Chemistry, Fertilizer, and the Environment

Grades 8-12

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California Foundation for Agriculture in the Classroom

Vision: An appreciation of agriculture by all.

Mission: To increase awareness and understanding of agriculture among California's educators and students.

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The California Foundation for Agriculture in the Classroom is dedicated to fostering a greater public knowledge of the agriculture industry. The Foundation works with K-12 teachers, community leaders, media representatives and government executives to enhance education using agricultural examples, in order to help young people acquire the knowledge needed to make informed choices.

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Introduction

This five-lesson unit for grades 8-12 uses agriculture to introduce chemistry and environmental science concepts in a way that is relevant to students' lives. Students will learn about plant nutrients, soil, chemical compounds, solutions and dilutions, and water quality as they explore different agricultural situations that farmers encounter each day in providing our food, fiber, flowers, fuel, and forest resources.

Through the *Chemistry, Fertilizer, and the Environment* unit, students will learn about the role California agriculture plays in environmental stewardship. Lessons are activity based and are aligned to California State Standards, including Common Core Standards for English Language Arts and Mathematics, and the Disciplinary Core Ideas of the Next Generation Science Standards. Standards are listed in the sidebar of each lesson and a California standards matrix, including standard descriptions for the entire unit, is located on pages 88-93.

Agriculture is an important industry in the United States, especially in California. As more rural areas become urbanized and more challenges arise to feed the people of the world, it is extremely important to educate students about their environment, agriculture, and the modern technologies that contribute to a healthy population and planet.

Unit Overview

Unit Length

Five 1–2 hours sessions

Objectives

Students will:

- Learn about solutes and solvents
- Use serial dilution and understand parts per million measurements
- Explore best practices associated with fertilizer use
- Learn about plant nutrient requirements
- Learn about the nitrogen cycle as they take on the role of a nitrogen molecule as it cycles through the environment
- Differentiate between atoms, molecules, and compounds
- Explore soil pH
- Learn how soil pH affects plant nutrient availability
- Research how soil amendments may alter pH
- Use online resources to identify crops that grow best in slightly acidic or alkaline soils
- Test soil samples for available nitrogen

Brief Description

This five-lesson unit for grades 8-12 uses agriculture to introduce students to chemistry and environmental science concepts. Activities are modeled after real-life challenges that modern farmers face while producing our food, fiber, and fuel. Labs are inquiry based and promote critical thinking skills.

It is recommended that the lessons be taught in sequence, however, lessons may be taught individually to best meet the needs of your classroom.

California Standards

This unit, *Chemistry, Fertilizer and the Environment*, includes lessons that can be used to reinforce many of the standards for California Public Schools, including Common Core State Standards, and the Disciplinary Core Ideas from the Next Generation Science Standards. The lessons encourage students to think for themselves, ask questions, and learn problem solving skills while learning concepts to better understand the agriculture industry upon which we all depend.

The specific California standards addressed are listed on the sidebars of each lesson. A matrix chart showing how the entire unit is aligned with the standards is included on pages 88-93.

Evaluations

Embedded assessment includes oral and written responses to open-ended questions, group presentations, and other knowledge application projects.

Visual Display Ideas

- Showcase agriculture careers in your local community. In addition to displaying pictures, include required skills, education level, and salary information. USDA's Living Science website offers extensive information about science-based agriculture careers: *www.agriculture.purdue.edu/usda/careers.*
- Invite a local agriculture expert to visit your classroom to show students various tools of the trade and demonstrations of their uses.

- Learn about best management practices to maximize nutrient utilization and environmental stewardship

Key Vocabulary

A glossary of terms is located on pages 94-98.

Thank you for recognizing the importance of helping students understand and appreciate agriculture. We hope you find this resource useful in your teaching endeavors.

- Take photos of student work as they carry out lab investigations. Display the photos in chronological order.

One in a Million

Purpose

In this lesson, students will learn about solutes and solvents and will use serial dilution while investigating parts per million—a term used to describe the nutrient concentration of a fertilizer solution.

Time

Teacher Preparation:
30 minutes

Student Activities:
60 minutes

Materials

For the class:

- Two 250 ml beakers
- One roll of paper towels
- Water
- One box of food coloring, exclude yellow
- Colored pencils or crayons
- Optional: Becker Bottle *(Flinn Scientific, Inc.)*

For each group:

- One white ice cube tray *(or well reaction plate with 12 wells)*
- One permanent marker
- One eye dropper
- One 1 liter beaker

Background Information

Fertilizers are used to provide nutrients that are not present in soil in amounts necessary to meet the needs of the growing crop. Plants can tolerate a wide range of watering and nutritional conditions, but for a commercial farming operation it is important to maximize production while minimizing environmental impact. Optimum watering and nutritional conditions vary depending on a variety of factors, including plant species, stage of life cycle, climate, and environmental conditions. Many growers purchase fertilizer in a concentrated solid or liquid form. The fertilizer is then mixed with water to create a fertilizer solution that can be applied to plants.

When fertilizer is applied in the field, farmers will calculate nutrient requirements in pounds per acre. However, in greenhouse production, the industry standard is parts per million. Greenhouses are often used for growing flowers, vegetables, fruits, and transplants. Greenhouses allow for greater control over the growing environment of plants. Depending upon the type of greenhouse, key factors which may be controlled include temperature, light, water, fertilizer, and atmosphere.

