PROFESSIONAL DEVELOPMENT

AP® Environmental Science

Agriculture and the Nitrogen Cycle

Curriculum Module

The College Board

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Equity and Access Policy

The College Board strongly encourages educators to make equitable access a guiding principle for their AP programs by giving all willing and academically prepared students the opportunity to participate in AP. We encourage the elimination of barriers that restrict access to AP for students from ethnic, racial and socioeconomic groups that have been traditionally underserved. Schools should make every effort to ensure their AP classes reflect the diversity of their student population. The College Board also believes that all students should have access to academically challenging course work before they enroll in AP classes, which can prepare them for AP success. It is only through a commitment to equitable preparation and access that true equity and excellence can be achieved.

Introduction

Instructors face a challenge in relating the laudatory goals of producing abundant, low-cost food with preserving environmental quality. Teachers of students from rural areas may face a defensive posture as farm families (somewhat understandably) feel tremendous pressure from market forces and regulations while desiring to do a societal good and preserve a way of life. Meanwhile, students in urban areas may be uneducated, misinformed, or entirely indifferent to the topic of agriculture. Instructors further face the difficulties of an interdisciplinary topic: incorporating earth science, ecology, climate, water resources, and human health as well as the specifics of farming itself. Agriculture ultimately touches students and educators fundamentally as we meet a basic human need; instructors can capitalize on an innate interest in our own well-being, and relate Environmental Science concepts to the everyday lives of students.

This Curriculum Module presents AP® Environmental Science teachers with resources to address the common misconceptions students have regarding nitrogen in the context of agricultural practices. Students will also be introduced to nitrogen's role as a pollutant in our air and water resources. These introductory ideas will facilitate deeper conceptual understanding later in the course, in the Global Change and Pollution Units. The three lessons in this Curriculum Module, when presented in one instructional sequence, will foster a more cohesive conceptual understanding of the role of nitrogen in agricultural practices and the harmful consequences it has on aquatic ecosystems and air resources. Prior to utilizing this instructional module, AP Environmental Science teachers need to introduce their students to the intricacies of agriculture, and to how farming affects the environment. In addition, students should already have a basic understanding of biogeochemical cycles, with special emphasis on the nitrogen cycle. This Curriculum Module will demonstrate to students how agriculture has deleterious effects on soil, water, and air, partly because of the excessive use of reactive nitrogen products (such as fertilizers) and because of the large amount of nitrogen-containing wastes that are produced by livestock animals.

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Lesson One: Nitrogen Additions to Soil by Agricultural Practices

Connections to the AP® Environmental Science Course Description

The nitrogen cycle and its connections to other cycles is found in the Course Description under

II. The Living World (10–15%)
  E. Natural Biogeochemical Cycles (carbon, nitrogen, phosphorus, sulfur, water, conservation of matter)

Fertilizer use in agricultural practices is found in the Course Description under

IV. Land and Water Use (10–15%)
  A. Agriculture
    1. Feeding a growing population (human nutritional requirements; types of agriculture; Green Revolution; genetic engineering and crop production; deforestation; irrigation; sustainable agriculture)

Learning Objectives

In this lesson, students will deepen their understanding of the nitrogen cycle and its role in the ecosystem as a vital nutrient for plant growth. At the end of this lesson, students will be able to identify the physical effects of nitrogen (excess and lack of nitrogen) in soils on plant growth. Students will therefore make the connection of why nitrogen-based fertilizers are heavily used in industrial agricultural practices.

Common Misconceptions of Students

Students often have a difficult time understanding the nitrogen cycle. They typically have a vague understanding of terminology and cannot provide details of individual processes such as nitrogen fixation, nitrification, ammonification, denitrification, and assimilation. Therefore, it is even more difficult for students to make the connection of how nitrogen from agricultural practices functions as an air and water pollutant.

It is also important for students to make the broader connection that availability of the organic matter in the soil to be decomposed affects the level of nutrients accessible to plants. Students often lack the true biological understanding of why fertilizers are heavily used to support crop yield in industrial agriculture. Also, many students are unable to identify nitrogen compounds and ions by their molecular formulas. Students should be able to recognize molecular formulas of nitrogen compounds found in the nutrient cycle and discuss their origins. For example, students should recognize that NO_3^- is nitrate and it is primarily added to the soil from the decomposition of organic wastes and humus or through the oxidation of ammonia. The most important nitrogen molecules or ions students should be able to identify are the following: N_2 (nitrogen gas), NO (nitric oxide), NO_2 (nitrogen dioxide), N_2O (nitrous oxide), NH_3 (ammonia), NO_3^- (nitrate), NO_2^- (nitrite).

Background Information

Before students can understand the role nitrogen plays as a pollutant of our air and water resources, they must first fully comprehend its natural role as an ecosystem nutrient. Since the element nitrogen is essential to all living things, the nitrogen cycle is one of the most vital biogeochemical cycles. Students should know the following prior to beginning these activities:

- Nitrogen (N_2), a relatively inert gas, is the most abundant gas in the atmosphere.
- Nitrogen is an essential element for life, as it is needed in order to make important macromolecules such as amino acids, proteins, and nucleic acids.
- Although the atmosphere has a large reservoir of nitrogen gas, this nonreactive form is not readily available for use by living organisms. Therefore, nitrogen is often a limiting factor in ecosystems, as its absence limits growth in primary producers at the base of the food chain (such as plants in terrestrial ecosystems and algae in aquatic ecosystems).
- Consequently, the nitrogen cycle is vital in that it converts nitrogen from the abundant unusable nitrogen gas found in the atmosphere to the nitrate and ammonium ions in the soil that can then be readily absorbed and utilized by primary producers in the ecosystem. (http://apcentral.collegeboard.com/apc/public/repository/nitrogen-cycling-in-ecosystems.pdf)

If students do not have sufficient depth of knowledge regarding the nitrogen cycle prior to engaging in this Curriculum Module, see the AP Environmental Science Teacher Resource page on AP Central® for a document with detailed information about the nitrogen cycle as well as an accompanying review activity for students.

Activity 1: Effects of Nitrogen on Plant Growth

This activity is designed to increase student understanding of the impact of nitrogen fertilizer on plant growth. Students will select a nitrogen-containing fertilizer, create a serial dilution of that fertilizer, and measure the effects of different levels of fertilizer on plant growth. It is best to use plant seeds that grow quickly, such as Mung bean (found at local grocery or garden supply stores) or *Wisconsin FastPlants* that can be ordered from Carolina Biological Supply and Nasco. Various treatment levels of manure or synthetic fertilizers may be tested. Manure may be a good choice because it is available cheaply at most hardware stores or nurseries and would be presumed to be "natural" (and by implication, perhaps less likely to be a pollutant). Another possibility is to use common synthetic fertilizers (lawn food/turf builder, garden fertilizer), which allow a more precise quantitative comparison. The package will have a "guaranteed analysis" of the nutrient content; often the nutrient level is also prominent on the front of the package (e.g., 10-5-10 fertilizer is 10 percent nitrogen, 5 percent phosphate, and 10 percent potash).

Students will be responsible for determining the dependent variables they wish to measure during the experiment. (See Appendix A for a copy of the Student Lab Sheet and the procedures for preparing serial dilutions.) Students can use the same solutions from this lab in the eutrophication simulation in the next instructional activity, "Introduction to Nitrogen Pollution of Water by Agricultural Practices," so they should be reminded not to waste solution or discard the bottles when their plant experiment is finished. (Since both activities rely on the same fertilizer solutions, teachers may choose to run this lesson concurrently with Activity 1 "Demonstration of Eutrophication from Agricultural Runoff," from the next lesson on page 12.) Students will also be conducting nitrogen tests on the soil once the lab is concluded, so they should be reminded to not discard the soil at the conclusion of the lab.

