Field Investigations: Biomass Yield and Root Growth in Crops

Overview: Field investigations to strengthen student understanding of the ability of plants to sequester carbon above and below ground. Students will measure above ground biomass by harvesting small samples, and root growth using ingrown root-cores. These activities are adaptable to school-yard plots, existing agricultural plots or natural areas.

Levels
6 through undergraduate

Subjects
Science, Environmental Studies, Agriculture

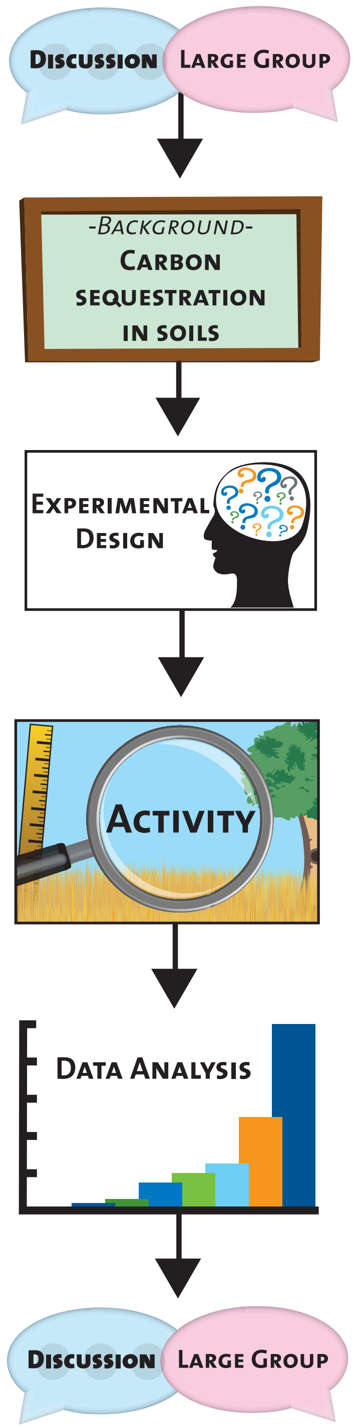
Objectives
- Design, conduct and analyze an experiment to measure primary productivity of above and below-ground biomass in a field.
- Describe the movement of carbon through a field ecosystem, focusing on above and below-ground components.
- Explain how land management practices (tilling, fertilization, etc) and different plants (prairie, grass, etc) have an effect on carbon cycling.

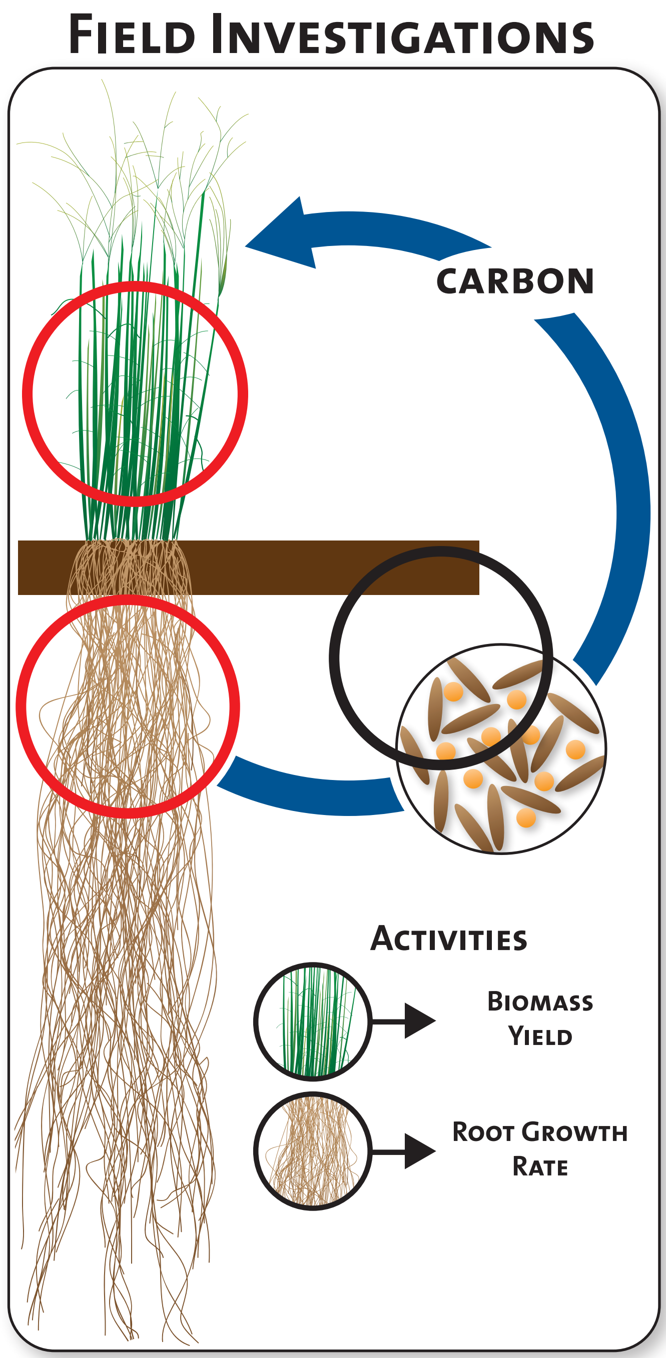
Materials
Field Investigations: Biomass Yield and Root Growth in Crops Package

