FIGURE SET HEADER for Set #4

Figure Set 4 homepage Carbon Sequestration in Agricultural Soils

Purpose: To teach students that degraded agricultural soils can sequester carbon, and that there are certain management strategies that can maximize carbon storage in soil.
Teaching Approach: Paired Think Aloud
Cognitive Skills: (see Bloom's Taxonomy) — Knowledge, interpretation, synthesis
Student Assessment: Short Essay

BACKGROUND for Set #4 (back4.html)

Background

Many agricultural fields in temperate regions have been cultivated for hundreds of years. In these fields, much of the carbon stored in soil has been lost to the atmosphere due to enhanced decomposition during cultivation (See Figure Set 1). Under conventional crop management, soil carbon loss eventually levels out & remains at a steady state at approximately 50% of original carbon levels. However, certain management strategies can slowly increase soil carbon content back towards original levels, which is called soil carbon sequestration. This can occur when net primary productivity due to plant growth exceeds respiration of organic carbon by soil biota. See Schlesinger (1999 – pdf included) or Post and Kwon (2000) for more information about carbon sequestration on agricultural soils. A simple explanation of carbon sequestration can be found at the U.S. EPA website: http://www.epa.gov/sequestration/local_scale.html.

The data on soil carbon sequestration in Figure 4 were collected from a Long Term Ecological Research (LTER) Experiment at the W.K. Kellogg Biological Station in southwest Michigan. In this experiment, six ecosystems were established in 1989 and compared from 1989 to 1999 to characterize their ability to sequester carbon in the soil. These systems were compared to conventionally tilled (physically turned over) agricultural fields in which soil carbon concentrations were hypothesized to remain relatively unchanged over time. The first three ecosystems were cultivated with annual crops, in a corn-soybean-wheat rotation.

- The **"Conventional"** ecosystem received both soil tillage and pesticides to control weeds and was fertilized to maximize crop yields.
- **"Organic"** refers to an ecosystem that received no fertilizer or pesticides, but tillage was used to control weeds and legume (nitrogen fixing) cover crops were used as nitrogen fertilizer sources.
- **"No-Till"** refers to an ecosystem in which the soil was not disturbed after the start of the experiment in 1989. Instead, weeds were controlled using pesticides.

The last three agroecosystems contained perennial plants and no tillage.

- **"Alfalfa"** is a perennial nitrogen fixing plant that is grown for animal feed. Alfalfa was planted in 1989 and the above ground growth was cut and removed from the fields 3-4 times per year. Although perennial, alfalfa was replanted every 5-7 years to maintain vigorous growth, as older plants died and weeds invaded the fields.
- Successional communities are those that are left fallow and receive no human induced disturbances. **"Early Successional"** ecosystems were last tilled in 1988, but were then

left undisturbed, except for occasional burning to prevent trees from growing in the experimental plots.

- **"Poplar trees"** were first planted in 1989, and were harvested after 10 years of growth. Trees were cut and used as biofuel for electricity generation. After harvest, the trees re-sprouted and will be harvested a second time for the same purposes.

FIGURES for Set #4 – (figure4.html)

Figure

Figure 4 CO_2 Sequestration

Legend

Figure 4. Soil organic carbon (SOC) levels in 1999 (kilograms per square meter) are shown for six experimental ecosystems in a long-term ecological research (LTER) experiment in southwest Michigan. Error bars represent standard error. Each Ecosystem Management treatment was initiated in 1989 and was replicated six times on randomly selected one hectare plots. The dashed line indicates average SOC for all treatments in 1989, when all treatments had similar SOC levels. Prior to 1989, the entire experimental area was farmed uniformly, where corn, soybeans and alfalfa were grown. Annual crops were harvested for agricultural production, alfalfa and poplar trees were harvested for biomass and the early successional community was left undisturbed, except for occasional spring burning to prevent colonization of tree species. Data to create Figure 4 was taken from Table 1 in Robertson et al. (2000), which is published in the journal '*Science*.'