Proper fertilization of greenhouse plants is essential for producing a high-quality crop. Some nutrients (such as calcium and magnesium) may be mixed into the growing medium prior to planting, but most of the nutrients are applied after planting using water-soluble fertilizers. Fertilizer injectors are used by most growers to deliver fertilizer to plants. These devices "inject" a small quantity of concentrated fertilizer into the irrigation line so that the solution leaving the hose is diluted to the proper concentration. To ensure an adequate supply of the essential elements for plant growth, growers may apply water-soluble fertilizers at a dilute concentration on a "constant feed" basis (with every watering), or on a periodic basis at a higher concentration. Fertilizer injectors can be set at different ratios depending upon the needs of the plants. If the injector ratio in a greenhouse operation is 1:100, the injector delivers one gallon of fertilizer concentrate with every 99 gallons of water (one part out of 100 parts is concentrated fertilizer).

Show students a two-minute video highlighting the career of a greenhouse manager. Visit *www.youtube.com/user/utahagclassroom* and select the video titled, "Greenhouse Manager."

One in a Million

- Three small plastic cups

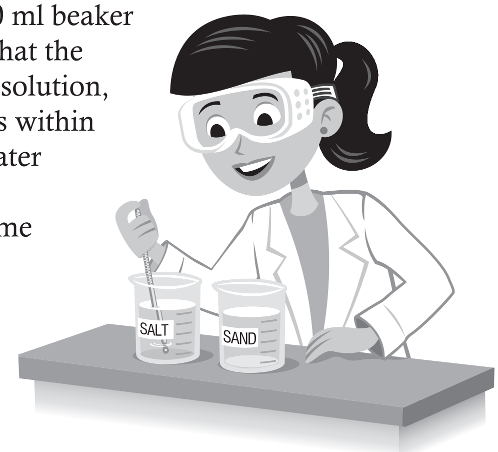
For each student:

- *One in a Million* lab worksheet (page 15)

Introduction

1. Ask the class if they have ever used a powdered concentrate to create a beverage, such as hot chocolate or fruit punch. Explain that whether they realized it or not, they were creating a mixture. A mixture is a combination of two or more different substances, which are not chemically bonded, and can be a solid, liquid, or gas. Explain that there are two types of mixtures: homogeneous (also called solutions) which are uniform and particles are not typically seen, and heterogeneous mixtures which are not uniform and in which the particles can be seen.

2. As a demonstration, add two tablespoons of salt to a 250 ml beaker of water and stir. Explain that the mixture is a homogeneous solution, meaning that the molecules within the solution, in this case water and table salt, are evenly distributed and look the same throughout.



3. Add two tablespoons of sand to a 250 ml beaker of water and stir. Have students compare and contrast the two mixtures. Ask students to describe the difference between the sand and water mixture and the salt and water mixture. Explain that the sand and water mixture is a heterogeneous mixture, meaning that the molecules will not be evenly distributed throughout the liquid.

4. Explain that in agriculture, fertilizer solutions are one way that farmers supply their crops with essential plant nutrients. In science terms, the solute is the fertilizer added to the water. The water is the solvent, which does the dissolving. The solution more or less takes on the characteristics of the solvent. The concentration of a fertilizer solution is defined by the amount of fertilizer (solute) dissolved in water (solvent).

One in a Million

California Standards

Grade 8

Common Core English Language Arts
SL.8.1b
RST.8.3
RST.8.7
RST.8.9

Next Generation Science Standards
MS-ETS1.B

Grades 9-12

Common Core English Language Arts
SL.9-12.1b
RST.9-12.3
RST.9-12.7

Common Core Mathematics
9-12.N-Q.1

Next Generation Science Standards
HS-ETS1.B

Standards descriptions are listed in the matrix on pages 88-93.

Parts Per Million

1. Ask students to raise their hands if they've ever heard the term "one in a million." Discuss what the term means and why people say it.

2. Build on the classroom discussion by explaining how unique "one in a million" really is. Show students a "One in a Million" Becker Bottle to illustrate the concept. This three liter bottle contains one million tiny colored spheres. Each colored sphere represents a different quantity, or concentration. The yellow spheres represent 100,000 in a million, the red spheres represent 10,000 in a million, the white spheres represent 1,000 in a million, the pink spheres represent 100 in a million, and the green spheres represent 10 in a million. The single black sphere in the bottle represents one in a million, or in scientific terms, one part per million. Explain that today the class is going to investigate the scientific concept of "parts per million"—a unit of measurement used to describe a very small amount of material.

3. Explain that in the scientific community, parts per million is expressed as "ppm." Parts per million is the unit of measurement commonly used to describe the nutrient concentration in a fertilizer solution. It can also be used to analyze contaminants in food, groundwater, air, and more.

4. Introduce the lab by explaining that students will use a dilution activity to create and investigate solution concentrations. Review laboratory safety instructions. Distribute and review the *One in a Million* lab worksheet. Divide the class into pairs or triads, and direct students to the necessary materials.

