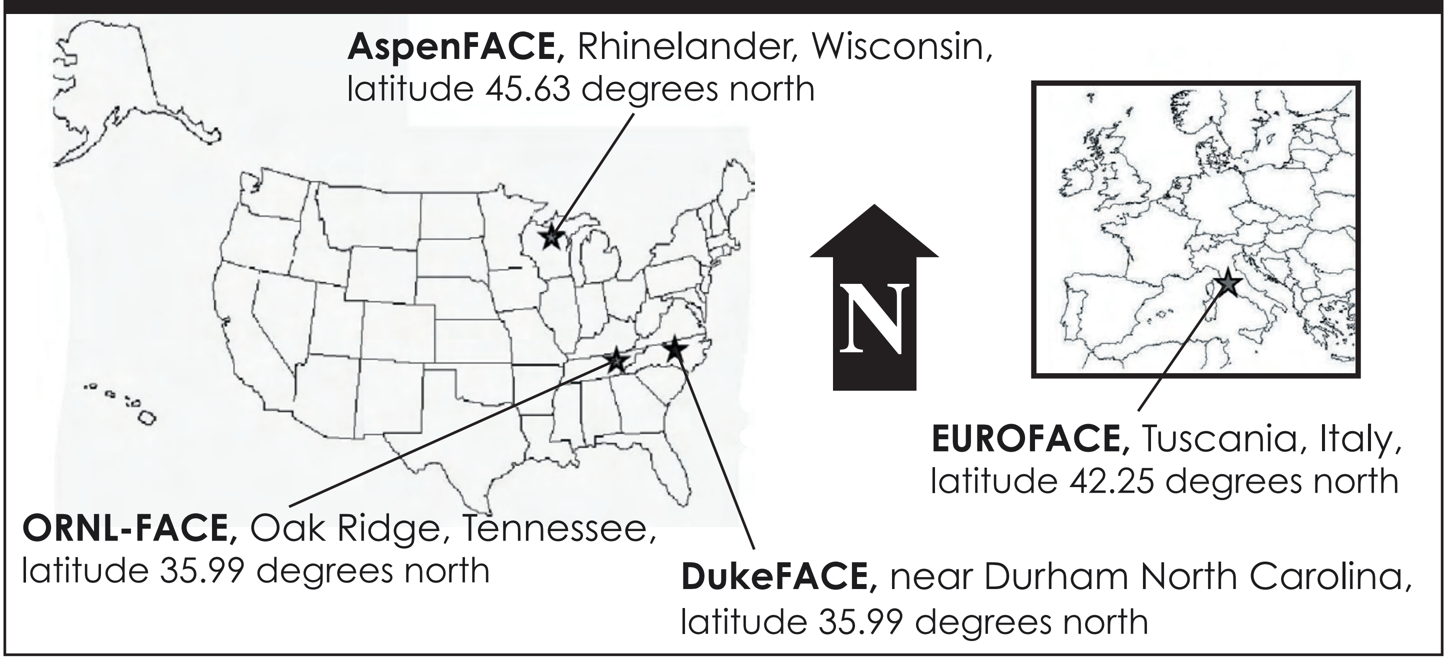


Figure 6. Using a globe or map, compare the latitude of the four areas. Latitude is measured by imaginary lines on Earth's surface. These lines are parallel with the Equator. The Equator is measured at 0 degrees, and the poles are measured at 90 degrees north and south.