Activity 2: Measuring Nitrogen Levels in Soil

Allowing students to test soil samples for the presence of nitrogen is a great way to physically and visually connect students to the concept of nutrient levels in soils. There are a variety of kits available to test nitrogen in soil that one can order from science supply catalogs. However, simple and inexpensive kits that allow one to test approximately 10 soil samples for nitrogen, phosphorus, potassium, and pH are also available at most local garden supply and hardware stores.

1. Once students have finished collecting all of their data and observations on fertilizers and plant growth from Activity 1, they should analyze the soil samples from each individual pot, representing all the fertilizer concentration levels tested. Students should utilize soil test kits to determine nitrogen levels. If time allows, students can compare these soil samples to previously conducted soil tests, or collect a new soil sample from the school grounds or other location to do some nitrogen level comparisons. If students collect outside samples as well, it is important that they note the condition of plants at the sampling site of where the soil samples are taken or take digital pictures. They will need to note how the concentration of nitrogen in the soil sample affects the physical characteristics of the plants. Teachers need to remind students that abiotic characteristics of the soil such as pH, nitrogen, phosphorous, and potassium levels are the key components that establish the health of vegetation.

2. Teachers can lead a post-activity discussion using the questions below. Prior to moving on to the final assessment for this lesson, it is important to identify the level of student understanding regarding the connection between nitrogen input and plant growth. The student responses to these follow-up questions, and their ability or inability to recall important information during the discussion, will give you guidance as to what concepts in this activity may need further elaboration or clarification.

The following questions can be used as an informal formative assessment to check for student understanding through a brief whole-group discussion after the activity. Alternatively, these questions can be given to students as a post-lab analysis activity. These questions will help identify any possible misconceptions that students may have about nitrogen's role in plant growth. Misconceptions should be addressed by reteaching those concepts prior to having students create any graphical analysis or written lab reports on the experiment.

Analysis Questions

1. What would be the effect on developing crops of increased nitrogen fertilizer applied to agricultural land?

2. What are all of the possible sources (both natural and unnatural) of nitrogen on agricultural land?

3. Why was it necessary in the experimental design to have some seeds germinating in water (0 percent fertilizer)?

4. If nitrogen is so important for growing plants, why did some of them die?

5. What are possible reasons why farmers would not want to put too much fertilizer on their crops?

6. Describe how the physical properties of the soil, such as water retention/

infiltration rates, may affect nutrient runoff and thus cause uneven distribution of the nitrogen. How might this cause uneven growth of plants?

Appropriate Student Responses for Analysis Questions

1. Students should make the connection that increasing nitrogen levels in soils typically increases crop yield.
2. Natural sources of nitrogen come from the microbial decomposers that break down organic matter in the soil and release nitrates and ammonia. Unnatural sources of nitrogen are synthetic nitrogen-based fertilizers or manure-based fertilizers that are applied onto agricultural fields to increase crop yield.
3. This group represents the control for the experiment and helps to validate the experiment's data regarding nitrogen's effect on plant growth.
4. Fertilizers also contain inorganic salts (mineral salts) that contain phosphates and potassium. If too much fertilizer is applied, the abundance of salt in the soil will leach out water from the root system thereby causing them to shrivel and dry out. This can lead to weak, unhealthy plants or even plant death.
5. Adding too much nitrogen-based fertilizers can cause soil acidification and reduce crop yield over time.
6. Soils that have lower water retention rates, such as sandy soils, typically do not store nutrients well and therefore they are at increased risk of nutrients being leached into moving water (runoff). This may cause an uneven distribution of nitrogen in the field, ranging from low to possibly lethal levels.

If some students seem to still have difficulty understanding the role of nitrogen on plant health, teachers can have them answer the first half of Free-Response Question 4 from the 2004 AP Environmental Science Exam (http://apcentral.collegeboard.com/apc/public/repository /ap04_frq_environ_sci_36198.pdf). Allow students to work in small groups and discuss their answers. Next, have the groups share the answers they agree on; however, only place group answers on the board if they are also found on the AP Exam Free-Response grading rubric (http://apcentral.collegeboard.com/apc/public/repository/ap04_sg_environ_scien_36981.pdf). If a group provides a potential answer that is not on the grading rubric, have the class brainstorm and provide reasons why this answer was not accepted on the AP rubric.

Formative Assessment

There are several ways teachers can assess the depth of knowledge students have gained from the activities in this lesson. For example, students can create a graphical analysis of their results from both the plant activity and the soil testing. First, they should brainstorm the most appropriate way to express their data (thinking critically about placement of independent vs. dependent variables). If possible, students should determine an LD50 for fertilizer on their seed populations. Based on students' selection of variables, teachers can determine their understanding of the concept that plant growth is dependent on nitrogen levels in soil, allowing the teacher to provide valuable written feedback to the students on their graphical analysis.

Another possible assessment for the lab activity is for students to write an abstract. The abstract should consist of the following five essential components:

- *Background* — Define important concepts, theories, or laws being examined.
- *Statement of Purpose* — What were you attempting to do in this lab?
- *Summary of Procedure* — What methods did you use to complete this investigation? This should be a summary, not a detailed procedure like the one you completed earlier.
- *Summary of Results* — What happened? Summarize observations and results of calculations and graphs.
- *Significance of Findings* — What important concepts or theories are reinforced by your results? What experimental errors or limitations might have negatively influenced your results?

Students can also write a full lab report for this lab. For tips on what should be included in a final lab report from a student, see the Environmental Literacy Council's Teacher Resource page at http://www.enviroliteracy.org/article.php/1174.html. For a sample rubric that can be used for lab reports, see Appendix B in this Curriculum Module.

If students are having trouble producing appropriate answers during the post-activity discussion, or when writing their abstracts, the instructor can further elaborate on the essential concepts from the activity by having students analyze the graph in Appendix C. Students may be asked to explain why the use of these three nutrients (nitrogen, phosphate, and potash) is monitored by the USDA. Students should explain specifically why the abundance of these nutrients in the soil is connected to overall crop yield. The goal is to have students connect their prior knowledge of the presence of decomposing organic matter in the soil with the abundance of plant nutrients such as ammonia and nitrates (nitrogen cycle). They should also see that artificially increasing these nutrients in the soil (by applying synthetic fertilizers or manure) would have a positive effect on plant growth. Students can use the data from the plant and soil lab to support these ideas during their discussion.

Lesson Two: Introduction to Nitrogen Pollution of Water by Agricultural Practices

Connections to the Course Description

Agriculture and its connections to other cycles is found in the Course Description under

IV. Land and Water Use
  Agriculture
  1. Feeding a growing population (Human nutritional requirements; types of agriculture; Green Revolution; genetic engineering and crop production; deforestation; irrigation; sustainable agriculture)

Eutrophication and its connections to other cycles is found in the Course Description under

VI. Pollution
  Pollution Types
  1. Water pollution (Types; sources, causes, and effects; cultural eutrophication; groundwater pollution; maintaining water quality; water purification; sewage treatment/septic systems; Clean Water Act and other relevant laws)

Learning Objectives

Students will understand how the Green Revolution fueled what is seen today in industrial-based agriculture. They will be able to identify the major agricultural practices that add nitrogen to the ecosystem, such as synthetic fertilizers used to increase crop yield and nitrogenous waste produced in meat production. Students should be able to explain how nutrient runoff from agricultural fields causes eutrophication in aquatic ecosystems.