5. After students complete the dilution lab activity and the O*ne in a Million* lab worksheet, use a classroom discussion to debrief their findings. Discussion points may include:

   a. Good fertilizer practices that match fertilizer inputs to crop nutrient requirements will achieve high-quality, economically sustainable yields and will protect the environment. Arable land available for growing food will continue to diminish as population growth continues. Efficiently managing inputs, such as water and fertilizer, will be essential to feeding a growing population.

   b. Improperly applied fertilizer can lead to environmental problems. It is important for anyone who applies fertilizer to follow application instructions. Farmers and researchers are constantly testing and implementing new methods for high precision use of fertilizers.

c. Fertilizer is expensive. It is in the farmer's best interest to apply the correct amount of fertilizer, supplying the plants with only the nutrients they need.

Extensions

- Offer an incentive for students who locate (and show you) the black sphere in the Becker Bottle.
- Review your city's annual water quality report. All public water systems are required to sample their source water and treated water for the presence of biological, inorganic, organic, and radioactive constituents. This report typically uses parts per million and parts per billion to summarize constituent levels. Look up and define unknown terms and summarize key findings.
- One part per million is equivalent to one hole in 55,555 rounds of golf! Put a million into perspective by challenging students to use the factor-label method to convert one part per million (or one part per billion) to a number that is meaningful to them. Consider expressing the unit of measurement in seconds, miles, U.S. population, etc.

ELL Adaptations

- Create a Venn diagram to capture the differences and similarities of homogeneous and heterogeneous mixtures.
- Use an overhead projector to demonstrate complex math problems.

One in a Million Lab

Today is your first day of on the job training at Green Thumb Growers, a greenhouse operation that produces a variety of flower and vegetable seedlings to home and garden centers throughout the state. Your job involves watering plants and applying the correct amount of fertilizer solution. Your boss has given you and your coworker the *One in a Million Lab* exercise to help you understand measurements and dilution before you can begin working on your own. You have been instructed to read the directions and carry out the lab. Your boss encourages you to ask questions to clarify anything you don't understand since these types of tasks will be part of your daily work at the greenhouse.

Fertilizers are used to provide nutrients that are not present in soil (or other growing media) in amounts necessary to meet the needs of the growing crop. Fertilizers are available in several forms:

- Pre-mixed liquid concentrates that are then diluted with water
- Pre-mixed powder concentrates that are then diluted with water
- Made from "scratch." Many commercial growers buy the individual compounds and mix the nutrient solution themselves

In this example, the fertilizer concentrate is the solute and the water is the solvent. The two are mixed to create a homogeneous solution. Dilution is the process of making the solution weaker or less concentrated, and can be used to regulate the amount of nutrients applied. In this lab, we'll be diluting the original substance to a concentration of one part per million (ppm) and one part per billion (ppb).

Very small quantities of a substance can be measured in parts per million and parts per billion. The ability to measure substances in such minute amounts allows growers to strategically apply the specific nutrients a plant needs to grow. But what do parts per million and parts per billion actually mean? These are difficult numbers to comprehend. The following activity will help illustrate the terms ppm and ppb.

Procedure

1. Fill three plastic cups about half full of water. Two cups will be used for cleaning the eye dropper, and one will be used for diluting.
2. Label ice cube tray "cells" 1 to 10 with a permanent marker.
3. In cell #1, place 10 drops of food coloring. This represents a pure substance, or a concentration of 1 million parts per million.
4. Using an eye dropper, take one drop of food coloring from cell #1 and place it in cell #2. Return any excess food coloring back to cell #1.

One in a Million Lab *(continued)*

5. Rinse the dropper in one of the plastic cups to remove all traces of food coloring.
6. Add 9 drops of clean water to cell #2 and stir the solution.
7. Take one drop of the solution from cell #2 and place it in cell #3. Return any excess solution back to cell #2.
8. Rinse the dropper.
9. Add 9 drops of clean water to cell #3 and stir the solution.

Continue repeating the procedure through cell #10, taking a drop of the solution from the previous cup and adding 9 drops of water. Remember to clean the dropper thoroughly between uses.

One in a Million Data Collection

Name: ______________________________

1. Determine the concentration of the solution for each cell and record it in the data table below. Example: In cell #2, one out of 10 drops was food coloring. The concentration of food coloring is $\frac{1}{10}$ or .10, or 100,000 ppm.

Cell #	**Concentration** *(fraction and decimal)*	**ppm**	**Color** *(use colored pencils)*
1			
2	$\frac{1}{10}$ or .10	100,000	
3			
4			
5			
6			
7			
8			
9			
10			

2. Compare and contrast the solutions in each cell. In which cell is the color most intense? Why?

____

____

In this activity, what agriculture concept does the solution in the first cell represent?

____

____

3. In which cell is the color least intense? Why?

____

In this activity, what agriculture concept does the solution in the last cell represent?