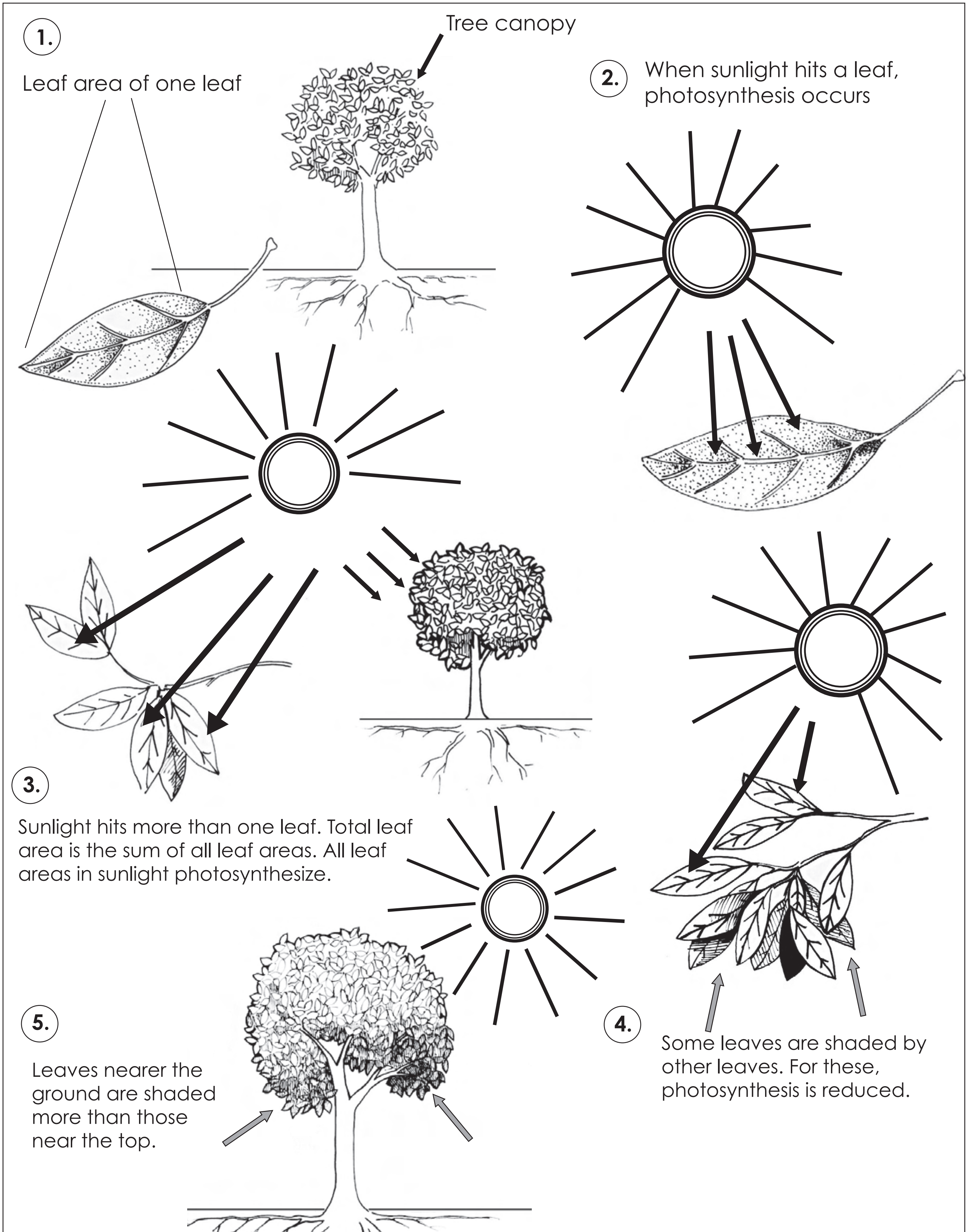


Figure 7. A tree canopy and the amount of leaf area exposed to sunlight.

The amount of leaf area exposed to sunlight and the amount of carbon dioxide in the air control the amount of photosynthesis. The scientists reasoned, therefore, that the amount of leaf area in a tree might be related to the amount of carbon captured by the tree. It is not easy, but it is possible for scientists to estimate the amount of leaf area in a tree.

Scientists can also estimate the amount of carbon sent below ground, although this is much harder for them to do. The carbon sent to the roots as glucose is used by the tree to keep the root system alive. When roots respire, they release carbon dioxide into the soil as they use the energy in the carbohydrates. Therefore, some of the carbon is used to make new roots and some is released as carbon dioxide **(figure 8)**.

The scientists selected trees at different points within the FACE area. For these trees, the scientists estimated the amount of carbon being sent belowground. This included carbon held in the roots, as well as the amount of carbon released during respiration. They did this at different times, and they did it when the trees were exposed to higher than our current levels of carbon dioxide.

The scientists compared the amount of carbon being sent underground with the amount of leaf area in the same trees. This included the amount of carbon held in the roots, as well as the amount released during respiration. They added these amounts to arrive at a total amount of carbon for each year, and they took measurements for four years.

The scientists, therefore, observed and recorded the relationship between the amount of a tree's leaf area and the amount of carbon sent belowground when different levels of carbon dioxide were in the air.

Photo by Jeffrey S. Pippen.

