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.

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. (http://apcentral.collegeboard.com/apc/public/repository/nitrogen-cycling-in-ecosystems.pdf)

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. The 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.

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.	

Appendix C

USDA Graph of Fertilizer Use in the United States