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Our first article is by Dr. Paul Weihe, Department of Biology and Environmental Science, Davis and Elkins College, in Elkins, West Virginia. Dr. Weihe has developed an undergraduate laboratory exercise designed to scale down the concept of global atmospheric buildup of carbon dioxide to a more comprehensible package using a tree and an automobile. His laboratory exercise requires students to take measurements, make observations, perform calculations, create written assignments, and participate in discussions. All relating to two things we know (and love) . . . cars and trees. Enjoy.—Ed.

TREE MEASUREMENT AND CARBON CYCLING: A LABORATORY EXERCISE

Introduction

Most ecologists would agree that the buildup of carbon dioxide in Earth's atmosphere is among the most pressing of environmental issues. The importance of greenhouse gases buildup and potential global climate change is evidenced by the activity of ecologists and environmental scientists working on the topic. The 1996 ESA meeting in Providence featured seven sessions or symposia devoted to the issue, and many more papers and posters in other sessions. Likewise, a key word search of *Biological Abstracts* from January 1990 through June 1996 yielded over 1000 titles on the topic.

I have developed a laboratory exercise to introduce this important concept to undergraduate science majors enrolled in introductory biology, ecology, or environmental science classes. In the exercise, biogeochemical cycling of carbon in the atmosphere is reduced in scope to an easily understood microcosm scale. A "mass balance" approach is used, in which the carbon content of a single tree is estimated, and compared to the carbon content of exhaust emissions from a single automobile. Most students (already familiar with both cars and trees) had little difficulty extrapolating to carbon cycling on a much larger scale, at least conceptually.

The general public has been sensitized to these issues, so students bring an interest and some background knowledge with them to the exercise. Most textbooks in introductory biology, ecology, or environmental science present an overview of global climate issues and their relation to carbon biogeochemistry. For more information, see recent review articles on greenhouse gases and global warming by Patterson (1995), Loaiciga et al. (1996), and Markham (1996).

In addition to an exploration of carbon cycling, the laboratory exercise provides an opportunity to integrate skills in chemical stoichiometry; measurements of the overall dimensions of a tree; and simple data manipulation. The activities could be easily expanded to include calculations of variation between estimates and other statistical analyses, or tree coring.

Methods

The introduction to the laboratory (presented to students orally at the beginning of the exercise and/or in writing) concerns the nature of carbon fixation (storage) in wood during photosynthesis, and carbon oxidation (release) during combustion of fossil fuels and other organic compounds; the chemical reactions are presented. The exercise consists of four activities:

1) Estimation of wood volume.

2) Calculation of tree carbon content.

3) Estimation of carbon in exhaust emissions.

4) Comparison of carbon sequestration during tree growth and carbon additions to the atmosphere during combustion.

We completed the first three activities in class. Students made comparisons and analyzed data individually.

1) Estimation of wood volume. We measured a sugar maple tree (*Acer saccharum* Marsh.); however, the constants provided in Part 2 could be adjusted for use with other tree species. The dimensions of the trunk and limbs were measured separately, then summed to obtain "total" wood volume. I didn't mention rootstock to the students, allowing them to think of it (or not) themselves.

The trunk volume was approximated as the volume of a cylinder, i.e. the area of the base multiplied by the height of the cylinder. First, using a pocket transit and a tape measure, the height of the tree trunk was estimated. (A transit with tripod would be easier and more accurate; however, a homemade transit such as a piece of board cut into a right triangle with known angles would also work.) The transit or triangle template must be held level to the ground; this is facilitated by pairing students, one sighting the tree and the other advising as to any deviation of the transit from level.

The basal area was approximated by using diameter at breast height (dbh). Knowing both trunk height and dbh, trunk volume is given by the formula:

$$V = (\text{dbh}/2)^2 \times \pi \times \text{height}$$

We visually estimated branch dimensions, disregarding small branches (< 5 cm diameter) and taking weighted averages of diameter and length along each limb. Alternate approaches might be to estimate using densiometers, or copies of a photograph of the tree.