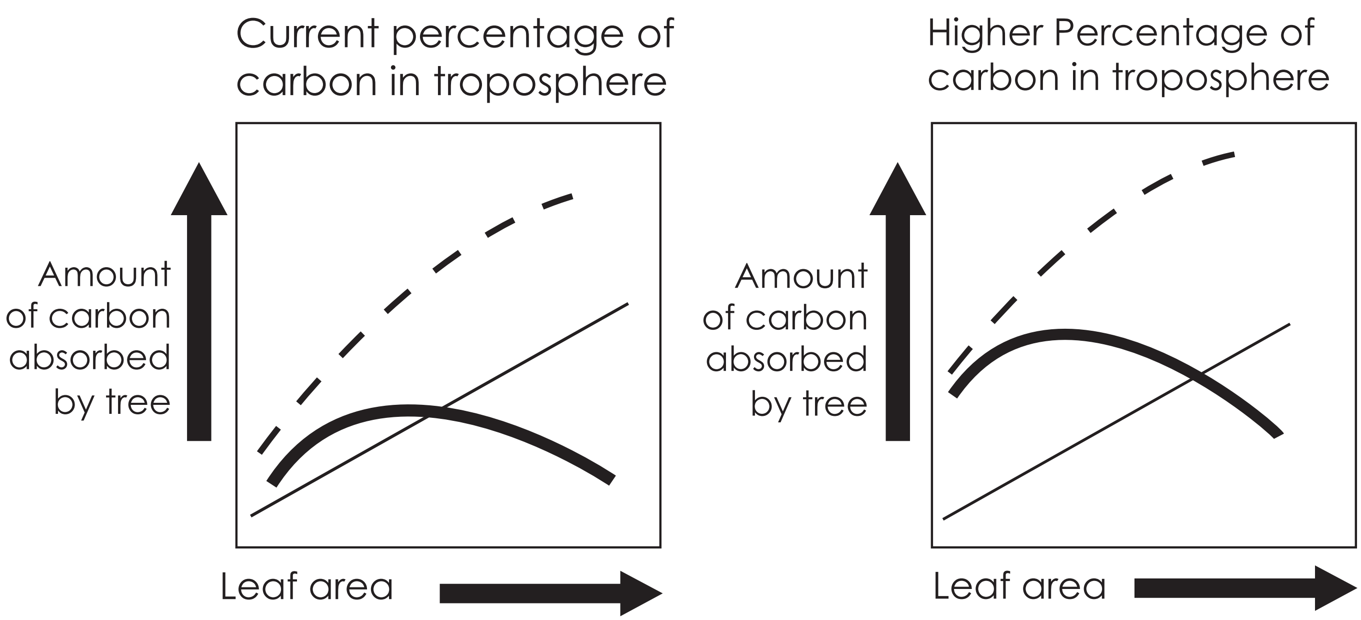
Figure 8. These cylinders, which measured the amount of carbon dioxide released from the soil, were moved every week to a new location under the trees.

Reflection Section

- What are some of the *variables* being studied by the scientists? Which variable is the dependent variable?
- Why would scientists want to know if there is a relationship between the amount of leaf area in a tree and the amount of belowground carbon?
- Why did the scientists increase the amount of carbon dioxide provided to the trees?

Findings

The scientists found that under the current amount of carbon dioxide in the air, the amount of leaf area in the trees was *inversely* related to the *proportion* of carbon sent below-ground. In other words, as leaf area increased, the proportion of carbon sent belowground decreased. The same relationship was found under increasing levels of carbon dioxide **(figure 9).**



——— = New growth in branches, leaves, and trunk
— — — = Amount of carbon taken in by tree minus the amount released during respiration
▬▬▬ = Total amount of carbon sent underground

Figure 9. The relationship between leaf area, photosynthesis, and the amount of carbon sent belowground in trees. As a tree grows, the amount of carbon taken in rises to a maximum level, and less carbon is sent belowground.

At some point the number of leaves on a tree exceed a certain amount. Then, the lower leaves begin to receive less sunlight. When the tree reaches this point, it does not photosynthesize as much as before. When photosynthesis is at its peak, scientists say a tree has reached *saturation*.

Reflection Section

- **Look at figure 9. Do you think that the amount of carbon sent belowground could continue to decrease to zero? Hint: Carbon is contained in every living thing.**

- **Does the relationship described by figure 9 make sense to you? Why or why not?**

Discussion

In this study, the scientists found that the amount of carbon sent belowground by a tree is inversely related to the amount of leaf area in the tree. As photosynthesis increases in a tree, therefore, the largest proportion of the carbon in the tree is kept aboveground.

Trees are dependent on a number of resources for health. They must have sunlight, water, and nutrients. Remember that through photosynthesis, carbon dioxide is converted to glucose. Trees use glucose for energy. Energy is created during the respiration process, when some of the carbon dioxide is released back to the troposphere.

When trees have enough water and nutrients, they put most of their energy into photosynthesis and aboveground growth. This means that they do not send a lot of carbon, and therefore energy, into their root systems. When trees do not have enough of the resources they need, they put less energy into aboveground growth and send more carbon (and energy) into their roots.

As the level of carbon dioxide in the atmosphere rises, the amount of carbon dioxide available for capture is increased. Under these conditions, trees may experience an increase in leaf area and photosynthesis until they reach saturation.

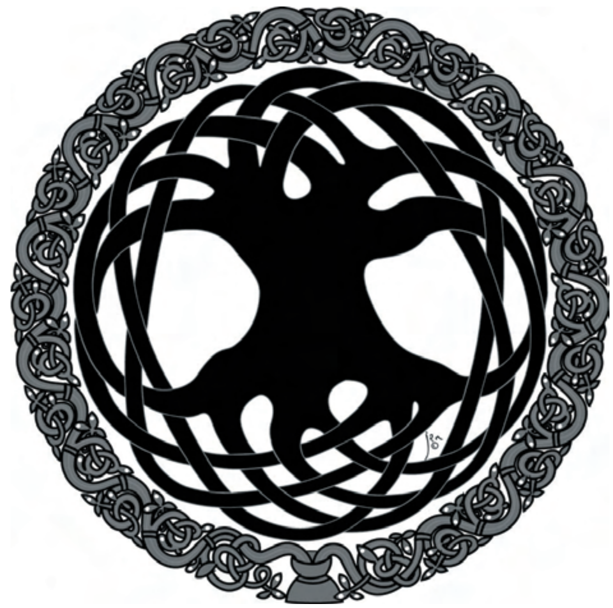
This research helps scientists better understand the relationship between a tree's leaf area, the rate of its photosynthesis, and its root system. It also helps scientists predict what might happen to trees as the climate changes. This is, however, just one study. For scientists to better understand these relationships, they must study a greater variety of tree *species.*