Common Misconceptions from Students

Modern agriculture (as practiced in much of the developed world) is quite removed from the "bucolic countryside" stereotype held by many students. In the case of water pollution, students need to understand that farms are larger, highly specialized, and use resources and produce waste much more intensively than the small, diversified family farm of yesteryear. These modern practices result in nearly miraculous yields, which consistently produce large amounts of food for sale at a low price. This idea is extremely important for students, as they often overlook the fact that fertilizers have economic and societal benefits. However, other results of producing this large quantity of low-cost food include huge inputs of chemicals (such as nitrogen fertilizers) and concentrated waste products (such as large volumes of nutrient-rich animal waste).

Even if aware of nitrogen inputs to surface or groundwater, students will often assume these are harmless, especially compared to contamination of the environment by heavy metals, radionuclides, or complex organics. After all, fertilizer helps things grow! Of course, nitrogen is both natural and necessary, and even limiting in some cases. Nevertheless, elevated levels of nitrogen in drinking water can lead to serious human health impacts, such as serious toxicity in newborns known as methemoglobinemia (often referred to as Blue Baby Syndrome). In addition to concerns for human health, the ecological effects of eutrophication are well understood and serious, particularly in famous cases such as the "Dead Zone" in the Gulf of Mexico and in the Baltic Sea.

Background Information

Nitrogen is frequently discussed in environmental science textbooks in one or more chapters on water quality/pollution/resources. Students should be able to recall important background information regarding the Green Revolution and its role in fueling the use of nitrogen-based fertilizers. It is important for students to understand that the issues of groundwater contamination, eutrophication of surface waters, and related problems are not due solely to agricultural contributions. However, agricultural runoff and inputs to subsurface aquifers are substantial, and modern agricultural practices are a major factor. For example, between 1960 and 1990, nitrogen inputs to the Mississippi River system (and Gulf of Mexico) increased from about one million metric tons to about seven million metric tons; about 89 percent of the increase in nitrogen loading to the Gulf during that time is attributed to agriculture, according to a USGS report (Goolsby and Battaglin, 2000).

Students may well be familiar with examples of eutrophication, such as the "Dead Zone" in the Gulf of Mexico, but several points may be important to clarify or elaborate. First, in recent years areas of anoxia/hypoxia have developed near river mouths in over 400 marine systems (Biello, 2008); this is not just a problem in the Gulf of Mexico, but all over the world. Second, although other nutrients and chemicals (and also soil) may contribute to the formation of anoxic regions, these areas form primarily due to inputs of nitrogen (Brown, 2010). It is important to point out to students that this occurs because eutrophication is sensitive to nitrogen: adding the element allows algae to grow. After a luxuriant "bloom" of algal growth, the cells sink to the bottom of the water and are decomposed by microbes, using oxygen in the process. The resulting low oxygen conditions inhibit all, or nearly all, life in wide swaths of what would otherwise be diverse and productive shallow ocean areas.

Activity 1: Agricultural Inputs of Nitrogen

AP Environmental Science students should have a clear understanding of how excess nitrogen is generated by agricultural practices. The three introductory questions below are used to activate their prior knowledge on agricultural practices in order to introduce the role that nitrogen will play as a pollutant in our air and water resources due to these human activities. Teachers may choose to have students work on these questions independently or in small groups. One could also choose to assign different groups different questions and have them present their answers to the class. These questions can help bring to light any misconceptions students may have generated about agricultural practices and can guide future discussion during the next activity. Following each question are some guidelines regarding the depth at which students should be able to answer these questions.

1. **How has the Green Revolution of the late 1940s–early 1950s contributed to the nutrient loading of our aquatic ecosystems we see today?**

   Students should be able to identify how the Green Revolution of the late 1940s through early 1950s fueled the industrialization of farming practices, vastly increasing the use of fossil fuel energy required to power the large machines used on the farm as well as to produce synthetic fertilizers and pesticides. The Haber process, which converts nitrogen gas to ammonia or urea, is a form of industrial fixation of nitrogen that relies on the energy released during the combustion of fossil fuels such as coal, oil, or natural gas. Fertilizer factories produce roughly 100 million tons of nitrogen-based fertilizers each year, and an estimated two billion people depend on these plant nutrients to help grow the food they eat. However, often these nitrogen-based fertilizers make their way into aquatic ecosystems through runoff of agricultural land.

2. **Was the first Green Revolution that started in the late 1940s a success in terms of crop production?**

   U.S. farmers were producing 30 bushels of corn per acre in 1920, whereas 1999 yields averaged about 134 bushels per acre, an increase of almost 350 percent. The second Green Revolution, which started in the late 1960s, involved the development of varieties of plants via hybridization and genetic engineering to be used primarily in developing nations such as China, India, and Africa. World grain production has more than tripled due to the combined efforts of both Green Revolutions.

3. **Identify and describe the TWO main ways agriculture adds nitrogen to waterways today.**

   a. Crops are provided with synthetic fertilizers, including forms of ammonia ("anhydrous"), nitrate, urea, and others. The farmer balances cost of the fertilizer (including cost to apply) with potential benefit (increased yield). Generally, the farmer will provide the entire crop with the amount needed to maximize growth (yield) under ideal conditions. Of course, conditions are seldom ideal, or at best ideal for only a portion of the crop. The excess fertilizer often leaves the field, causing pollution to a surface or groundwater resource. According to the USDA-NRCS (2010), more than half of all croplands in the prime farm belt of the Upper Mississippi River Basin require additional conservation measures to properly control nitrogen runoff.

   b. Livestock (poultry, swine, cattle, etc.) produce large amounts of liquid and solid waste. The "manure" may be applied to crops as a fertilizer; however, this is imprecise and is not immediately available to plant roots. Therefore, such application is prone to substantial loss from the soil and subsequent pollution of waters. These losses are likely to contribute substantial amounts of nitrogen, at times in toxic concentrations and frequently at levels sufficient for eutrophication (Smith and others, 2001). The modern "factory farm" (CAFO: Concentrated Animal Feeding Operation, or feedlot) exacerbates this problem. Thousands of animals in a small space produce sufficient quantities of waste to require holding pools (lagoons), and present problems with odor, possible spills, and volumes of highly mobile nutrient-rich waste contributing to eutrophication upon disposal.

Activity 2: Demonstration of Eutrophication from Agricultural Runoff

AP Environmental Science students should be challenged to "connect the dots" between concepts and skills in different areas of the course. To reinforce prior knowledge of chemistry concepts, instructors may begin an agriculture discussion by asking students to write a chemical reaction for nitrogen oxidation on the board, or recall the importance of solubility to the delivery of nutrients to roots in the soil. This is an ideal time to review simple math calculations that may be required on the AP Environmental Science Exam. For example, basic math concepts are practiced to estimate runoff of nitrogen in a stream given a typical application rate and retention percentage. Provide these two practice problems to students to help introduce the next activity on eutrophication as well as connect prior knowledge regarding the nitrogen cycle. These simple calculation problems should help students see how nitrogen makes its way into aquatic ecosystems from agricultural fields.

Problem 1

A recommended application rate is 125 lbs. (57 kg) of N per acre (0.4 hectare) for a cornfield. One ton (2000 lbs.; 900 kg) of pig manure contains 14 lbs. (6.4 kg) of nitrogen.

a. How many tons of manure must be applied to achieve the recommended rate of nitrogen application on one acre (hectare)?

b. How much must be applied on an average 300 acre (120-hectare) corn farm?

Answers: (a) $\frac{57\text{ kg N}}{1\text{ acre}} \times \frac{1\text{ ton}}{6.4\text{ kg N}} = 8.91\text{ tons}$

(b) $\frac{8.91\text{ tons}}{1\text{ acre}} \times 300\text{ acres} = 2{,}673\text{ tons}$

Problem 2

a. If a typical acre (0.4 hectare) of corn that is receiving the recommended application rate loses 4.2 lbs. (1.9 kg) of nitrogen to runoff, what percentage of the application is lost in runoff?

b. How many tons of nitrogen will potentially become runoff from the 300-acre corn farm?