____

____

One in a Million Data Collection *(continued)*

4. Carefully examine your cells. Are there any cells where the liquid is colorless? ________ Is there any food coloring in these cells? _______ How do you know? ____

____

____

5. A fertilizer solution contains 1% nitrogen and 12% calcium. Write these percentages as concentrations in ppm.

   There is a factor of 10,000 between ppm and percentage; ppm stands for parts per million, whereas percent means per hundred, and there is a factor of 10,000 between one hundred and one million. To go from ppm to percentage divide by 10,000 and from percentage to ppm multiply by 10,000. For example: 1.5% would be 1.5 x 10,000 = 15,000 ppm and 0.12% would be 0.12 x 10,000 = 1,200 ppm

____

____

6. Which cell is closest to the concentration of nitrogen? Which cell is closest to the concentration of calcium?

____

____

7. Nitrogen, phosphorus, potassium, magnesium, and calcium are essential nutrients for plant growth. Deficiencies in these nutrients can be corrected by fertilizer application. **General recommended nutrient concentrations for cucumbers are listed below.** Convert the ppm concentrations to ppb. Which of your cells of food coloring is closest in concentration to each fertilizer concentration?

Nutrient	Concentration	Cell Number
Nitrogen (N)	230 ppm = ppb	
Phosphorus (P)	40 ppm = ppb	
Potassium (K)	315 ppm = ppb	
Magnesium (Mg)	42 ppm = ppb	
Calcium (Ca)	175 ppm = ppb	

Explain why greenhouse growers use the process of dilution.

____

____

____

8. Explain at least two possible problems associated with applying a fertilizer solution that is too concentrated.

____

____

9. Explain at least two problems associated with applying a fertilizer solution that is too diluted.

____

____

____

10. Your boss gives you a bag of fertilizer with the following chart and instructs you to prepare a fertilizer solution for the stock tank that will deliver 100 ppm nitrogen to the flower seedlings in one of the greenhouses. Your boss tells you that the injector ratio is set to 1:200.

Nitrogen ppm	**Injector Ratios**		
	1:100	***1:200***	***1:300***
50	3.38 oz	6.75 oz	10.13 oz
75	5.06 oz	10.13 oz	15.19 oz
100	6.75 oz	13.50 oz	20.25 oz
150	10.13 oz	20.25 oz	30.38 oz

a. Find the column that matches the type of injector you have with the row that matches the desired concentration of fertilizer in ppm. This will tell you how many ounces of fertilizer mix you need. Write the amount here: ______________________ oz of fertilizer mix needed per gallon of concentrated fertilizer solution.

b. Your boss tells you to make enough concentrated fertilizer solution for the 5 gallon stock tanks. How many ounces do you need to make 5 gallons? _________________________oz.

c. You look for a way to measure out your dry fertilizer mix and notice that your scale is in grams. If 1 oz = 28.3 grams, how many grams should you weigh out for your 5 gallon mixture? _____________________ grams. What is your next step?

One in a Million Data Collection Lab Answer Key

1. Determine the concentration of the solution for each cell and record it in the data table below. Example: In cell #2, one out of 10 drops was food coloring. The concentration of food coloring is 1/10 or .10 or 100,000 ppm.

Cell #	Concentration *(fraction and decimal)*	ppm	Color *(use colored pencils)*
1	1/1 or 1 *(a pure substance)*	1,000,000	
2	1/10 or .10	100,000	
3	1/100 or .01	10,000	
4	1/1,000 or .001	1,000	
5	1/10,000 or .0001	100	
6	1/100,000 or .00001	10	
7	1/1,000,000 or .000001	1	
8	1/10,000,000 or 0000001	.01	
9	1/100,000,000 or .00000001	.001	
10	1/1,000,000,000 or .000000001	.0001	

2. Compare and contrast the solutions in each cell. In which cell is the color most intense? Why?
   Cell #1. This cell represents a pure substance, with no solvent present.

   In this activity, what agriculture concept does the food coloring in the first cell represent?
   A pure fertilizer concentration.

3. In which cell is the color least intense? Why?
   Cell #10. This cell has the largest quantity of solvent and is therefore the most diluted. Cell #10 has 1 part food coloring and 999,999,999 parts water.

   In this activity, what agriculture concept does the solution in the last cell represent?
   A very diluted fertilizer solution.

4. Carefully examine your cells. Are there any cells where the liquid is colorless? _____________ Is there any food coloring in these cells? _____________ How do you know?
   Yes. Cells 6 through 10 are colorless; however there is still some food coloring in the cells. The concentration is so weak, color is not visible. We know there is food coloring because in a homogeneous solution, the solute is evenly distributed throughout the solvent, regardless of sample size.

One in a Million Data Collection Answer Key *(continued)*

5. A fertilizer solution contains 1% nitrogen and 12% calcium. Write these percentages as concentrations in ppm.
   There is a factor of 10,000 between ppm and percentage; ppm stands for parts per million, whereas percent means per hundred, and there is a factor of 10,000 between one hundred and one million. To go from ppm to percentage divide by 10,000 and from percentage to ppm multiply by 10,000.

   Nitrogen: 1% x 10,000 = 10,000 ppm
   Calcium: 12% x 10,000 = 120,000 ppm

6. Which cell is closest to the concentration of nitrogen? Which cell is closest to the concentration of calcium?
   Cell # 3 (10,000 ppm) is closest in concentration to nitrogen.
   Cell # 2 (100,000 ppm) is closest in concentration to calcium.