Activity Time
Three 50-minute classroom period minimum plus wait time for plant growth.

Standards
Next Generation Science Standards (2013)
- Scientific and Engineering Practices: asking questions and defining problems; planning and carrying out investigations; analyzing and interpreting data; constructing explanations and designing solutions
- Disciplinary Core Ideas: ecosystems
- Crosscutting Concepts: patterns; energy and matter; structure and function
- Performance Expectations: See page 3 for details

NGSS Lead States. 2013. Next Generation Science Standards: For States by States. Washington DC: The National Academies Press





For Teachers - Field Investigations: Biomass Yield and Root Growth in Crops
in Crops

Overview:

Field investigations to strengthen student understanding of the ability of plants to sequester carbon above and below ground. Students will measure above ground biomass by harvesting small samples, and root growth using ingrown root-cores. These activities are adaptable to school-yard plots, existing agricultural plots or natural areas.

Learning Outcomes: Students will...

- Design, conduct and analyze an experiment to measure primary productivity rates above and below-ground biomass in a field.
- Describe the movement of carbon through a field ecosystem, focusing above and below-ground components.
- Explain how land management practices (tilling, fertilization, etc) and different plants (prairie, grass, etc) have an effect on carbon cycling.

Activity time is variable: Three 50-minute classroom period minimum plus wait time for plant growth.

This lesson assumes some basic knowledge of the greenhouse effect, photosynthesis, glucose transport in plants and the carbon cycle.

Standards

Next Generation Science Standards (2013)

Performance Expectations

Middle School:

- **MS-LS2-1.** Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.
- **MS-LS2-3.** Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.
- **MS-LS2-4.** Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.

High School:

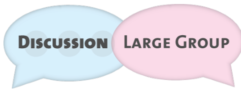
- **HS-LS2-2.** Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.
- **HS-LS2-5.** Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of cabon among the biosphere, atmosphere, hydrosyphere, and geosphere.

NGSS Standards, Continued

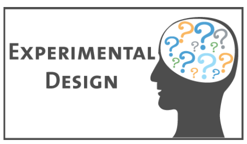
Scientific and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Asking questions and defining problems Planning and carrying out investigations Analyzing and interpreting data Constructing explanations and designing solutions	**LS2**: Ecosystems: Interactions, energy, and dynamics	Patterns Energy and matter: Flows, cycles and conservation Structure and function

See Appendix for alignment with other standards.

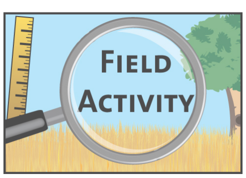
Sequence:



Part 1. Pre-Assessment & Discussion (pages 1-2) (up to one class period)
Ask students to describe the difference between burning fossil fuels and biofuels (like ethanol) as it relates to the carbon cycle. How would you measure the ability of plants to take carbon dioxide out of the air? Where does the carbon go? Is it ever returned to the atmosphere? Use the soil community food web picture included in the student activities document as a talking point, showing how plants capture energy and carbon for this diverse community.

