FIGURE SET HEADER for Set #3

Figure Set 3: Nitrogen Fertilizers Increase Nitrous Oxide Emissions

Purpose: To teach students that nitrous oxide is a very important greenhouse gas produced in soil, and that excess nitrogen fertilizer results in high levels of greenhouse gas emissions.
Teaching Approach: Guided Class Discussion
Cognitive Skills: (see Bloom's Taxonomy) knowledge, interpretation, synthesis
Student Assessment: Short Essay

BACKGROUND for Set #3 (back3.html)

Background

Although the cumulative radiative forcing estimates for nitrous oxide (N_2O) are lower than either carbon dioxide or methane, N_2
atmosphere. Per unit mass, the radiative effectiveness of N_2O is 298 times more than carbon dioxide, making each kilogram of N_2O 298 times more relevant. The Intergovernmental Panel on Climate Change (IPCC) reported in 2007 that N_2O has increased by 10% since pre-industrial time periods, but lasts in the atmosphere for approximately 114 years. In soil, bacteria produce N_2O during the processes of nitrification and denitrification. During nitrification, ammonium is converted to nitrate, and N_2O is a byproduct. Denitrification, the reduction of nitrate to nitrogen gas (N_2), is an anaerobic process. Nitrous oxide is an intermediate product for many denitrifyers but can be the end product for some denitrifying bacteria (Robertson and Grace 2004). More information about nitrous oxide can be found on the U.S. EPA website: http://www.epa.gov/nitrousoxide/index.html.

Nitrous oxide is an important greenhouse gas because of its high relative radiative effectiveness. Two factors influence relative radiative effectiveness, which are physical chemistry (including radiation absorption properties) and lifetime of a molecule in the atmosphere. Physical chemistry of a molecule determines the infrared (IR) wavelength absorbed. Gases with absorption bands in the non-visible portion of the IR spectrum, particularly between 1,000-1,200 wavenumbers, have the highest radiative forcing effect. Carbon dioxide absorption peaks occur at 2350 and 650 wavenumbers while nitrous oxide absorption peaks occur at 2,200 and 1,250 wavenumbers.

Agricultural soils high in available nitrogen are a major contributor of N_2O to the atmosphere. Reactive (biologically available) nitrogen in the biosphere is twice as high as pre-industrial times, largely due to agricultural practices of fertilization and increased growth of nitrogen fixing crops (Vitousek et al. 1997). A good general source about human alteration of the global nitrogen cycle can be found on the Ecological Society of America website: http://www.esa.org/science_resources/issues.php.

FIGURES for Set #3 (figure3.html)

Table

	Carbon Dioxide (CO_2)	N_2O
Atmospheric concentration	(ppm)*	(ppm)
Pre-industrial	280	0.29
Present (2005)	379	0.32
% Increase	36%	10%
Atmospheric lifetime (years)	50-200	114
Relative radiative effectiveness		
Per unit mass over 100 years	1	298

* ppm: parts per million

Legend

Table 3a. This table was constructed using data from the Intergovernmental Panel on Climate Change (IPCC) report in 2007. Information is shown regarding two important greenhouse gases, Carbon Dioxide (CO_2) and Nitrous Oxide (N_2O). Atmospheric concentration data are reported as parts per million (ppm) in the atmosphere, while the % increase indicates the change in ppm for each gas between pre-industrial and present time points. Table created using data from the Intergovernmental Panel on Climate Change Fourth Assessment Report (2007).