7. Nitrogen, phosphorus, potassium, magnesium, and calcium are essential nutrients for plant growth. Deficiencies in these nutrients can be corrected by fertilizer application. General recommended concentrations for cucumbers are listed below. Convert the ppm concentrations to ppb. Which of your cells of food coloring is closest in concentration to each fertilizer concentration?

Nutrient	Concentration	Cell Number
Nitrogen (N)	230 ppm = *230,000* ppb	5
Phosphorus (P)	40 ppm = *40,000* ppb	6
Potassium (K)	315 ppm = *315,000* ppb	5
Magnesium (Mg)	42 ppm = *42,000* ppb	6
Calcium (Ca)	175 ppm = *170,000* ppb	5

   Why do growers use the process of dilution?
   Dilution allows growers to strategically apply the specific nutrients a plant needs to grow. Most fertilizers are purchased in concentrated formulas that cannot be directly applied to plants without dilution.

8. Explain at least two possible problems associated with applying a fertilizer solution that is too concentrated.
   Plants can only use a certain amount of nutrients. In some cases, too much of a single nutrient can be toxic to the plant or even induce a deficiency in another nutrient. High concentrations applied in excessive amounts can pollute water sources and encourage weed growth. It is in the grower's best interest to apply the correct concentration and quantity of a fertilizer solution. The farmer is also losing money when paying for the extra fertilizer that is being used to over fertilize the crops.

9. Explain at least two problems associated with applying a fertilizer solution that is too diluted.
   A fertilizer solution that is too diluted may not contain the sufficient nutrients required for healthy plant development. This can impact crop yield, and in some cases cause plant death and the farmer will lose money. Additionally, a solution that is too diluted will require more solvent (water) to deliver the same amount of nutrients. Water is a precious resource in California and must be used conservatively.

10. *a. 13.50 oz, b. 67.50 oz, c. 1,910.25 grams. Next, you will mix the 1,910.25 grams of fertilizer concentrate with 5 gallons of water in the stock tank and make sure that the fertilizer injectors are calibrated to a 1:200 ratio.*

Concentrate on the Solution

Purpose

In this lesson, students will use their knowledge of solutes, solvents, and parts per million to analyze fertilizer options that meet plant nutrient requirements while evaluating costs associated with managing plant nutrients.

Time

Teacher Preparation:
15 minutes

Student Activities:
50 minutes

Materials

For each student:

- *Concentrate on the Solution* worksheet
- Periodic Table of the Elements

Background Information

The correct amount of plant nutrients is essential for growing healthy crops. How do farmers know if a crop should be fertilized and what type of fertilizer to use?

Collecting and testing multiple soil samples is a key step in determining whether fertilizer is needed to supplement nutrient deficiencies in the soil. Farmers compare soil test results to the nutrient requirements of their crops and then decide which fertilizer, if any, should be applied. If a fertilizer is needed, farmers make precise plans for choosing the right fertilizer, amount, application method, and timing. One type of fertilizer doesn't fit all needs. Too much of one nutrient can cause deficiencies in other nutrients. For example, applying too much magnesium can interfere with plant potassium uptake. Also, excess application of fertilizer costs the farmer money and can lead to environmental problems. For these reasons, fertilizer production, transportation, application, and storage are heavily regulated by numerous agencies in California and throughout the U.S.

The continued development of farming technology and precise management of fertilizer inputs is necessary for farmers to grow more food on less land to feed our growing population. In 1910, the discovery of the Haber-Bosch process for fixing atmospheric nitrogen gas into commercial fertilizer drastically increased the amount of food that farmers could grow. It is estimated that nearly half the world's population is dependent upon commercially produced fertilizers.

There are 17 chemical elements that are essential to plants. Of these 17, carbon, hydrogen, and oxygen are provided to plants by air and water. Carbon is the basic building block for life and is taken in by plants in the form of carbon dioxide from the atmosphere. Through photosynthesis, carbon is combined with hydrogen and oxygen to form carbohydrates. The remaining 14 elements are absorbed by plant roots from the soil and are categorized as follows:

Primary Nutrients: Nitrogen, Potassium, and Phosphorus

- These are the three most commonly deficient nutrients in the soil. After carbon, hydrogen, and oxygen, plants take up more potassium and nitrogen than any other nutrient.
- Nitrogen is used by plants to make proteins, chlorophyll, and enzymes.

Concentrate on the Solution

California Standards

Grade 8

Common Core English Language Arts
- SL.8.1b
- RST.8.3
- RST.8.7
- RST.8.9
- WHST.8.1b
- WHST.8.4

Next Generation Science Standards
- MS-ESS3.A
- MS-ESS3.C
- MS-ETS1.B

Grades 9-12

Common Core English Language Arts
- SL.9-12.1b
- RST.9-12.3
- RST.9-12.7
- WHST.9-12.1b
- WHST.9-12.4

Common Core Mathematics
- 9-12.N-Q.1

Next Generation Science Standards
- HS-PS1.A
- HS-ESS3.A
- HS-ETS1.A
- HS-ETS1.B

- Potassium is important for efficient water use by plants because it is required to open and close stomata. Potassium is also important for root growth and formation of starch.
- Phosphorus is needed for plants to make DNA and RNA.