Answers: (a) $\frac{1.9\text{ kg N (lost to runoff)}}{57\text{ kg N (applied)}} \times 100 = 3.33\%$

(b) $2{,}673\text{ tons} \times 0.033 = 89.1\text{ tons of runoff}$

Demonstrating Eutrophication

Teachers can easily simulate the cultural eutrophication of surface waters with a simple demonstration in which pond water or water from a local stream is “spiked” with agricultural input. Unless the local water is unusually toxic from other chemicals, it will contain algae that will grow profusely (“bloom”) in response to the nutrient additions. The effect will typically be readily apparent as algae have rapid cell division and produce bright colors (such as blues or greens).

In this activity, students will design their own experiment in order to test how nitrogen runoff from agricultural practices impacts aquatic ecosystems. They will be utilizing the fertilizer solutions created in Activity 1 of the "Nitrogen Additions to Soil by Agricultural Practices" lesson. Students should be familiar with all of the key components of experimental design; however, the teacher may need to refresh their memory prior to the activity. It is often a good idea for them to write out their experiment for the teacher's approval prior to beginning the activity. The teacher should ensure that students include the hypothesis, materials and procedures, variables (independent and dependent), control and constants.

Examples of Possible Materials to Use

Various fertilizers (everything from manure to commercial products to ammonium nitrate could be used), pond water, empty 16 oz. water bottles (10), 2 L bottles (10), 100 mL graduated cylinders, turbidity sensor, colorimeter, dissolved oxygen kit or probeware, and spectrophotometer (optional).

Examples of Possible Data Collection

The color change could be quantified if a spectrophotometer is available to measure absorbance in the green color wavelengths. A control (pond water without added nutrient input) may also turn at least a pale green, raising interesting questions ("Does our water supply contain nutrients, too?"). If probeware is available, make daily quantitative readings of samples from each of the bottles. If a dissolved oxygen probe is available, the teacher can let the bottles continue for another month, making periodic determinations of dissolved oxygen. If probes are not available, students could test dissolved oxygen content with water test kits as well. However, since this is more time consuming, they may choose to only do this once prior to the experimental treatment and once at the end of the experiment.

At this point, it is important to determine if students have a clear understanding of what effects may occur if nitrogen runoff from agricultural settings enters into an aquatic ecosystem. Simple whole-group discussion of the post-activity questions below can provide teachers with an informal formative assessment to determine whether students are ready to move on to the next learning activity where they are asked to synthesize all the information from Lessons One and Two.

Analysis Questions

1. What are possible sources of nitrogen in bodies of water?
2. Why was it necessary in the experimental design to have some bottles using pond water without fertilizer input (0%)?
3. What happened to the dissolved oxygen concentration over time? Provide explanations for any patterns you observed.

Appropriate Student Responses for Analysis Questions

1. At this point, students should be able to identify runoff of nitrogen-based synthetic fertilizers and manure from agricultural fields as sources of nitrogen in water. They should also be able to see how overflow from waste lagoons in CAFOs can make its way to local waterways and therefore be a source of nitrogen. (Teachers can further elaborate on other sources of nitrogen, such as entering waterways, when they teach the water pollution unit.)
2. This group represents the control for the experiment and helps to validate the experiment's data regarding nitrogen's effect on stimulating algae growth and leading to eutrophication.
3. Initially, dissolved oxygen levels may increase due to the increased photosynthesis from the growing algae population. However, over time the dissolved oxygen concentration should decline. This is due to the increasing population of aerobic bacteria that is decomposing the algal bloom that formed from increased nutrient levels.

There are several options other than water-quality testing that teachers can incorporate in this lesson to reach the more visual learners in the classroom, or as a means of elaboration and reteaching of the concept for students who may need it. Teachers can access existing water-quality data through government agencies such as the EPA and use the data to help illustrate eutrophication issues, or as a comparative means, to examine the collected data on local water quality. Some localities and states may provide water-quality data on nitrogen levels and dissolved oxygen concentrations directly to the public through the Internet or published reports archived in public or academic libraries. A good clearinghouse for surface water data is the "Surf Your Watershed" website of the EPA (http://cfpub.epa.gov/surf/locate/index.cfm). Data obtained from published reports can be further processed by classes with access to appropriate technology. Instructors familiar with GIS systems may import data files and map patterns in agricultural practices versus water quality (such as nitrogen levels in a watershed). Data could be graphed using software such as a spreadsheet, and students could be asked to interpret seasonal or spatial trends in water pollutants.

Formative Assessment

Students can be challenged to see the "Big Picture" by incorporating activities that require them to synthesize information; such activities can include using various forms of "concept maps." Broadly speaking, these are tables, diagrams, or other structures students create to outline important ideas and the relationships between those ideas. These concept maps provide valuable feedback from students as to the depth of knowledge they have gained about agricultural practices and their impact, and they may also help illuminate and correct any misconceptions that may have formed during the unit. Students can be challenged to create their own concept maps. For an example of a concept map that is appropriate for this lesson, see Appendix D.

Teachers may find that some students are unable to provide detailed information on their concept maps regarding agricultural practices and its environmental impacts to aquatic systems. If this is the case, the teacher can emphasize these concepts further by asking students to provide examples of environmental, social, and economic impacts of agricultural practices on 3x5 cards, including key costs or benefits; students would arrange these on a table to illustrate the positive and negative effects of various farming methods. Students could make the cards, work (perhaps in teams) to arrange them, and present their map to the class. Key concepts may include, but are not limited to:

1. **Legumes.** Many farmers use soybeans, alfalfa, or similar crops in the Bean/Pea family to enrich the soil, "rotating" them into a field every couple of years between corn or other grain crops. Legumes feature an ecological partnership (mutualism) with nitrogen-fixing microbes located in nodules on the plant root.
2. **Synthetic fertilizers.** Provided to crop plants by the farmer, these chemicals are produced in factories and are energy-intensive to manufacture, but do increase crop yields.
3. **Organic fertilizers.** These chemicals are produced by animals, plants, or microbes rather than a chemical production factory; they generally require more time and work to use.
4. **Manure.** Animal waste can be used as a fertilizer, but it is difficult to apply as evenly and efficiently as synthetic fertilizers and is prone to runoff, which pollutes waters.
5. **Application rates.** The amount of fertilizer or other chemical to put on the crop. Balancing desire for yield, variability in crop requirements, expense to purchase and apply, and concerns about pollution all make finding the correct rate difficult.
6. **Crop yield.** How much food (grain, hay, etc.) produced in a certain field.
7. **Meat production.** Increasingly, livestock are kept in large confinements where their needs can be met efficiently, and growth maximized while controlling costs.
8. **No-till agriculture.** A method of growing crops without digging or plowing the soil. This practice minimizes soil erosion, but does require special techniques and equipment.
9. **Grass buffer strips.** Growing a narrow plot of grass to catch runoff and slow erosion in vulnerable portions of the farm fields. Larger strips protect the soil and water effectively, but require farmers to drive machinery with finesse, and obviously remove land from crop production.

10. **Retention ponds.** Holding ponds for surface or drainpipe runoff. These reduce peak flow after large rains, protect downstream areas from floods, and improve water quality.
11. **Constructed wetlands.** Shallow retention ponds that clean water of soils and agricultural chemicals and provide wildlife habitat and flood protection.