Figure

Figure 3a N Fertilizer Crop Yields

Legend

Figure 3a. Corn yields were measured in six replicate fields across a gradient of nitrogen fertilize rates at the W.K. Kellogg Biological Station in SW Michigan from 2001 2003. Solid

ha^{-1} -axis label indicates kilograms of nitrogen fertilizer applied per hectare (one hectare $^{-1}$ -axis label indicates metric tons of grain produced per hectare (one metric ton is 1,000 kilograms). This figure was taken directly from F *Global Change Biology*

Figure

Figure 3b N Fertilizer Nitrous Oxide

Legend

Figure 3b. Nitrous oxide (N_2O) emissions from soil were measured in six replicate corn fields across a gradient of nitrogen fertilizer rates at the W.K. Kellogg Biological Station in SW Michigan from 2001 2003. Nitrous oxide was measured by placing closed chambers over the soil and monitoring the rate of change in N_2O in the chambers over time as it was released from the soil. Error bars represent standard error. This figure was taken directly from Figure 1 in *Global Change Biology*

STUDENT INSTRUCTIONS for Set #3 (students3.html)

Student Instructions

Part 1

There are several gases produced by human activities that contribute to climate change. Carbon dioxide (CO_2) receives the most attention in the media, but other gases are also very important contributors to climate change by trappi $_2$O) is considered to be one of the other important greenhouse gases, as human activities have increased its concentration in the atmosphere since pre-industrial time periods.

Examine Table 3a, which provides data from the Intergovernmental Panel on Climate Change (IPCC) 2007 report. Think about what the data mean and make sure you understand all of the terms. Ask your instructor if you are unfamiliar with any of the terms. After interpreting Table 3a, consider the following questions.

- Is there more carbon dioxide or nitrous oxide in the atmosphere?
- Which of the two gases (CO_2 or N_2O) has had larger increases in the atmosphere since pre-industrial times?
- In your own words, what do you think relative radiative effectiveness means?.
- Why do you think scientists pay attention to relative radiative effectiveness?
- The concentration of carbon dioxide in the atmosphere is more than 1,000 times higher than nitrous oxide. Why is nitrous oxide considered to be an important greenhouse gas?
- Why might nitrous oxide have a higher relative radiative effectiveness than carbon dioxide?

Part 2

It has been estimated that 50% of human induced nitrous oxide (N_2O) emissions are produced in agricultural soils (IPCC 2001). Nitrogen fertilizers applied to soil increase plant growth and food production, but plants are not the only organisms that use the nitrogen. Soil microorganisms also use nitrogen for growth and energy. Specifically, certain bacteria are involved in the process of nitrification and denitrification, and nitrous oxide is a minor product in both of these reactions.

Figure 3a and 3b show data of N_2O emissions and corn crop yields in a study conducted in corn fields of southwest Michigan. The researchers measured N_2O emissions from soil, but also measured corn crop yields.

Interpret Figure 3a and 3b for a moment on your own. Ask your instructor to describe anything that you do not understand. After examining the figure, consider the following questions.

- Using Figure 3a, do corn yields increase linearly with increasing nitrogen fertilizer rates?
- Using Figure 3b, what happens, in terms of N_2O emissions when a farmer applies more fertilizer than needed for maximum crop growth (more than 101 kg in this study)?
- Do you think that 101 kg of nitrogen fertilizer enough to maximize crop growth in all fields or for all crops?
- Why might a farmer apply more than enough nitrogen fertilizer?

- Corn crops are being grown to produce biofuel (ethanol) for fueling vehicles. This practice is intended to reduce greenhouse gas emissions because less fossil fuel is being used to power vehicles. Based on the data in Figure 3, how might the strategy of growing re?

NOTES TO FACULTY for Set #3 (faculty3.html)

Faculty Notes

In this guided class discussion, the suggested strategy is to show Table 3a to your students, have them interpret the table on their own for a moment, and then discuss the Table as a class using the questions listed in the student instructions as prompts. Instead of asking for a show of hands to answer questions, call on randomly selected students to ensure participation by the entire class. Repeat the same strategy for Figure 3.