Secondary Nutrients: Calcium, Magnesium, and Sulfur

- Similar amounts of these nutrients are needed as the primary nutrients but are classified as secondary nutrients since the soil is less likely to be deficient in these nutrients.
- Calcium is important in the formation of new cell walls and membranes.
- Magnesium is essential in forming chlorophyll for photosynthesis.
- Sulfur is involved in protein synthesis and the formation of nitrogen fixing nodules on legume roots.

Micronutrients: Zinc, Iron, Manganese, Copper, Boron, Molybdenum, Chlorine, and Nickel

- Micronutrients are just as important to plants as the primary and secondary nutrients, but are used in much smaller amounts.

Procedure

1. Ask the class if they have ever tried growing their own flowers, vegetables, or house plants. Ask how they kept their plants healthy. What did they do if their plants began to die or show signs of disease?
2. Explain that farmers must know as much as possible about their land, especially their soil properties. Farmers collect soil samples and send them to laboratories for analysis. Soil properties are then compared with the needs of the crops the farmer plans to grow. If soil is lacking in one or more essential nutrients, fertilizer may be applied.
    - Not all fertilizers contain the same amounts of primary nutrients. Fertilizers are prepared in different compositions so the consumer, farmer, or home gardener can apply precisely what is needed.

- In this lesson, students will take on the role of manager of their school farm. This job will require students to use their chemistry, math, and communication skills to compare the cost and nutrient content of different types of fertilizers in order to make the best recommendations for purchase of different fertilizers.
- Explain that soil sample results from the school farm indicate areas with different nutrient deficiencies. Students will need to determine which fertilizer to use in order to remedy these deficiencies. Their success will positively impact both crop yield and environmental health.

3. Lead the class through a review of the periodic table of the elements as well as the characteristics of a compound:
    - Elements can be combined to form a compound. An example of an element is hydrogen. An example of a compound is water (H_2O).
    - A compound formula uses subscripts to indicate the number of atoms of each element present. For example, in the compound H_2O, there are two atoms of hydrogen and one atom of oxygen present.
    - Compounds contain the same elements in the same proportions regardless of sample size.
4. Explain that plant nutrients are typically added to the soil or growing media in compound forms. This means that instead of adding pure nitrogen (which would be difficult, since nitrogen in its pure form is a gas), we might add ammonium nitrate (NH_4NO_3), which is a solid, plant available form.

5. Distribute the *Concentrate on the Solution* worksheet to each student and organize the class into groups of two or three. Assign groups one of the following nutrient deficiencies and the supplemental nutrient amount needed. *For example, one group may be assigned phosphorus and the supplemental nutrient amount needed is 40 ppm.*

Nutrient *Each of these represents an element*	**Supplemental Nutrient** *Amount needed*
Nitrogen (N)	230 ppm
Phosphorus (P)	40 ppm
Potassium (K)	315 ppm
Magnesium (Mg)	42 ppm
Calcium (Ca)	175 ppm

6. Students may choose to apply one of the following fertilizer compounds: Use a document projector to display this chart to the class. Have students use a periodic table of the elements from their textbooks or project one on the board. *Explain to students that each subscript represents the number of atoms of each element in the fertilizer compound.*

Fertilizer Compound	**Name**
KH_2PO_4	Monopotassium Phosphate
H_3PO_4	Phosphoric Acid
KNO_3	Potassium Nitrate
K_2SO_4	Potassium Sulfate
$Ca(NO_3)_2$	Calcium Nitrate
$CaCl_2$	Calcium Chloride
$MgSO_4$	Magnesium Sulfate
NH_4NO_3	Ammonium Nitrate
$K_2MgO_8S_2$	Potassium Magnesium Sulfate

7. Do one example with your class. After students complete all of the problems, review the solutions as a class. Discuss how you might apply this lesson to an actual school farm or community garden.

Variations

- Rather than assigning a nutrient deficiency and the supplemental amount needed, distribute photos of plants with nutrient deficiencies. Assign students homework that includes identifying the nutrient deficiency and the recommended application in ppm. The Internet has a wide range of resources. Recommend that students use university websites as a primary source.

Extensions

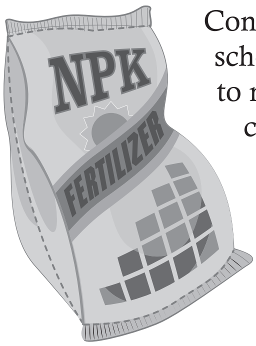
- Have students research plant nutrients to determine if there are any elements that can be directly applied to plants as fertilizer. Investigate the chemical properties of these elements to determine why they are suitable for individual application.

ELL Adaptations

- Ask students to write a few sentences about the importance of precise measurements when preparing fertilizer then have them speak about the process with another student.
- Use an overhead projector to demonstrate complex math problems.

Concentrate on the Solution

Name: ______________________________________



Congratulations! You have been appointed as one of the managers in charge of your school farm. This job takes the place of one of your elective classes this year. Your job is to monitor, manage, and supply the nutrients needed to produce a high-quality vegetable crop. Vegetables from your school farm are sold each week at your local farmers market to raise money for school field trips, clubs, and sports. Your teacher has submitted soil samples to the lab and results show various nutrient deficiencies. You have been instructed to analyze the following information to show your teacher that you are ready to tackle the responsibilities of your new job and are prepared to develop a solution to your nutrient deficiency problems.