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Lesson Three: Introduction to Nitrogen Pollution of Air by Agricultural Practices

Connections to the Course Description

Nitrogen-based gases and their role as air pollutants is found in the Course Description under

VII. Global Change (10–15%)
  A. Stratospheric Ozone (Formation of stratospheric ozone; ultraviolet radiation; causes of ozone depletion; effects of ozone depletion; strategies for reducing ozone depletion; relevant laws and treaties)
  B. Global Warming (Greenhouse gases and the greenhouse effect; impacts and consequences of global warming; reducing climate change; relevant laws and treaties)

Learning Objectives

In this lesson, students will examine the effects of nitrogen from agricultural practices and its impact on the atmosphere. Students will be able to explain the similarities and differences between nitrous oxide produced from the decomposition of synthetic fertilizers versus decomposition of nitrogenous waste from feedlots, or Concentrated Animal Feeding Operations (CAFOs). At the end of this lesson, students will be able to analyze data of changes in global nitrous oxide concentrations over time and have a deeper understanding of the steps of the nitrogen cycle and its role in climate change.

Common Misconceptions from Students

Students typically have several misconceptions about the nitrogen cycle and its role in atmospheric changes. First, students must understand the chemical transformations that take place in the nitrogen cycle and the steps in which those transformations occur. Many students know the names of the steps of the cycle, but they do not understand the chemical transformations that occur in each particular step. Students also incorrectly believe that plants fix nitrogen rather than symbiotic organisms that live in the root nodules of certain plants.

Additionally, students have difficulty distinguishing the various forms of nitrogen-containing substances, confusing the molecule NO_2 (nitrogen dioxide) with the NO_2^- ion (nitrite) or the N_2O (nitrous oxide) molecule. NO and NO_2 are precursors to photochemical smog, while N_2O is a greenhouse gas and an ozone-layer depleting compound. Students need to realize that the ability of nitrous oxide to cause ozone damage is not in any way connected to the reason it contributes to global warming or climate change. Students frequently (and incorrectly) suggest that stratospheric ozone depletion is the main cause of climate change. Additionally, they have difficulty distinguishing between tropospheric ozone and stratospheric ozone.

Background Information

Most of the nitrous oxide (N_2O) is added to the troposphere through agricultural soil management practices. These practices accounted for 68 percent of all of the anthropogenic nitrous oxide added to the atmosphere in 2008 (EPA Inventory of Greenhouse Gas Emissions). Agricultural soil management practices that add nitrous oxide to the atmosphere primarily include:

- Nitrogen-based compounds, such as synthetic fertilizers (anhydrous ammonia, urea, nitrates, etc.), manure, and compost are added to crop land and pasture lands in large quantities to increase and maintain current plant yields. These nitrogen-based compounds are reduced to nitrogen gas during denitrification. During this process that yields N_2, nitrous oxide is released as an intermediate gas.
- Waste produced from high-density feedlots of animals such as cows, pigs, and poultry are decomposed by aerobic microbial activity into nitrates during the nitrification processes. The nitrates are further reduced into nitrogen gas during the denitrification process. Again, nitrous oxide is an intermediate gas released during this process.

Although nitrous oxide is commonly known as “laughing gas,” increasing concentrations of nitrous oxide in the atmosphere is no laughing matter. Nitrous oxide acts as a potent greenhouse gas in the troposphere and is converted into an ozone-depleting compound in the stratosphere.

Activity 1: Graphing Levels of Global Nitrous Oxide

1. Have the students read the "Pre-Activity Reading: Global Nitrous Oxide Levels" (Appendix E). Facilitate whole-group discussion to provide some feedback from the reading in order to determine at what level students understand the role nitrogen plays in climate change. Have a brief whole-group discussion to ensure that students have an understanding of how nitrogen compounds enter the atmosphere from both natural and anthropogenic sources.
2. Next, students need to plot the data given for global nitrous oxide concentrations. (See Appendix F.) Ensure that they leave room to extend data results to 2020. (See #2 on Analysis/Analysis Questions in Appendix F.)
3. Have students calculate the average rate of increase from 1890 to 1950 and the average rate of increase from 1950 to 2010 and compare these two rates. Using the trend line on the graph they have created, students should predict what nitrous oxide levels will be in 2020.
4. Students can form small groups and answer the analysis questions (on the handout in Appendix F) together. Allow each group to present their alternative farming method from Question 3 to the class. Challenge groups to all have different answers to this question. Guide a class discussion that allows students to provide feedback to individual groups on whether or not their ideas are realistic and sustainable alternative-farming methods.

Activity 2: Nitrogen's Transition from Soil to Air

After completing Activity 1, students should have a basic understanding that that nitrogen-based fertilizers and wastes produced in agricultural practices can become pollutants for our air resources. The next step is to facilitate students' ability to make the connection between the natural rate of denitrification in ecosystems and the unnatural excess of these gases due to agricultural practices. Have the students independently diagram the nitrogen cycle (including the chemical transformations that take place in each step), paraphrase the definitions of the following key terms, and then form small groups. Each member of the group should describe a segment of the cycle to the other members of the group. Finally, have each group identify potential stages where nitrogen-based compounds could be released into the atmosphere and become air pollutants. Some students may feel more comfortable writing a narrative summary for each step rather than diagramming the cycle. Allowing students to write out their answers instead is a simple way to differentiate this part of the activity for students.

Key Terms that Should Be Included in Student Diagrams/Narrative:
Nitrogen, Nitrification, Ammonification, Decomposer, Nitrogen Fixation, Ammonia, Decomposition, Nitrites, Nitrates, Denitrification, Assimilation

Formative Assessment

Provide each group with a handout of the "Nitrogen's Role as a Greenhouse Gas." (See Appendix G.) Teachers could have students work on and answer the questions in small groups or individually. Prior to moving on to the second part of the handout, it is beneficial to determine the depth of the students' understanding after they have completed the first set of analysis questions. One method to determine depth of student understanding at this point in the activity would be to have several students go to the board (or one member from each group if working in small groups) to solve the math problems from Analysis Question 2 (Appendix G). Students commonly struggle with basic algebraic problems, and it is best to determine if they know how to solve a rate-change problem before moving on to the next section. Have students share their answers to Analysis Question 3.

Next, students need to complete the second part of the handout, "Agricultural Practices and Climate Change." The teacher can respond to individual student's answers, or they can facilitate a whole-group discussion on the answers to the questions, thereby helping students to identify their own strengths and weaknesses on this topic.

Based on their responses, students may be in need of further development in their understanding of this topic before moving on to the summative assessment. This can be done by facilitating a whole-group discussion where students are asked to explain how nitrogen is added to both air and water resources. Based on the rate of change in nitrous oxide (N_2O) concentrations over the past 60 years, ask the students to predict when atmospheric concentrations of nitrous oxide (N_2O) will double. Students may work in teams to devise strategies for reducing the amount of nitrous oxide (N_2O) added to the atmosphere via anthropogenic sources. Teams can present their ideas to the class and receive feedback from both the teacher and the students on their presentation. Next, students can refer to the second free-response question from the 2009 AP Environmental Science Exam (http://apcentral.collegeboard.com/apc/public/repository/ap09 _frq_ environmental_science.pdf). They should answer parts (b), (c), and (d) to this question. Teachers should grade this question using the released AP Exam rubric (http://apcentral .collegeboard.com/apc/public/repository/ap09_env_sci_sgs.pdf) and provide written feedback to students as to why they did or did not earn points.

Summative Assessment

Give the students the first free-response question from the 2009 AP Environmental Science Exam (http://apcentral.collegeboard.com/apc/public/repository/ap09_frq_environmental _science.pdf). Have students create a rubric that could be used to score parts (a) and (d) for that question; remind them that the point totals from each section should sum to 10. This can be done independently or in small groups. Once finished, provide students with the actual rubric used to score the question that year (http://apcentral.collegeboard.com/apc/public/repository/ap09_env _sci_sgs.pdf). Have students compare their rubric to the actual AP rubric. For any answer they listed that did not actually appear on the AP rubric, have them do some further research to provide justifications as to why their answers were not included.