Reflection Section

→ **If climate change includes changes in rainfall patterns and rising temperatures, some trees may not receive all of the resources they need. If that happens, what do you predict might happen to the amount of carbon being sent belowground to these trees' roots?**

→ **Why would it be a good idea for the scientists to study a greater variety of tree species before they fully understand the relationship between a tree's leaf area, the rate of its photosynthesis, and its root system?**

Tree of Life



Here is a design called the **"Tree of Life."**

Think about the article you just read. Compare this design with what you know about the roots of trees.

In what ways is this design accurate in what it suggests about trees and their roots?

In what ways is it inaccurate?

What does this design suggest about trees? Is it meant to be an accurate representation of a tree? Draw your own design of a tree and its roots.

Celtic Tree of Life by Jen Delyth ©1990
www.kelticdesigns.com

FACTivity

Time: 1 class period

Needed: Cloth tape measure, ruler, paper and pencils, copies of forms from page 24.

Note: In advance, your teacher may want to examine the trees in the schoolyard to identify potential trees for this activity.

The questions you will answer with this activity are:

1) What is the estimated leaf area of two similar trees in your school yard?

2) How healthy do those trees appear to be?

3) Based on what you learned through reading this research, how might the trees' root systems compare?

(Note: This activity must be done when leaves are on the trees.)

The method you will use to answer the questions is:

Before you begin, write one or two hypotheses (hi **poth** uh ses) stating what you would expect to find out in this inquiry. Each student may write their own, or you may develop the hypotheses as a class.

Note: A **hypothesis** is a written **"if-then"** statement that follows this form: "If X (a variable that you define) is related to Y (another variable that you define), then changing or observing a difference in X in this way (a change or difference that you define) will result in a change to or a difference in Y in this way (a change or difference that you define)."

1. Select two small trees of similar trunk size. You must be able to reach into the tree's canopy. If possible, select trees of the same species but growing in different areas of the schoolyard. Scientists measure tree trunks at the same height every time. This height, called diameter at breast height or d.b.h., is 1.37 meters or 4.5 feet from the ground. You should measure your trees at d.b.h. using a cloth measure. You will measure the circumference (not the diameter) of the tree's trunk. The important thing is to find two small trees about the same size, and hopefully of the same species.

Divide the class into six groups. Three groups will work with one tree the other three will work with the second tree.

2. Select a *random* sample of leaves from each of the trees. Have a group of four students (two students from one tree, two from the other) quickly determine the best way to make a *random* selection of leaves. You must be able to reach the leaves without using a ladder or other prop.

One group from each tree will select 20 leaves from their tree, using the selection process determined by the group of four students. If possible, do not pick the leaves but measure them while they are on the tree. Using a ruler, measure each leaf's length and width.

Multiply the length by the width to calculate an estimate of the leaf's area. Measure at the widest point in the leaf. Do this for each leaf in your sample. Note that your measurement for each leaf's area will be too large, because leaves are not rectangular. However, if you measure the leaves on both trees in the same way, you can still compare the leaf area of the two trees. This is because the measurements will be equally too large. Accurately record the measurements for each tree, keeping the two trees' samples separate. Then, each group will calculate the average leaf area of their tree's leaves.

(Note: Do not climb into the tree or use a ladder or other prop to reach the leaves. Only measure the leaves you can reach while standing on the ground.)

Tree Site Conditions

Question	Answer and point value	Number of points
Does the tree have mulch around its base?	Yes=1 No=0	
Is the soil around the tree *eroded*?	Yes=0 No=1	
Is the tree shaded?	All day=0 More than half of the day=1 Less than half of the day=2 No=3	
Are insects eating the leaves?	Many leaves affected=0 Some leaves affected=1 Few leaves affected=2	
Is there damage to the tree's bark?	A lot of damage=0 Some damage=1 No=2	
Are the leaves green and healthy?	Most=1 Most are not=0	
Does the tree get adequate water? (Leave this question out if you do not know)	Yes=1 No=0	
TOTAL POINTS		

NOTE: See page 24 for copyable template.

3. Meanwhile, the second group from each tree will record the tree's site conditions. Use the chart on page 16 to observe and record the tree's site conditions.

4. Meanwhile, the third group for each tree will estimate the number of leaves on their tree. One idea is to count the number of leaves on one branch, then count or estimate the number of branches on the tree. By multiplying the two amounts, you will have an estimate of the number of leaves on the tree.

5. Inside the classroom, calculate the total leaf area of each tree. Do this by multiplying the estimated number of leaves on the tree by the average leaf area. For each tree, complete the table below. If possible, reproduce this table on the white board so that the entire class can see it.