Our Challenge

Nutrient deficiency: ____

Supplemental nutrient amount needed: ____

Step 1

Look at the possible fertilizer compounds on the chart. Select two compounds that you think would supplement the nutrients you need.

Find the molecular mass of each of your chosen fertilizer compounds. Do this by adding the individual atomic weights for each element. (Show your work)

Compound _________________________ Compound _________________________

Molecular mass ______________________ Molecular mass ______________________

Concentrate on the Solution *(continued)*

Step 2

Once you have the molecular mass of your compound, find out what percent of the compound is made up of the desired nutrient by weight. For example, if your compound molecular mass is 100 and the atomic weight of calcium in the compound is 40, then calcium = 40% of your fertilizer compound. (Show your work)

____________________ =_____% of ______________________
nutrient *fertilizer compound*

____________________ =_____% of ______________________
nutrient *fertilizer compound*

Assume that both fertilizer compounds are sold for the same price. Which compound provides the best value for your specific nutrient deficiency?

____

____

Step 3

What solute to solvent ratio will you use to prepare the fertilizer concentration needed? (Show your work)

$$\frac{\text{desired concentration of nutrient}}{\text{\% nutrient in compound (decimal)}} = \frac{\text{unknown concentration (x) of fertilizer compound}}{\text{\% total compound (decimal)}}$$

How many mg of the solvent will you need to add to make 1 L of the fertilizer solution to be applied to your plants? Note: ppm = mg/1
Example: if you need 150 ppm of Calcium and your percentage of calcium in the fertilizer compound is 10%, how many mg of fertilizer compound do you need per liter of water?
150 ppm Ca ÷ .10 Ca = 1,500 ppm = 1,500 mg of fertilizer per liter of water.

Explain your next steps after preparing this fertilizer solution along with any additional information you might need about the farm before taking action.

____

____

____

Concentrate on the Solution *(continued)*

Step 4

You have a great opportunity for a summer job at a local farm. Your potential boss wants you to demonstrate your skills for communicating clear instructions to employees who may be working as your assistants. Your teacher suggests that you write up a detailed description of how you solved the nutrient deficiency problem for the school farm. Your answer should defend your choice of fertilizer compound and provide an explanation of how to prepare the fertilizer solution. Directions should be easily followed by an entry level employee who has very little knowledge of fertilizer components and preparation.

Congratulations, your experience working on the school farm has earned you an interview for a summer job with a local farm. Answer the following questions to prepare for the interview:

1. The farm has two different fertilizers in the barn. One is K_2SO_4 and the other is KCl. The two fertilizers cost the same per ton, but we want to be conscious of costs by using the fertilizer with the highest percentage of potassium, since we won't have to apply as much. Which fertilizer should we use? Show your calculations.

Concentrate on the Solution *(continued)*

2. Animal manures are often used to add nutrients to soil. Assume that the average price for chicken manure is $30 per ton *(cost is an estimate only)* and contains 31 pounds of nitrogen per ton.

   - What percentage of nitrogen does the manure contain? ________________________________
   - What is the cost per pound of nitrogen? ____

3. Ammonium nitrate contains 35% nitrogen, so a ton of ammonium nitrate would contain 700 pounds of nitrogen. Assume ammonium nitrate costs $300 per ton, what is the cost per pound of nitrogen?

4. Which is more cost effective to apply, chicken manure or ammonium nitrate?

5. What are some issues other than price that might affect which of the fertilizers a grower would choose to use?

6. What types of valuable experience might you gain during a summer job at the farm?

Concentrate on the Solution Answer Key

Answers may vary, depending on the assigned nutrient deficiency.

Our Challenge

Our nutrient deficiency (given): *Nitrogen*

Supplemental nutrient amount needed (given): *230 ppm*

The fertilizer compound we will apply: *Calcium Nitrate $Ca(NO_3)_2$* *(Answers will vary)*

Example for Steps 1 - 3

What percent of the fertilizer compound contains the desired nutrient, by weight? (Show all work)

Nutrient	*Atomic Weight*		
Ca	*40.08*	*x 1 = 40.08*	*40.08*
N	*14.01*	*x 2 = 28.02*	*28.02*
O	*15.99*	*x 3 x 2 = 95.94*	*+95.94*
			164.04 = molecular mass

$$\frac{28.02 \text{ N atomic weight}}{164.04 \text{ molecular mass}} = .170 = 17\%$$

What solute to solvent ratio will you use? (Show your work) *Hint: ppm=mg/l*

$$\frac{230 \text{ ppm N}}{.17 \text{ N}} = \frac{x \text{ ppm } Ca(NO_3)_2}{1} \qquad \frac{230 \text{ ppm N}}{.17} = \frac{.17x}{.17}$$

$$x = 1352.94 \text{ ppm} \quad \text{or} \quad 1352.94 \text{ mg } Ca(NO_3)_2 \text{ per liter of water}$$

When comparing the % content of the desired nutrient from the two fertilizer compounds, students should choose to use the one with the highest percentage of the nutrient, since they will need to use the least amount which is cost effective.