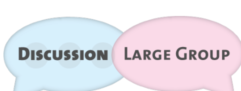


Part 2. Experimental design (pages 3-8) (up to one class period)
Decide which of the techniques you will make available to students. With planning, different class groups could conduct both activities simultaneously. However, please note that each activity requires different amounts of preparation, field time and follow-up analysis time. Hand out the corresponding *Field Instructions* page. As a class, or in groups, read through the handout and choose a question or write one to investigate. The basic procedures are described, but the class should discuss where to sample, when to sample, what to compare, number of replicates, how to collect data, and how to behave in the field to reduce disturbance. If you will be comparing results from year to year, it may be worth tracking weather patterns as well. The *Site Description* page included in this section as an option. Page 3 provides a guide for experimental design. Students should develop a hypothesis based on their understanding of how the system functions.



Part 3. Conduct experiment (varies).

Part 4. Data Analysis and Discussion (pages 9-10) (1-2 class periods)
Students pool, average and graph data. They should be asked to describe how the evidence they collected during their experiment supports or refutes their hypothesis. What have they learned from this investigation and what would they still like to know? Bring the discussion back to the idea of biofuels and the potential for crops to sequester carbon. They should be able to describe where carbon is stored in the field and how it moves from place to place. Discuss the potential of perennial crops both to provide a harvestable above-ground crop while sequestering carbon underground in the roots and potentially reducing atmospheric carbon levels.



Extensions

- Dig it! The Secrets of Soil, Greenhouse Gas Calculator (Smithsonian Museum of Natural History) *http://forces.si.edu/soils/index.html* This interactive, animated online activity puts students in the role of a farmer, deciding what crops to grow and what farming practices to use to balance high yield with lower greenhouse gas emissions.
- Build the *Root Depth Model* to show students the depth of various root system and potential for carbon sequestration.
- Follow the carbon cycle by focusing in on respiration from soil communities by conducting experiments using one or more of *Measuring Soil Microbial Activies* available from our website.

Master Materials List and Sampling Considerations:

For a class of 24 with 8 groups

Safety warning: Please use proper precautions if students will use power tools, hand tools, sharp instruments, and strong adhesives. Also, please learn if any students are allergic to bee stings as fieldwork always presents possible exposure.

Biomass Yield

- 16-24 pairs of scissors or plant shears
- Eight quadrats – 30 x 30 cm squares can be constructed with rulers (small hoola-hoops work well)
- Optional: garden gloves
- Eight pan(s) for collecting and drying
- Oven(s) for drying

Experimental Design

Root Growth Rate

Note: Teachers may wish to have one set of students construct these and put them in the ground in spring, and another set retrieve them in the fall.

Discuss with students how close together they can reasonably place corers without trampling the plants around them. Different sampling densities are often used based on vegetation growth patterns, but with a large class, reducing damage to vegetation may be the biggest consideration.

- Two #5 plastic mesh plastic canvas sheets (13 1/4" x 22" needlework mesh)
- E6000 Adhesive or similar product (available at larger craft stores)
- Eight utility knives or scissors
- Eight 2" knockout test caps (available at hardware or plumbing supply store)
- Masking Tape
- Stapler and staples
- Eight to Twenty-four sets of tweezers
- Eight-16 trays for separating root mass (baking pans will do)
- Bulb planter, 2" diameter soil probe
- Eight marker flags
- Up to 8 Shovels
- Eight rulers
- Optional: garden gloves

Answers to Discussion Questions

3. Draw a diagram which demonstrates how carbon moves through your study site. Include the plants, roots, soil organisms with linking verbs describing the processes that are occurring.

   Drawings should demonstrate photosynthesis, carbon storage in leaf, stem, and roots, leaf and root death, decomposition of matter by microbes, and plant respiration.

Experimental Design

4. Using what you have learned from your readings and evidence gained from this activity, explain why burning fuel in our cars that was made from plants might reduce greenhouse gas emissions more than burning fossil fuels. Provide one or two pieces of advice for a farmer who is trying to decide what to grow or how to grow crops to be used for biofuels if they want to reduce overall emissions from their field.