Part 1

Stu

unit-less measure that compares the heat trapping potential of a molecule of different greenhouse gases to a molecule of carbon dioxide, where a molecule of carbon dioxide is set as the baseline. Greenhouse gases are also compared on a volume basis. There are several natural and anthropogenic sources of N_2O, which are listed in Table 3b, which is included for faculty reference. Management practices on agricultural soils are the single largest category in terms of N_2O emissions, contributing 3.3 Tg N_2O-N per year.

Table:

Nitrous Oxide Sources	Tg N_2O N per Year
Ocean	3.0
Tropical	
Wet Forests	3.0
Dry Savannas	1.0
Temperate	
Forests	1.0
Grasslands	1.0
Agricultural Soils	3.3
Biomass Burning	0.5
Industrial	1.3
Feedlots	2.1
Total	16.2

Tg = teragrams (10^{12} grams)

Legend

Table 3b. Global nitrous oxide budget based on calculations in 1997. Data are from the Intergovernmental Panel on Climate Change (IPCC) 1997 report.

Part 2

Students may have trouble answering the last question because it is designed to make them think through the problem. Guide them through the question to help them realize that nitrous oxide emissions may be very high during corn crop production, thus off-setting the climate benefits of growing corn as a biofuel. As stated in the background material, a good general source about human alteration of the global nitrogen cycle can be found on the Ecological Society of America website: http://www.esa.org/science_resources/issues.php.

Nitrous oxide is a kind of by-product of both nitrification and denitrification. Sometimes denitrification does not go all the way to nitrate, with nitrous oxide as the end product instead. The equations for nitrification and denitrification are listed below. The terminology here is very confusing, largely because the terms (e.g. nitrification) do not have an obvious meaning; therefore you need to decide what information you want students to remember, because the details can be overwhelming.

respiration and nitrate is used instead of oxygen. It may be wise not to tell students this level of detail, but it is good for you to recognize these differences.

McSwiney and Robertson (2005) found that N_2O emissions did not increase linearly with

$_2$O

emissions. Nitrogen is a limiting nutrient for corn crop growth, but the application of nitrogen fertilizer can saturate the supply of nitrogen. Above 101 kg N per hectare, corn crops no longer responded with larger yields, and the supply of nitrogen in the soil was larger than the demand by the corn crops. Excess nitrogen in the soil resulted in much higher rates of N_2O production via the nitrification and denitrification processes. Previous studies (Bouwman 1996) had estimated a linear relationship between N_2O emissions and nitrogen fertilizer rates (see student assessment).

There appears to be a threshold where crop yields level off above 101 kg N per hectare while N_2O emissions increase dramatically. Nitrous oxide emissions were particularly high at 134 kg N per hectare, which cannot be directly explained. It could be due to experimental error, which would be unlikely due to randomization in the experimental design and multiple years of data collection. The authors of Figure 3b suggest a potential change in the microbial process by which N_2O is produced, or that another N sink (luxury plant uptake, microbial immobilization) could be competing for nitrogen at the higher N rates. This may be a good discussion point for the class asking them why N_2O emissions were so much higher at 134 kg N than 168 and 202 kg N per hectare.

The assessment below is a short essay that requires students to describe the relationship between nitrogen fertilizer rates and nitrous oxide emissions. A linear equation does not appear to fit the data well, as nitrous oxide emissions are variable and quite high above fertilizer rates of 101 kg ha^{-1}. Students need to understand the equation for a linear model in order to answer the question completely. Introductory students may need some guidance to answer the question, but should be able to provide an answer using basic algebra and geometry.

Post Lesson Assessment – Short Essay (100 – 200 words):
An article published in 1996 provides an equation for estimating nitrous oxide emissions from agricultural fields based on the amount of fertilizer applied (Bouwman 1996). The equation that they use to calculate nitrous oxide emissions is: **E = 1 + 1.25F** (E = kg nitrous oxide per hectare, F = kg nitrogen fertilizer per hectare).

Would this equation (E = 1 + 1.25F) accurately estimate the amount of nitrous oxide emitted from the fields that were studied to generate the data in Figure 3? Why or why not?