2) Tree carbon content. I estimated a value for the constant of carbon mass per unit volume of wood: 249 kg C/m^3 wood. This figure is derived using mean sugar maple wood density, and the molecular formula for cellulose. Using that constant, the carbon content of the tree was obtained:

(__ m^3 tree volume) × 249 kg C/m^3
= __ kg C in tree

Note that this carbon was stored over the entire life of the tree. The age of the tree must be estimated to determine an assimilation *rate* to compare with the automobile's emission rate. Tree age can be determined by coring (by the students or the instructor), or a reasonable estimate can be approximated if the land use history of the locale is known.

3) Carbon produced by gasoline combustion. As an estimate of a person's "typical" contribution of carbon dioxide to the atmosphere in automobile exhaust, we used the contribution of the Weihe family car (a Ford Escort). Since its purchase 7 years ago, it has produced an average *per year* of 85.4 kg C (mostly as carbon dioxide) in exhaust. (*Note*: the exact amount of emissions depends on the type of fuel and the engine. I assumed an average of 89 octane, and 100% combustion; see Appendix for further explanation). The students use this figure in their analysis and report. In an Environmental Science class, however, it may be interesting to have the students individually determine their own gasoline consumption and exhaust emissions.

Discussion

In the most simplified form (all constants and equations clearly laid out with blanks for the relevant measurements), this exercise worked very effectively with first-year undergraduate science majors. In an expanded form with students deriving formulas and performing simple statistics, this laboratory would be appropriate for more advanced students.

As a follow-up to the exercise, I required students to prepare a formal laboratory report using accepted scientific writing style and citing relevant references. In their discussion sections, I asked them to consider the accuracy and precision of our measurements and estimates, and to recognize potential sources of error. They were also asked to comment on the validity of the underlying assumptions.

In the laboratory exercise, I mentioned that afforestation (tree planting) has been proposed as a method of reducing carbon dioxide levels in the atmosphere. Students were asked to comment on this strategy, and propose alternative measures that could be taken instead. Most correctly assessed that the additional carbon uptake resulting from tree planting would not compensate for the carbon dioxide being emitted to the atmosphere. Most published estimates predict a doubling of CO_2 as a result of anthropogenic activities.

Of course, the permanence of carbon storage during tree growth is another point for discussion. We didn't consider carbon storage in leaves, since ostensibly much of that carbon is returned to the atmosphere during litter decomposition. Even woody carbon may be returned to the atmosphere in a few years, depending on the fate of the tree.

Literature cited

Loaiciga, H. A., J. B. Valdes, R. Vogel, J. Garvey, and H. Schwarz. 1996. Global warming and the hydrologic cycle. Journal of Hydrology **174**:83–127.

Markham, A. 1996. Potential impacts of climate change on ecosystems: a review of implications for policymakers and conservation biologists. Climate Research **6**:179–191.

Patterson, D. T. 1995. Weeds in a changing climate. Weed Science **43**:685–701.

Appendix

Gasoline is a blend of several hydrocarbons, mostly heptane (C_7H_{16}) and isooctane (C_8H_{18}). The "octane rating" is an estimate of the relative amounts of these two constituents. For example, 89 octane gasoline is approximately 89% octane and 11% heptane. In my calculations, I assumed all of my gasoline consumption was 89 octane (most of it was). The 100% combustion assumption is less realistic. In fact, some of the gasoline would be unburned, and some of the unburned portion would be trapped in the catalytic converter. An estimate of unburned hydrocarbon (HC) emissions is reported in the results of standard auto emissions tests.

The carbon emissions of a given automobile can be estimated by using the following formula:

(__ L gasoline consumed) ×
(49.3 g C/L gasoline) = __ g C

(assuming 89 octane gasoline and 100% combustion). To convert gallons to liters, multiply by 3.785.

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