Tree 1	Tree 2
Species:__________	Species:__________
Circumference:__________	Circumference:__________
Estimated # leaves: __________	Estimated # leaves:__________
Estimated average leaf area:__________	Estimated average leaf area:__________
Total estimated leaf area:__________	Total estimated leaf area:__________
Site condition score:__________	Site condition score:__________

NOTE: See page 24 for copyable template.

Hold a discussion to compare the two trees. Is one tree healthier than the other? How do you know? Based on your reading of this research, how do you think the root systems of the two trees compare? Which root system, if any, may be receiving a greater amount of carbon? Give a reason or reasons for your claim.

As a class, make a list of at least three weaknesses of the inquiry process you just completed. Further discuss what you would do differently to improve the inquiry process. ***(Hint: For example, if you could have sampled leaves from the entire tree, your sample would better represent the entire tree.)***

Extension: After completing the **FACTivity**, have students reread "Thinking About Science." In small groups or as a class, have students discuss their experience of working in groups while doing this **FACTivity**. Students should be reminded to be sensitive and courteous in their discussion.

If you are a Project Learning Tree-trained educator, you may use Activity #28, Air Plants, as an alternative activity or an extension.

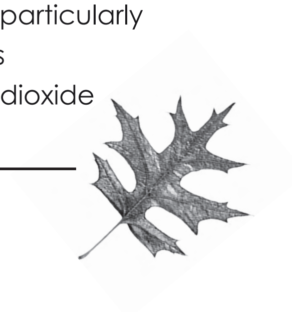
From: Palmroth, S., Oren, R, McCarthy, H. R., Johnsen, K. H., Finzi, A. C., Butnor, J. R., Ryan, M. G., Schlesinger, W. H. (2006). Aboveground sink strength in forests controls the allocation of carbon below ground and its [CO_2]-induced enhancement. Proceedings of the National Academy of Sciences, Vol. 103(51): 19362-19367. http://www.treesearch.fs.fed.us/pubs/27136

Note to Educators:

Welcome to the *Natural Inquirer* Monograph Series!

The *Natural Inquirer* is a middle school science journal. The journal presents the work of Forest Service scientists and their fellow scientists. Each journal contains 6-7 articles. The *Natural Inquirer* Monograph Series is similar to the journal, except that it presents research from only one study. To aid you in classroom use, this monograph also includes a number of educational resources.

The research presented in this monograph is about trees. It explores the processes trees use to capture the sun's energy and turn it into energy used for growth and maintenance. It is particularly concerned with how trees allocate the carbon captured during photosynthesis to areas aboveground and belowground. The research also explores how rising levels of carbon dioxide might affect these processes in trees.



This monograph contains a number of sections to help students read about and understand the scientific process, as well as learn something new about trees. The sections include:

Meet the Scientists: Introduces the scientists whose research is presented.

Glossary: Introduces potentially new terms used in the monograph.

Thinking About Science: Provides one concept about the nature of scientific inquiry.

Thinking About the Environment: Provides background information to introduce the topic studied by the scientists.

Introduction: Introduces the problem or question the scientists addressed.

Method: Presents the method used by the scientists to collect and analyze their data.

Findings: Presents the results of the research.

Discussion: Places the findings into the context of the original problem or question.

Reflection Sections: These questions are not a test! They are placed after the Introduction, Method, Findings, and Discussion sections to help students critically think about what they have read. The questions can also be used to informally assess student comprehension.

FACTivity: Presents an activity that can be done in the classroom and out-of-doors.

Citation: Gives the original article citation.

Lesson Plan: Presents a lesson plan for using the *Natural Inquirer* monograph in the classroom.

Possible answers to the Reflection Questions

Correlation to Science Education Standards: Presents Science Competency Goals for North Carolina (7th grade) and National Science Education Standards (grades 5-8) that can be addressed by the monograph.

For more information about the *Natural Inquirer*, to order additional copies, or explore educator and student resources for using the journal, visit http://www.naturalinquirer.usda.gov/.

For other information or assistance, contact Dr. Babs McDonald at bmcdonald@fs.fed.us. Please put "Educator Feedback" in the subject line. Physical address: 320 Green St., Athens, GA 30607-2044, 706-559-4224.

Lesson Plan

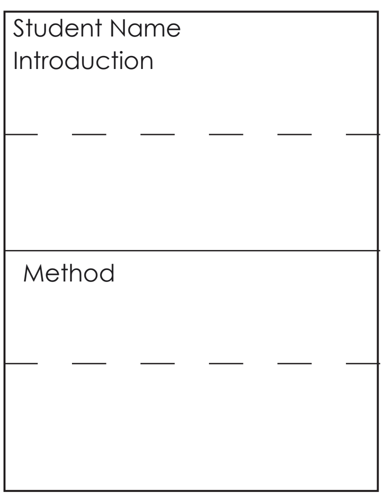
For homework

Have students read Meet the Scientists and review the Glossary. Then read Thinking About Science and Thinking About the Environment. After they have read these sections, have them write a paragraph that addresses the question in Thinking About Science. They should then think about and write one sentence summarizing the topic they think the article will address.