   Fossil fuels originated in the Carboniferous Period, 354 to 290 million years ago. Plants and other organisms that became coal and petroleum died and were buried over a 64 million year period. When we burn fossil fuels, we are burning ancient carbon which cannot quickly be recycled and returned to the place from which we extracted it. In contrast, plants today sequester carbon from the atmosphere through photosynthesis and when we harvest it and use it as fuel we return it to the atmosphere in a short life cycle.

   Farmers could consider planting perennial crops, which take carbon and sequester it in extensive root systems that remain underground. They can practice no-till farming, which reduces microbial activity. They may also choose not to convert established perennials or forests to annual crops; a conversion process which released a tremendous amount of greenhouse gases.

Extensions and Variations:

1. As a warm-up or follow-up activity play the Fields of Fuel video game or Bioenergy Farm board game so students can grapple with the economic-environmental tradeoffs associated with farming in a realistic multiplayer simulation.
2. Before this activity, have students read and discuss the short Science of Farming research story for an in-depth look at the scientists working on this experiment.
3. Before this activity, have students complete the Growing Energy Data Dive comparing biomass yields between different crops.
4. Use the Root Depth Model activity to help create a visual representation of the differing root depths in biofuel crops and prairie plants as well as promote disussion about plants' ability to sequester carbon and contribute to soil carbon.

Appendix:

Suggested references:

Cahill, K.N., C. J. Kucharik, et al. 2009. “Prairie restoration and carbon sequestration: difficulties quantifying C sources and sinks using a biometric approach.” Ecological Applications. 19(8): 2185-2201.

Carbon Sequestration In Soils. GLBRC. 2009. *http://www.greatlakesbioenergy.org/wp-content/uploads/2009/12/carbon_sequestration.pdf*

Dale, V., K. Kline, et al. 2010. Ecological Society of America. “Biofuels: Implications for Land Use and Biodiversity.” - This report provides a thorough scientific summary of the issues associated with biofuel crop production, and the corresponding potential changes in land-use and biodiversity. It is appropriate for high school and college students.

Fargione, J., J. Hill, et al. 2008. “Land clearing and the biofuel carbon debt.” Science 319(5867):1235-1238. - Land use for the production of biofuels can have a significant impact on global CO2 emissions and corresponding climate change. The authors of this semi-technical article describe the variation in this effect and detail a global set of biofuel production cases. Of particular interest is a bar graph of nine different biofuel/land use systems and the years needed to repay the corresponding carbon debt for their use. This article is scientifically dense and is likely best for advanced high school or undergraduate students.

Mosier, A.R., A.D. Halvorson, et al. 2005. “Measurement of Net Global Warming Potential in Three Agroecosystems.” Nutrient Cycling in Agroecosystems 72; 67-76.

Robertson, G.P., E.A. Paul, et al. 2000. “Greenhouse Gases in Intensive Agriculture: Contributions of the Individual Gases to the Radiative Forcing of the Atmosphere.” Science 289, 1922-1924.

Standards:

WI MODEL ACADEMIC STANDARDS:

E.8.4 – Using the science themes, analyze the influence living organisms have had on the Earth's systems, including their impact on the composition of the atmosphere and the weathering of rocks.
E.12.2 - Analyze the geochemical and physical cycles of the earth and use them to describe movements of matter
F.8.8 – Show through investigations how organisms both depend on and contribute to the balance or imbalance of populations and/or ecosystems, which in turn contribute to the total system of life on the planet.
C.8.3 – Design and safely conduct investigations that provide reliable quantitative or qualitative data, as appropriate, to answer their questions.

AAAS PROJECT 2061 (1993):

1B - The Nature of Science: Scientific Inquiry
5E - The Living Environment: Flow of Matter and Energy
8A - The Designed World: Agriculture
11A - Common Themes: Systems

See page 3 for Next Generation Science Standards (2013) alignment.

Field procedure developed by Jake Eaton, Madison Country Day School, Waunakee, WI, while working with Dr. Randy Jackson's field team at the University of Wisconsin - Madison. Funding and additional support provided by the Great Lakes Bioenergy Research Center.