STUDENT INSTRUCTIONS for Set #4

- Which experimental ecosystems appear to have had the lowest soil carbon content in 1999?
- Why might some agricultural practices (such as growing perennial plants) be more effective at sequestering carbon in the soil? To address this question, consider various sources of carbon to the soil
- Did any agroecosystems decline in soil carbon content from 1989 to 1999?
- What is the best management strategy to build soil organic matter among annual agroecosystems (conventional, no-till, organic)?
- In addition to removing carbon dioxide from the atmosphere, what benefits do you think a farmer might gain from having higher organic matter content in his/her soil?

NOTES TO FACULTY for Set #4 (faculty4.html)

Faculty Notes

The suggested student active approach for Figure Set 4 is "Paired Think Aloud." This approach is designed to allow students that are shy to present their opinion to another student, without having to talk immediately in front of the whole class. Students work on the questions in pairs. We suggest that the older student answers the question while the younger student records the answers. The younger student may then present the answer to the larger group. You may choose another strategy for assigning the students to be talkers or recorders, such as using the last digit of a phone number.

Familiarize yourself with each of the six agroecosystems in Figure 4. Photos from the agroecosystems can be found at www.lter.kbs.msu.edu/photo_gallery/overview.php. Robertson et al. (2000) found that early successional plots dominated by herbaceous perennial plants (grasses, forbs, legumes) exhibited significant increases in soil organic carbon from 1989 to 1999, and sequestered the most carbon (>200 g CO_2 m^{-2} $year^{-1}$) when established on previously cultivated soils from (Tables 1 and 2 in Robertson et al. 2000). Alfalfa and poplar trees, both perennial crops, also sequestered substantial amounts of carbon in soil during this time period. Several factors contributed to carbon sequestration by perennial cropping systems, including year round plant cover and root growth / turnover, high root productivity, and no soil tillage, which enhances decomposition.

Among annually cropped fields, no-till strategies were the most effective at sequestering soil carbon. Much of the plant residue from these fields was left on the soil surface after harvest, and decomposed slower than the residue in the tilled plots (conventional and organic). Cover crops were grown during the winter in organic plots, thus continuing plant growth across the entire season and building soil carbon whereas conventional plots did not utilize cover crops. Nitrogen fertilizer was also applied in conventional plots, which has been shown to accelerate rates of decomposition within the light soil carbon fraction (decadal turnover time) (Neff et al. 2002).

In general, perennial crops sequestered more carbon in soil than annual crops. No-till strategies were the most effective at increasing soil carbon in annually planted plots, and no agroecosystems exhibited further decline in soil carbon. Students are asked what benefits a farmer might gain from having increased soil organic matter. These benefits can be increased nutrient supply from the soil, increased water holding capacity, reduced risk of erosion, pH buffering capacity and potentially reduced risk of soil pathogen outbreaks. Other answers not mentioned here may also be correct.

Agricultural researchers debate whether raising a productive agricultural crop, such as corn, for many years in a row can increase soil organic carbon levels. The answer to this question likely varies depending on climate and management conditions, but it may be an interesting question to bring up with your students. Perhaps consider the question of whether or not continuous corn cropping can build organic matter in conventional vs. no-till managed fields.

The short essay assessment below asks students to consider why ecosystems with perennial crops exhibit higher rates of carbon sequestration rates in soil than ecosystems where annual crops are grown. They could list several reasons for this, and it is your discretion to determine if an answer is satisfactory. Students could provide answers that include deep root systems of perennial plants, lack of soil tillage, plant cover during winter months, cooler soil temperatures in summer due to plants covering the soil, etc.. to explain the differences between annual and perennial dominated ecosystems.

Post Lesson Assessment – Short Essay (100 – 200 Words):

Why do agroecosystems with perennial crops (alfalfa, successional, poplar trees) build soil carbon faster than agroecosystems containing annual crops (conventional, no-till, organic)? Consider what you know about perennial and annual plants and the ways they are managed to develop your answer.