Summary

The activities in this Curriculum Module involved both descriptive and quantitative analyses of the content to help foster a conceptual understanding of nitrogen's role as an air and water pollutant generated from agricultural practices. It is vital that students understand why the addition of nitrogen to the soil helps the rapid and healthy growth of plants, thus improving the yields of crops in agricultural settings. The data from the plant experiment and soil-testing activities in Lesson One should show students that plant growth was increased in the presence of nitrogen fertilizers. These activities are used to illustrate to students why an abundance of fertilizers are used in monoculture agricultural systems in order to produce high yields to meet the needs of a growing population. This concept is vital in order for students to make the connection between nutrient runoff from agricultural land into aquatic systems and a subsequent increase in algae populations (algal bloom) leading to eutrophication.

A student-centered, inquiry-based approach is used to allow students to explore how nitrogen can affect aquatic ecosystems. This demonstration of eutrophication in Lesson Two should show students that, as nitrogen levels in water increase, so do algae populations. This in turn reduces water quality for other organisms by decreasing the available dissolved oxygen as aerobic decomposers feed on the algal bloom. Allowing students the opportunity to design and analyze their own experiment provides valuable experience in the practice of constructing explanations of phenomena based on evidence produced through scientific practices.

Learning activities in Lesson Three serves to introduce students to the idea that nitrogen from agricultural land can also make its way into our atmosphere, where it can produce negative effects on air quality, climate, and the ozone layer. These activities were designed to have students evaluate different sources of data in order to answer specific questions regarding nitrogen and our air resources. These concepts will be further developed in the course during the unit on Air Pollution and Climate Change.

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Appendix A

Nitrogen's Role in Agricultural Practices

As human populations increase, our use of technology and our impact on the physical and biological environment also increases. With the Green Revolution and the demand to feed an ever-growing human population, the amount of nitrogen fertilizer applied has doubled the natural rate at which fixed nitrogen enters the land-based nitrogen cycle. This activity will investigate the effect of varying fertilizer concentrations on plant growth.

Materials:

Various fertilizers (everything from manure to commercial products to ammonium nitrate could be used), quick-growing plant seeds, soil, six 2 L bottles, 100 mL graduated cylinders, 10 planting pots, and wide mouth funnel

Procedure

You will be setting up an experiment using a nitrogen-containing fertilizer involving serial dilutions. A serial dilution is a set of dilutions with several steps in which each step has the same dilution factor. For this lab, the dilution factor is 10, which means that each subsequent sample gets 10 times less concentrated than the previous one.

1. First set out a series of six 2 L bottles and label them 1:1, 1:10, 1:100, 1:1,000, 1:10,000, and control. Fill the bottle labeled control with distilled water.
2. Making the first solution, which is the most concentrated, will depend on whether inorganic fertilizer or manure is used. If inorganic fertilizer is used, make a heavily concentrated solution by adding the dry material (store-bought fertilizer such as Miracle Grow) to the water in the 2 L bottle. Make a 0.1 g/mL solution by adding 200 g of the dry fertilizer to the 2 L bottle and filling it up with water. If using manure, add three liters of water to a bucket of manure. After letting it sit overnight, strain two liters of the "liquid manure" into the first container. This first container should be labeled 1:1 and is your most concentrated solution.
3. Next, pour 200 mL of the first bottle (the 1:1 solution) into the second bottle (labeled 1:10) and fill the remainder with water. This is a 1 to 10 dilution, which makes the sample roughly 10 times less concentrated as the original solution.
4. Next, pour 200 mL of the solution from the second dilution bottle (the 1:10) and put it in the third bottle (labeled 1:100). This is another 1 to 10 dilution, which makes the sample roughly 10 times less concentrated as the 1:10 solution, and 100 times less concentrated as the original 1:1 solution. Continue to repeat this process until you have finished making solutions for the 1:1,000 and the 1:10,000.

5. Fill 10 planting pots with top soil (do not use potting soil since it contains added nutrients already) and plant 30 seeds of a fast-growing plant (such as Mung beans) to each pot (30 seeds is an adequate sample size to yield statistically significant results). Make sure each pot is labeled with a corresponding concentration (1:1, 1:10, 1:100, 1:1,000, 1:10,000, and control).
6. Add enough distilled water to the pot with the control seeds and the respective concentrations of fertilizer/water to the remaining experimental groups to moisten the soil. Remember, it is important that all groups receive the same volume of water or solution each time.
7. Place the pots under a growing lamp and let the plants grow for the next one to two weeks. If you do not have a grow light available, you can place the plants in the window where they all receive relatively the same intensity of sunlight. You may want to cover the plants with a clear plastic wrap the first few days to ensure the seeds do not dry out. Check daily to see if the soil is dry by inserting a sharpened pencil into the soil. If the exposed wood on the pencil has no soil attached, add the fertilizer solution (in uniform amounts) to the plants that corresponds to the dilution written on the side of the pot.
8. Your lab group should decide what dependent variables will be measured in this experiment to determine the impact of the varying fertilizer concentrations on plant growth. Once determined, this should be observed and recorded every day for the length of time determined by your teacher or your lab group.
9. Remember to keep all soil and solutions once you complete the lab, as you will be utilizing these samples later.

Appendix B

Sample Lab Rubric

	Far Below Expectations or Work Is Missing	Below Expectations	Meets Expectations	Exceeds Expectations
1. Title, Date, Student Name(s), Class Period	*Points earned = 0* The lab report fails to meet two or more of the expectations for this section.	*Points earned = 1* The lab report fails to meet one of the expectations for this section.	*Points earned = 2* 1. Title is present and is descriptive. 2. Date is recorded and accurate. 3. Student name(s) (first and last) is/are present. 4. Class Period is recorded.	
2. Abstract	*Points earned = 0* The Abstract fails to address two or more of the five expected topics. OR Abstract is missing.	*Points earned = 4* The Abstract fails to address any ONE of the five expected topics.	*Points earned = 6* The abstract addresses all FIVE of the expected topics, including 1. *Background* 2. *Statement of Purpose* 3. *Summary of Procedure* 4. *Summary of Results* 5. *Significance of Findings*	*Points earned = 7* The student demonstrates exceptional accuracy in thought while connecting the experimental results to the theories or laws being examined.
3. Procedure	*Points earned = 0* Mostly copied directly from the lab description, with little attempt at creative thought or brevity. OR Procedure is missing.	*Points earned = 2* Represents a summary of the written procedure in the lab document, but it omits important details that would be necessary to successfully repeat the lab.	*Points earned = 4* Is a brief summary of each of the steps taken in completing the lab. Summary is detailed enough to perform lab again from the description given. However, it is NOT an exhaustive description containing minute detail.	
4. Results	*Points earned = 0* The Results fail to meet two or more of the expectations for this section. OR Results section is missing.	*Points earned = 4* The Results fail to meet one of the four expectations for this section.	*Points earned = 6* 1. ALL data and observations are neatly organized and easy to interpret (tables/graphs contain descriptive titles). 2. All data is correctly labeled and represents the limits of the measuring instruments. 3. The student makes no more than 3 errors in graphing, labeling, and calculations. Axes of graphs must be labeled with the appropriate scale and dimensions. 4. At least one complete sample calculation must be shown for each type of calculation utilized.	*Points earned = 7* The student demonstrates exceptional attention to detail, neatness, and accuracy in presenting the results. This includes excellence in drawings, graphing, and in the presentation of experimental data.
5. Neatness and Organization	*Points earned = 0* The lab report fails to meet two or more of the expectations for neatness and organization.	*Points earned = 1* The lab report fails to meet one of the expectations for neatness and organization.	*Points earned = 2* 1. The lab is legibly written. 2. The lab sections are in correct order. 3. No more than five spelling/grammatical errors.	