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DOE Bioenergy Research Centers

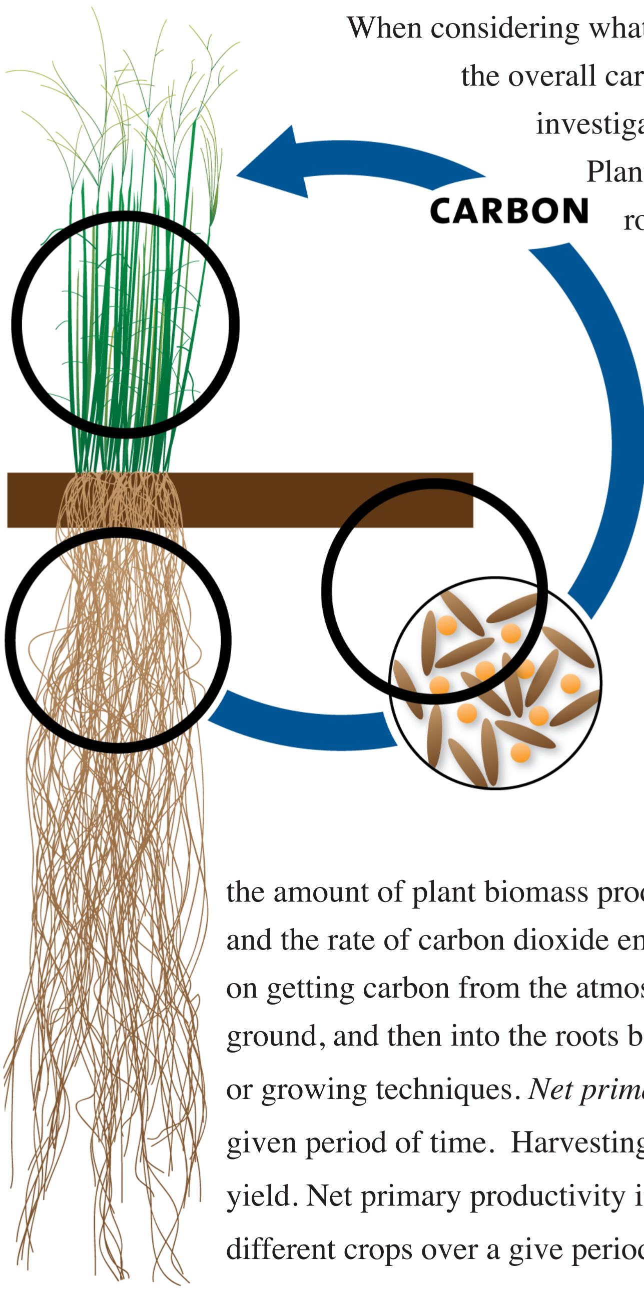
WWW.GLBRC.ORG/EDUCATION
EDUCATION@GLBRC.WISC.EDU

U.S. DEPARTMENT OF ENERGY

Name___________________________________ Date_______________ Hour_______

Field Investigations: Biomass Yield and Root Growth in Crops

Consider what you know about photosynthesis and cellular respiration. How does carbon become part of a plant? Which part of the plant? In what ways does the carbon get released from the plant? Where does it go?