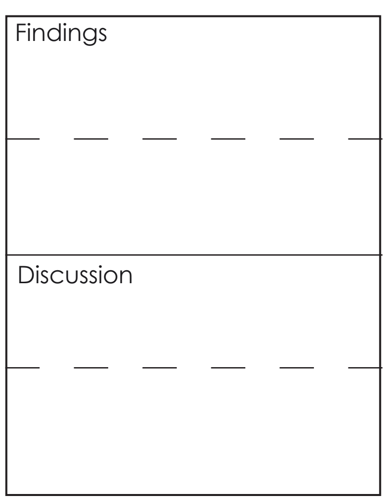
Have students take one sheet of plain paper and create the following, using both sides of the paper.

Divide each side into half with a solid line, then into quarters using a dashed line. Place their name at the top of the first page. Write Introduction in the first quarter, Method in the second quarter, Findings in the third quarter (beginning on the back), and Discussion in the last quarter.

The paragraph, sentence, and sheet of paper should be brought to class.



Front side of prepared sheet



Back side of prepared sheet

Day 1

Materials needed: *Natural Inquirer* article, pencils, prepared sheets; homework.

5 minutes

Introduce the *Natural Inquirer*. Explain that scientists do their research and write it up using a fairly standard format. The *Natural Inquirer* provides scientific articles for students. The format scientists use to write up their research generally, but not always, follows the following:

Introduction • Gives the background of and reasons for the research question or problem. The research question or problem is almost always found near the end of the introduction.

Method • Gives the method the scientist(s) used to collect and analyze their data.

Findings • Presents the findings. This usually, but not always, includes tables, charts, and graphs.

Discussion • Explains what the findings mean in light of the research question or problem presented in the Introduction.

Explain that the sections they read for homework were added to give them additional background to better understand the upcoming article, which they will read in class.

5 minutes

Hold a class discussion about Thinking About the Environment. What is the main idea of the paragraph? What are some ideas students have about what topic they think the article will address? What words or sentences did they use as clues?

10 minutes

Have a student read the Introduction section aloud. As each paragraph is finished, have students silently note what they think is the paragraph's main idea by writing this on the first quarter of their prepared sheet of paper, under the label "Introduction."

Hold a class discussion about the main idea of the section. Have students identify what the scientists wanted to study. Have the students restate this as a research question. *(Example: How do rising levels of carbon dioxide in the troposphere affect the amount of carbon sent to tree roots belowground?)*

15 minutes
Repeat the above process with the Method section. This time, students will write the main idea of the paragraphs on the top part of the lower half of the first page. (Note: The students will not identify the research question again.)

5 minutes
Repeat the above process with the Findings section. This time, students will write the main idea of the paragraphs on the top quarter of the second side of the page.

Homework
Have students complete the Reflection Sections for the Introduction, Method, and Findings sections by writing on the appropriate section of their prepared sheet, which is the section below the dotted line. Emphasize that these questions are not a test.

Day 2:

15 minutes
Remind the students that they have read the Introduction, Method, and Findings sections. Review the article by discussing their answers to the Introduction, Method, and Findings Reflection Sections. Remind them of the upcoming section: Discussion.

10 minutes
Repeat the process used previously for the Discussion Section. This time, take 5 minutes after reading the section to discuss the reflection questions in class.

Now spend about 5 minutes discussing the implications of the article, from their perspective. Ask students to "fast forward" 25 years. The troposphere now has a greater percentage of carbon dioxide. The climate is warmer and rainfall patterns have changed with longer periods of either rain or drought. How will this affect trees around the world? How will it affect tree roots?

Optional • Do the **FACTivity** for the remainder of Day 2 and on Day 3:

In the last 10-15 minutes of class, introduce the **FACTivity**. Have the students read the first two paragraphs of the **FACTivity**. Have students develop and write one or two hypotheses for their inquiry, either individually, in groups, or as a class.

Day 3

Continue with the **FACTivity**. The classroom time should be split about half between outdoor work and indoor work.

Assessment • Student discussion, answers to the reflection questions, and the completed prepared sheets may be used for assessment of student comprehension.

Possible answers to the Reflection Questions

Note to Educator: The purpose of the Reflection Questions is to encourage students to think critically about what they have read. The following "answers" are only suggestions to assist you in using these questions in the classroom.