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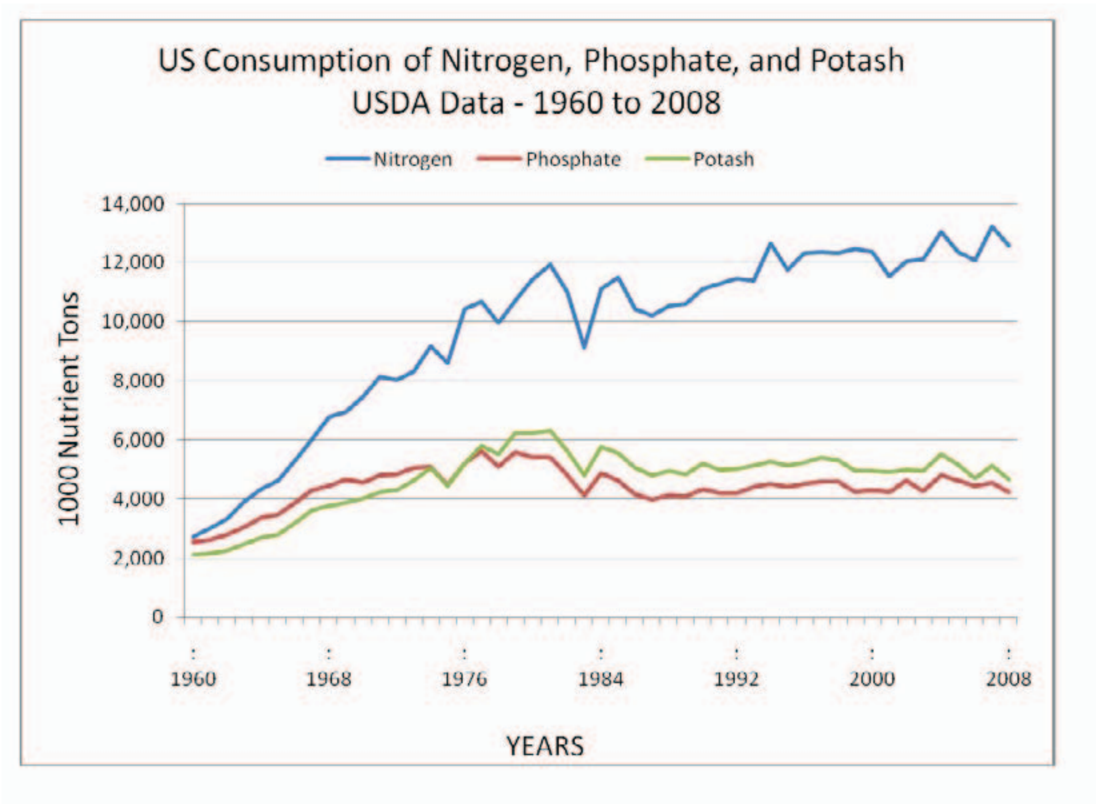
Appendix C

USDA Graph of Fertilizer Use in the United States



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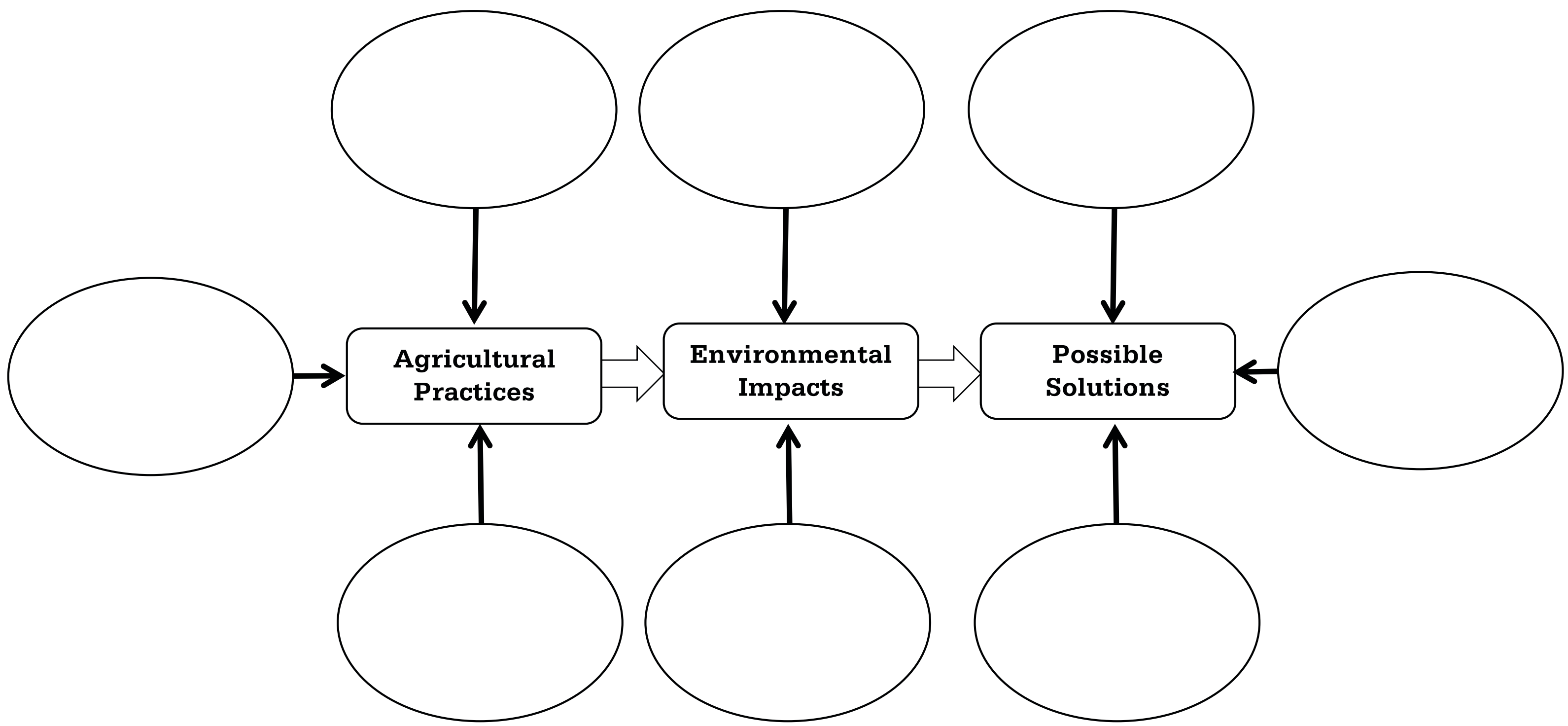
Appendix D

Concept Mapping: Agricultural Practices, Impacts, and Solutions



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Appendix E

Pre-Activity Reading: Global Nitrous Oxide Levels

From the pre-industrial era to today, the level of nitrous oxide (N_2O) in the troposphere has increased roughly 18 percent. This increase can primarily be attributed to agriculture, specifically the decomposition of both synthetically produced fertilizers and animal manure.[1] The original catalytic converters in automobiles also added nitrous oxide to the atmosphere. Nitrous oxide poses a substantial threat to climate change because it is a very long-lived greenhouse gas, having a residence time of about 120 years in the troposphere. Nitrous oxide tends to absorb wavelengths of infrared radiation not absorbed by either water or carbon dioxide molecules. It is considered one of the top three greenhouse gases with a GWP (global warming potential) of 310. By contrast, methane has a GWP of 21 and carbon dioxide of 1. It is important to note that although nitrous oxide has a much higher Global Warming Potential than CO_2, it only represents 5 percent of the total emissions of greenhouse gases versus the 80 percent that CO_2 accounts for in the troposphere. As the climate warms and the permafrost begins to melt, more nitrous oxide that was previously sequestered in the frozen soil will be released into the atmosphere.