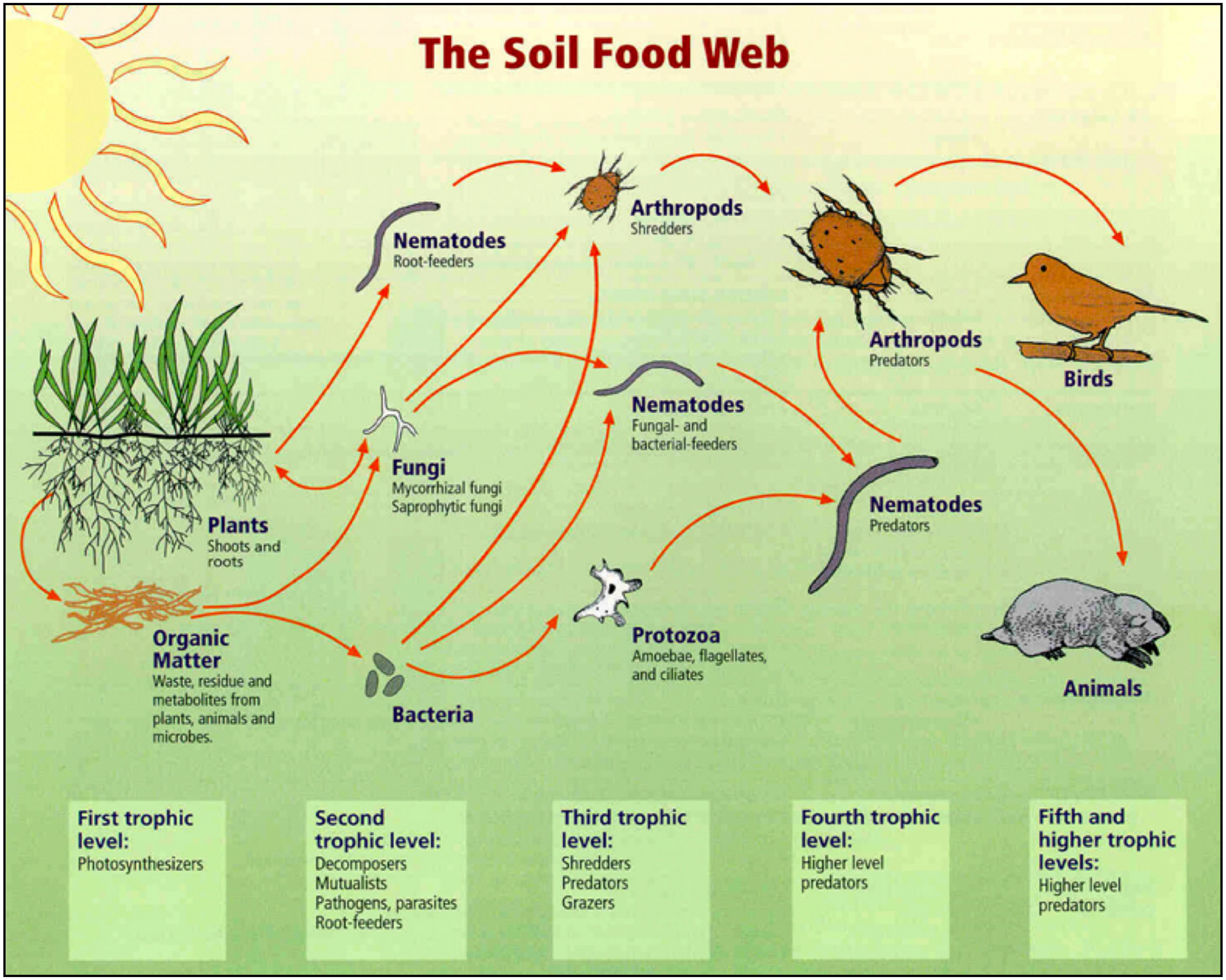


When considering what plants to grow for sustainable biofuels we must look at the overall carbon cycle of all the steps involved in production. These investigations focus in on what happens on the field and underground. Plants *sequester*, or capture, carbon in their leaves, stems and roots in a variety of molecules, including carbohydrates, which can be harvested to make biofuels. Normally, some of the plant is left behind on the field or underground after harvesting. Soil microbes may then consume those roots, or pieces of dead plants and return carbon dioxide to the atmosphere through cellular respiration. Decisions farmers make as to what to plant, how to plant and then later, how and when to harvest these crops affect soil microbial activity and decomposition rates--influencing how much and how quickly carbon from the plants is returned to the atmosphere.

When comparing potential feedstocks (crop options) and field treatments for biofuel production, scientists measure the amount of plant biomass produced above ground, the rate of root growth below ground, and the rate of carbon dioxide emissions from the soil. In this investigation we will focus on getting carbon from the atmosphere into the plant--first into the leaves and stems above-ground, and then into the roots below-ground, making comparisons between different species or growing techniques. *Net primary productivity* is useful to investigate plant growth in a given period of time. Harvesting above ground, this provides information on the potential yield. Net primary productivity in roots gives an idea of the carbon sequestration potential of different crops over a give period of time.