Introduction

State in your own words why it is important to be able to estimate the amount of carbon sent belowground by trees. *Global climate change is an important issue today. To fully understand how trees will be affected by climate change, scientists need to estimate the total amount of carbon a tree captures, holds, and respires. This includes the carbon sent belowground to roots. If scientists cannot estimate how much total carbon a tree captures, holds, and respires, they will not have accurate information to predict how trees might be affected by climate change and how they affect carbon dioxide concentration in the atmosphere.*

Do you think more of a tree's carbon is kept aboveground or sent belowground? Why? *Most of a tree's carbon is found aboveground. This makes sense because the trunk, branches, and leaves of a tree are larger and have more weight than the roots underground.*

Method

What are some of the variables being studied by the scientists? *The amount of leaf area in a tree, the amount of carbon dioxide in the air (measured as a percentage), and the amount of belowground carbon*. Which variable is the dependent variable? *The total amount of carbon sent belowground.*

Why would scientists want to know if there is a relationship between the amount of leaf area in a tree and the amount of belowground carbon? *The amount of leaf area in a tree can be measured, as can the amount of carbon sent belowground. It is, however, much more difficult to measure the amount of carbon sent belowground for maintenance and respiration. If there is a relationship between the amount of leaf area and the amount of carbon sent belowground, scientists could estimate the amount of carbon sent belowground from the measurement of leaf area. That would make the estimation of the total amount of carbon sent belowground much easier, and it would be a lot less damaging to the trees.*

Why did the scientists increase the amount of carbon dioxide provided to the trees? *So they could discover if rising levels of carbon dioxide affect growth and if rising levels of carbon dioxide have any effect on the relationship between the amount of leaf area and the amount of carbon sent belowground.*

Findings

Look at figure 9. Do you think that the amount of carbon sent belowground could continue to decrease to zero? Hint: Carbon is contained in every living thing. *No, the amount of carbon sent belowground could not decrease to zero. Trees need roots to live, and therefore there will always be a certain amount of carbon sent by trees to the roots belowground.*

Does the relationship described by figure 9 make sense to you? Why or why not? *Students will have their own answer to this question. However, any answer should be backed up by the student's reasoning.*

Discussion

If climate change includes changes in rainfall patterns and rising temperatures, some trees may not receive all of the resources they need. If that happens, what do you predict might happen to the amount of carbon being sent belowground to these trees' roots? *Based on this research, if trees come under stress, they will send more carbon and energy to their roots and put less into the trunk, branches, and leaves aboveground.*

Why would it be a good idea for the scientists to study a greater variety of tree species before they fully understand the relationship between a tree's leaf area, the rate of its photosynthesis, and its root system? *Because the relationship might be different for different tree species. A scientist cannot assume that the same relationship exists for most tree species until they have studied a wider variety of species.*

Which science education standards can be addressed through this monograph?

STANDARD		Lesson Plan	FACTivity
Science Competency goals for North Carolina (7th grade)			
Goal 1:	The learner will design and conduct investigations to demonstrate an understanding of scientific literacy.		
1.01.	Identify and create questions and hypotheses that can be answered through scientific investigations.	X	X
1.04.	Analyze variables in scientific investigations. Identify dependent and independent variables Describe relationships between variables	X	X
1.05	Analyze evidence to:		
	Explain observations	X	X
	Make inferences and predictions	X	X
	Develop the relationship between evidence and explanation	X	X
1.06.	Use mathematics to gather, organize, and present quantitative data resulting from scientific investigations:		
	Measurement		X
	Prediction models	X	
1.08	Use oral and written language to		
	Communicate findings	X	X
	Defend conclusions of scientific investigations	X	X
1.10.	Analyze and evaluate information from a scientifically literate viewpoint by reading, hearing, and/or viewing:		
	Scientific text	X	
	Articles	X	
Goal 3:	The learner will conduct investigations and utilize appropriate technologies and information systems to build an understanding of the atmosphere.		
3.05.	Examine evidence that atmospheric properties can be studied to predict atmospheric conditions and weather hazards (carbon)	X	
3.06.	Assess the use of technology in studying atmospheric phenomena and weather hazards. (FACE)	X	

STANDARD	Lesson Plan	FACTivity
National Science Education Standards addressed by this article		
Science as inquiry		
Abilities necessary to do scientific inquiry		
Identify questions that can be answered through scientific investigation	X	
Design and conduct a scientific investigation		X
Develop descriptions, explanations, predictions, and models using evidence	X	X
Think critically and logically to make the relationships between evidence and explanations	X	X
Life science		
Regulation and behavior		
All organisms must be able to obtain and use resources, grow, reproduce, and maintain stable internal conditions while living in a constantly changing environment	X	
An organism's behavior evolves through adaptation to its environment	X	
Populations and ecosystems		
For ecosystems, the major source of energy is sunlight. Energy entering ecosystems as sunlight is transferred by producers into chemical energy through photosynthesis. That energy then passes from organism to organism in food webs.	X	X
Earth and space science		
Structure of the earth system		
The atmosphere is a mixture of nitrogen, oxygen, and trace gases that include water vapor. The atmosphere has different properties at different elevations	X	
Science and technology		
Understandings about science and technology		
Science and technology are reciprocal. Science helps drive technology. It is essential to science because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.	X	
Science in Personal and Social Perspectives		
Science and technology in society		
Societal challenges often inspire questions for scientific research	X	
Science cannot answer all questions and technology cannot solve all human problems or meet all human needs	X	X
History and nature of science		
Science as a human endeavor		
Women and men of various social and ethnic backgrounds – and with diverse interests, talents, qualities, and motivations– engage in the activities of science, engineering, and related fields such as the health professions	X	
The work of science relies on basic human qualities, such as reasoning, insight, energy, skill, and creativity– as well as on scientific habits of mind, such as intellectual honesty, tolerance of ambiguity, scepticism, and openness to new ideas	X	X
Nature of science		
Scientists formulate and test their explanations using observation, experiments, and theoretical and mathematical models	X	X
It is normal for scientists to differ with one another about the interpretation of the evidence or theory being considered	X	