Increased global concentrations of tropospheric N_2O have also been associated with the depletion of stratospheric ozone. Once in the stratosphere, N_2O converts into nitric oxide (NO), which can react with ozone to produce oxygen gas (or O_2) and NO_2. According to a recent study conducted by NOAA, N_2O is currently the primary ozone-depleting compound produced by human activities (or by humans) and may remain so throughout the 21st century.

While anthropogenic sources of N_2O have declined (such as mobile emissions from cars due to newer control technology), agricultural sources have continued to increase. Early in the Green Revolution, the primary consumers of synthetic fertilizers were the developed countries. However, as the developing nations progress, more and more synthetic fertilizers are being used to enhance crop yields to help feed growing populations. According to the 2008 EPA Executive Summary of greenhouse gas emissions in the United States, annual nitrous oxide emissions from agricultural fields have increased by about 6 percent since 1990, while overall anthropogenic emissions of nitrous oxide have decreased by about 1.3 percent during this same time period.[2] However, the increased reliance on biofuels, such as ethanol produced from nitrogen-hungry corn, and

1. Wuebbles, D.J. 2009. *Science* 326: 56–57.
2. "Inventory of U.S. Greenhouse Gas Emissions and Sinks." United States Environmental Protection Agency, Washington, DC: U.S. Government Printing Office. Accessed October 2010, http://epa.gov/climatechange /emissions/index.html.

the increasing production of meat could contribute to increased levels of nitrous oxide over time.

Specific limits of nitrous oxide emissions are not regulated. The United States Clean Air Act has emission regulations on NOx (NO and NO_2) but not nitrous oxide. Greenhouse gases such as carbon dioxide (CO_2) are addressed by the Kyoto Protocol in some countries but not in the United States. Ozone-depleting substances such as Freon (common examples include chlorofluorocarbons and hydrochlorofluorocarbons) and methyl bromide are addressed through the international agreement called the Montreal Protocol. However, there are no agreements, nationally or internationally, that address nitrous oxide emissions. Increasing global concentrations of nitrous oxide are of serious concern, requiring the development of strategies to control emissions.

Appendix F

Table 1: Global nitrous oxide (N_2O) concentrations (ppb) from 1890–2010.

Source: unfccc.int/resource/brazil/phase2/isam/isam_concentration_p2.doc

Year	Concentration (ppb)	Year	Concentration (ppb)
1890	266.4	1972	288.6
1895	266.9	1974	290.5
1900	267.4	1976	292.5
1905	267.9	1978	294.6
1910	268.5	1980	296.7
1915	269.1	1982	298.8
1920	269.7	1984	301.0
1925	270.4	1986	303.1
1930	271.1	1988	305.3
1935	271.9	1990	307.4
1940	272.6	1992	309.4
1945	273.8	1994	311.4
1950	275.5	1996	313.4
1955	277.6	1998	315.4
1960	279.8	2000	317.3
1962	280.9	2002	319.3
1965	282.8	2004	321.4
1966	283.5	2006	323.5
1968	285.1	2008	325.7
1970	286.8	2010	328.0

Analysis Questions:

1. Describe the overall trend in nitrous oxide emissions within this time period.
2. Discuss the factors that explain why the rates of increase of nitrous oxide concentration during the 1890 to 1950 time period is not the same as the rate of increase during the 1950 to 2010 time period.
3. Using prior knowledge of agricultural practices, discuss alternative methods for farming that could slow down the increasing emissions of nitrous oxide.

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Appendix G

Nitrogen's Role as a Greenhouse Gas

Carbon dioxide has a significant impact on climate change as anthropogenic activities that generate this gas, such as burning fuel for producing electricity and providing transportation, make up over 80 percent of the annual emissions of all greenhouse gases. However, carbon dioxide is not the only greenhouse gas of concern. Research scientists are finding more evidence each year that nitrogen also plays an increasing role in climate change. Nitrous oxide released from numerous human activities, including agriculture, can easily convert to precursors of ground-level ozone such as nitric oxide (NO) or nitrogen dioxide (NO_2), collectively known as NOx. Ground-level ozone is also a minor greenhouse gas that can potentially influence climate change. Examine the data on nitrous oxide emission trends taken from the U.S. EPA's Executive Summary of Greenhouse Gas Emissions from 2008.

Table 2: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks
(units measured in Tg CO^2 Equivalence or million metric tons CO^2 Equivalence)

Nitrous Oxide (N_20) Source	1990	1995	2000	2005
Agricultural Soil Management	203.5	205.9	210.1	215.8
Mobile Combustion	43.9	54.0	53.2	36.9
Nitric Acid Production	18.9	21.0	20.7	17.6
Manure Management	14.4	15.5	16.7	16.6
Stationary Combustion	12.8	13.3	14.5	14.7

Analysis Questions

1. Discuss what type of human activities would be included in the category "Agricultural Soil Management," "Manure Management," and "Mobile Combustion."
2. Calculate the rate of change in emissions from 1990 to 2005 for Agricultural Soil Management, Manure Management, and Mobile Combustion sources. Round your answer to the hundredths place.
3. Explain any possible causes behind the differences in rate of change and the trends in emissions you see for these categories.

Agricultural Practices and Climate Change

The increasing emission of the greenhouse gas nitrous oxide that is being released from nitrogen-based fertilizers and waste lagoons used in agricultural practices is a growing concern for many scientists. An increasing amount of fertilizers is being applied to crops to maintain and increase yield and meet the demands of a growing population. At the same time, modern livestock practices are also taking an industrial approach, as most meat producers now rely on large-scale Concentrated Animal Feeding Operations, commonly known as CAFOs. Liquid manure, called slurry, is often stored on-site in waste lagoons that commonly have no waste-treatment program or covers to prevent atmospheric leaching of methane, ammonia and nitrogen-based gases. These waste lagoons are also common sources of nutrients leaching into waterways that contaminate local aquatic ecosystem and human drinking water resources. Examine the data tables below regarding ammonia and nitrous oxide emissions produced from swine waste lagoons and monoculture corn fields.

Emission in Swine Waste Lagoons and Corn Field Crop Production

Production in the Year 2000	
Type of Gas Emission	kg N yr-1
Field NH_3	2, 860.4
Field N_2O	88.2
Lagoon NH_3	13,566.9
Lagoon N_2O	235.4

Production in the Year 2010	
Type of Gas Emission	kg N yr-1
Field NH_3	3, 181.9
Field N_2O	96.4
Lagoon NH_3	14,828.7
Lagoon N_2O	276.6

Analysis Questions

1. Explain in detail what agricultural practices and biological processes are occurring on the farm that may lead to the release of nitrogen compounds into the atmosphere.
2. Calculate the rate of change, from 2000 to 2010, in emission of nitrous oxides from the waste lagoon. Next, calculate the rate of change in nitrous oxide emission from the manure management data as provided in the Executive Summary of total U.S. nitrous oxide emissions. How do these two rates compare? Are they in the same order of magnitude? Would you have predicted these two statistics to be similar? Why or why not?
3. Identify and describe TWO other air pollutants that are formed due to activity from the farm. Remember that these emissions may be primary pollutants that lead to secondary pollutants, too.
4. Choose one of the gases you used in Analysis Question 2. Discuss what type of environmental changes could occur due to the emission of this gas.
5. Describe several alternative practices that could be implemented by the farms to reduce their contributions to air and water pollution. Be specific about the changes needed in the monoculture farm versus the CAFO.
6. Relate what the economic or social impact might be if the farms had to implement some of the alternative practices you provided in Analysis Question 5.

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CM11ENVHB18600