In this activity, you will design an experiment to measure plant growth rates in the field to gather data to help determine the best crop choice for biofuel production.

Name______________________ Date__________ Hour_______



Soil food web showing plants, organic matter, microbes, invertebrates, and birds and mammals.
Image courtesy of USDA Natural Resources Conservation Service, *http://soils.usda.gov/sqi*

How does carbon enter this system?

Name___________________________________ Date_______________ Hour_______

Experimental Design

1. What question will you investigate? Why is this of interest?

2. Which technique(s) will you use to collect data? How many replicates will you have?

3. Where will you do your sampling? (you may want to mark sites on a map) Why are you choosing those locations?

4. When will you do your sampling? Over what period of time? Why?

5. Do we need to take any precautions when walking out to or working in the sampling area? If so, please describe them and explain their necessity.

6. What is your hypothesis? Explain what you predict will occur and **why** using solid scientific reasoning.

7. Describe the type(s) of evidence you will collect and how they will be recorded. Use another piece of paper if necessary.

Name__________________________________ Date_______________ Hour_______

Site Description

Observer's name _________________________________

Site name _________________________________ Date of observation____________

Address or latitude/longitude ______________________________

Time of observation _____

Habitat description:

Type of vegetation ____ # species ____

Annual or perennial or mixed? ______________

Vegetation height ____________________

Size of habitat ______________________

Soil cover? *None* *dense vegetation* *litter cover* *other* ________________

Soil moisture *Dry* *Average* *Saturated* *other* __________________

Soil temperature __________

Site use history ____

Land management description (burned, tilled, fertilizer use, etc) ______________

____

Adjacent land use (wooded, grassland, agricultural, urban, etc) ________________

____

Weather:

Air temperature ___ Daily high/low ________

Cloud cover? *None* *mostly sunny* *mostly cloudy* *complete cover*

Wind speed _______________

Precipitation at time of sampling _________________

Precipitation in last 24 hours _________

Site map and other relevant observations:

Name___________________________________ Date_______________ Hour_______

Field Instructions: Biomass Yield

Objective
To investigate plant growth above ground in a given period of time. This provides information on the potential yield.

Sample Questions
What is the yield of a corn field compared to a prairie?
How does fertilizer affect the yield of this switchgrass?
Should perennial grasses be harvested once or twice a year to maximize yield?

Materials

- 1-2 pairs of scissors or shears
- Quadrat – 30 cm x 30 cm squares can be constructed with rulers (small hoola-hoops work well)
- Pan(s) for collecting and drying
- Oven for drying
- Optional: garden gloves

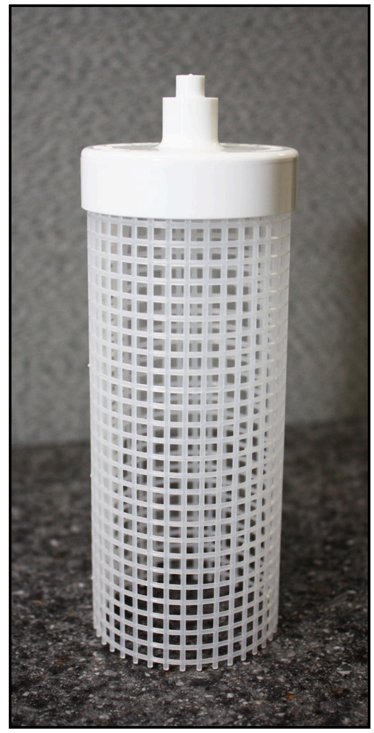
1. Locate sample field.
2. Randomly toss quadrats into field site.
3. Clip and collect all above-ground portions of plants rooted within the quadrat.
4. Dry this material in an oven for 24 hours if possible (at least overnight) at 105 ºC (225 ºF).
5. Mass the dry material the following day.
6. If an oven is not available, use a microwave to do the drying:
    a. Create a donut ring of biomass—mass starting weight.
    b. Place a glass jar half-full of water in the microwave (to protect microwave).
    c. Microwave for one minute—mass again.
    d. Repeat until mass doesn't change more than 1/10 g.
7. Average your results and compare to other fields.