Question	Answer and point value	Number of points
Does the tree have mulch around its base?	Yes=1 No=0	
Is the soil around the tree eroded?	Yes=0 No=1	
Is the tree shaded?	All day=0 More than half of the day=1 Less than half of the day=2 No=3	
Are insects eating the leaves?	Many leaves affected=0 Some leaves affected=1 Few leaves affected=2	
Is there damage to the tree's bark?	A lot of damage=0 Some damage=1 No=2	
Are the leaves green and healthy?	Most=1 Most are not=0	
Does the tree get adequate water? (Leave this question out if you do not know)	Yes=1 No=0	
TOTAL POINTS		

Tree 1	Tree 2
Species:__________	Species:__________
Circumference:__________	Circumference:__________
Estimated # leaves: __________	Estimated # leaves:__________
Estimated average leaf area:__________	Estimated average leaf area:__________
Total estimated leaf area:__________	Total estimated leaf area:__________
Site condition score:__________	Site condition score:__________

What is the US Forest Service?

The Forest Service is part of the Federal Government. It is made up of thousands of people who care for the Nation's Federal forests and grasslands. The Forest Service manages over 150 national forests and almost 20 national grasslands. National forests, like national parks, provide places for people to recreate, and they provide homes for wildlife, and clean water and air for everyone. National forests also provide resources for people to use, such as trees for lumber, minerals, and plants used for medicines. Some people in the Forest Service are scientists, whose work is presented in this monograph (mon o graf). These scientists work to solve problems and provide new information about natural resources so we can make sure our natural environment is healthy, now and into the future.

Learn more about the Forest Service by visiting

http://www.fs.fed.us

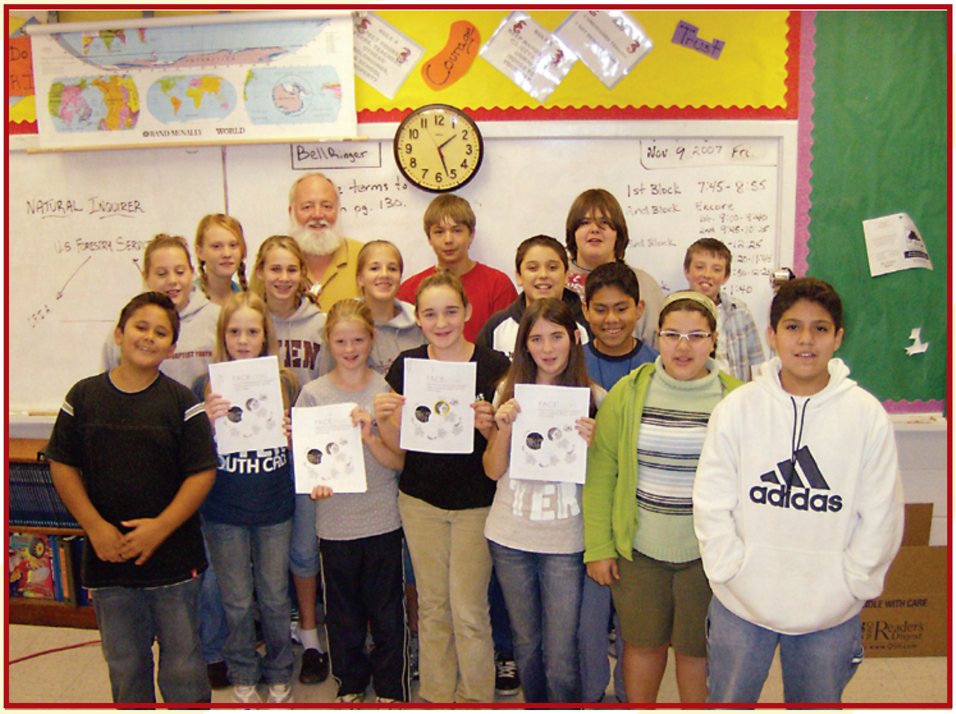
What is the Cradle of Forestry in America Interpretive Association?

The Cradle of Forestry in America Interpretive Association (CFIA), is a non-profit organization founded in 1972 by a group of people interested in forest conservation. The CFIA helps the US Forest Service tell the story of forest conservation in America, and it helps people better understand both forests and the benefits of forest management. The CFIA invites everyone to visit its Forest Discovery Center in the Pisgah National Forest near Brevard, North Carolina.

Learn more about the CFIA by visiting

http://www.cradleofforestry.org

The Natural Inquirer FACELook! Review Boards



Don Slye's 7th grade class, Owen Middle School,
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