Name___________________________________ Date_______________ Hour_______

Field Instructions: Root Growth Rate

Objective
To investigate root growth and carbon sequestration potential of different crops over a give period of time.

Sample Questions
How much root growth occurs over the summer in a prairie compared to an abandoned field?
Does tilling the soil allow for more root production?



Materials

- #5 plastic mesh plastic canvas sheets
- E6000 Adhesive or similar product
- Utility knife or scissors
- 2” knockout test cap
- Masking Tape
- Stapler and staples
- 1-4 pair of tweezers
- Tray(s) for separating root mass
- Bulb planter, 2” dia. soil probe or 2” dia. soil sampling tube
- Marker flags for each core
- Shovel
- Ruler
- Optional: garden gloves

Constructing the core screens

1. Cut the #5 plastic canvas to the desired height and width. The standard height of an in-growth core is 15 cm. The width is determined by the size of the knockout cap. Check to be sure the canvas rolls up (without gaps) and fits snugly in the knockout cap with ½-1 inch overlap.
2. Use this sheet as your template and cut addition pieces if you will be making more than one corer.
3. Staple the end of the core screen and glue it to the test cap with E6000 adhesive. Be sure to do this (and allow it to cure) in a well-ventilated area.
4. Staple along the long axis of the column. These staples may not stay in place well, but they will function as a semi-permanent clamp.

5. Reinforce the staples with tape on the outside of the screen if necessary to hold it together.
6. Apply adhesive along the seam in the column and allow to cure (~24 hours).
7. Place upright. Allow to dry overnight.
8. Remove the tape after the adhesive has dried and check to be sure the core screen will not easily pull apart.

Installing an in-growth root core

9. Define your study area. All cores should be dug at least one meter from the edges of plots and one meter away from other holes. Select a day to install the core screens when it has not recently rained.
10. Mark each site with a marker flag.
11. Using the long-handle bulb planter, extract a core of soil 15 cm deep. Try not to make the hole any wider than the core screen. If you dig too deep, replace some of the soil, but don't pack it down too much. Be careful to preserve the soil core you remove.
12. Working over a tray, begin to remove the roots from the soil core by carefully breaking it apart and by using the tweezers. The roots can be discarded, but save the soil.
13. Once the roots have been removed, pour the soil into the core screen. It may be helpful to work over another pan so that if soil misses the core screen, it can still be used.
14. It is okay to lightly press the soil into the screen, but pressing hard can change the consistency of the soil.
15. Place the loaded core screen into the hole you dug.
16. You may wish to create a map of your flag locations.

Removing an in-growth root core (to be completed by students)

1. At the end of the growing season or the desired interval of time, locate your flag.
2. Dig up the core using a shovel. Remove the core and some soil around it.
3. Carefully scrape off the excess soil (try not to pull exposed roots from the core) from around the core and cut the roots that are outside of the core.
4. Empty a core into the pan.
5. Separate out the roots from the soil using tweezers and by breaking the soil apart.
6. Mass the total root matter.
7. Place the roots in an oven-safe container and dry for 24 hours if possible (at least overnight) at 105 deg C (225 deg F).
8. Mass the total root matter again.
9. Average your results and compare to other fields.

Name________________________________ Date______________ Hour_______

Data Analysis and Discussion

1. After you analyze the results of your experiment as indicated by your teacher, summarize the evidence you collected in the space below and describe whether or not your hypothesis was supported.

2. Describe any unexpected events or problems that occurred that may have affected the results of your experiment. Are there any ways to avoid those issues and improve your methods?

3. Draw a diagram which demonstrates how carbon moves through your study site. Include the plants, roots, soil organisms with linking verbs describing the processes that are occurring.

4. Using what you have learned from your readings and evidence gained from this activity, explain why burning fuel in our cars that was made from plants might reduce greenhouse gas emissions more than burning fossil fuels. Provide one or two pieces of advice for a farmer who is trying to decide what to grow or how to grow crops to be used for biofuels if they want to reduce overall emissions from their field.