Explain your next steps after preparing this fertilizer solution along with any additional information you might need about the farm before taking action.

Possible next steps include: *Identify the irrigation system being used. Set the fertilizer injector at the proper delivery rate. Determine the crop's water requirements and create a larger quantity of the solution (at the same concentration) for application. Apply the solution to fertilize the plant. Test the water runoff for fertilizer residue.*

Possible questions include: *Do the plants have any additional nutrient deficiencies besides the one given? What stage of the growth cycle are plants in? Are the plants currently producing fruit? What is the existing nutrient composition of the growing medium? Are any nutrients found in the irrigation water? Where does the water go after irrigation occurs? How many plants are there? How much total water will be used for irrigating?*

Concentrate on the Solution Answer Key *(continued)*

Step 4

Answers will vary but should include concise, step-by-step directions of how the calculations were done, the best fertilizer compound selected and mixed to the appropriate concentration.

Congratulations, your experience working on the school farm has earned you an interview for a summer job with a local farm. Answer the following questions to prepare for the interview:

1. The farm has two different fertilizers in the barn. One is K_2SO_4 and the other is KCl. The two fertilizers cost the same per ton, but we want to be conscious of costs by using the fertilizer with the highest percentage of potassium, since we won't have to apply as much. Which fertilizer should we use? Show your calculations.

   K_2SO_4 = 158.25 %K = 78.12/158.25 x 100 = 49% K

   KCl = 74.55 %K = 39.1/74.55 x 100 = 52% K

   KCl would be the most cost effective

2. Animal manures are often used to add nutrients to soil. Assume that the average price for chicken manure is $30 per ton *(cost is an estimate only)* and contains 31 pounds of nitrogen per ton.
   - What percentage of nitrogen does the manure contain? *31 lbs N/2000 lbs = 0.0155 or 1.55% Nitrogen*
   - What is the cost per pound of nitrogen? *$30/31 lbs = $0.97 per pound*
3. Ammonium nitrate contains 35% nitrogen, so a ton of ammonium nitrate would contain 700 pounds of nitrogen. Assume ammonium nitrate costs $300 per ton, what is the cost per pound of nitrogen? *$300/700 lbs of nitrogen in a ton = $0.43 per pound of nitrogen*
4. Which is more cost effective to apply, chicken manure or ammonium nitrate? *Ammonium nitrate*
5. What are some issues other than price that might affect which of the fertilizers a grower would choose to use? *Ease of application, effect on soil microbes, plant's need for other nutrients, effect on soil organic matter, availability of nitrogen for immediate and/or delayed uptake by plants, transportation costs, safety, reduced nitrogen loss to the environment, etc.*
6. What types of valuable experience might you gain during a summer job at the farm? *Math skills including algebra and unit conversions, knowledge of plant physiology, mechanical skills for maintaining and assembling irrigation systems and farm machinery, chemistry knowledge (specifically plant nutrients), how to accurately weigh materials, formulating solutions to problems, explaining directions, etc.*

Matter of Fact

Purpose

In this lesson, students will take on the role of a nitrogen molecule and experience how various forms of nitrogen cycle through the environment. Students will be able to identify and differentiate between atoms, molecules, and compounds.

Time

Teacher Preparation:
30 minutes

Student Activities:
Part I: 60 minutes
Part II: 60 minutes

Materials

For the teacher:

- Document projector
- Transparency film (optional)
- Tactile molecular models
- *Matter of Fact Notes* answer key
- *What Goes Around, Comes Around* answer key

For each station:

- Station instructions
- Die
- Twenty toothpicks
- Bowl

Background Information

All organisms require nitrogen to live and grow; it is a fundamental component of DNA and RNA, the building blocks of life. Approximately 78% of the Earth's atmosphere is made of nitrogen gas. This atmospheric form (N_2) is unusable by most plants. In order to be used by plants, nitrogen gas must be converted to ammonium, nitrate, or urea through a process called nitrogen fixation.

The nitrogen cycle is the process by which nitrogen is converted between its various chemical forms as it moves between the atmosphere, living organisms, and the Earth's crust. The cycle illustrates how nitrogen from the atmosphere interacts with microorganisms that can convert, or "fix," N_2 gas into forms of nitrogen that are usable by plants. Nitrogen can also enter the cycle from other sources besides the atmosphere including manure, decaying plant material, and commercial fertilizers. As nitrogen atoms move throughout the cycle, their chemical composition may change numerous times.

Forms of Nitrogen Highlighted in the Lesson

Chemical Formula	Name	State	Form
N_2	Nitrogen Gas	Gas	Molecule
NH_4^+	Ammonium	Solid	Compound
NO_3^-	Nitrate	Solid	Compound

Part I

1. Prior to the lesson, prepare several tactile molecular models to represent each of the following forms of nitrogen: N, N_2, NH_4^+, NO_3^-. Display for the class the *Matter of Fact Notes* handout and the Nitrogen Cycle diagram onto overhead transparencies (optional). Set up seven stations evenly spaced around the classroom. Place a bowl of gumdrops, toothpicks, and a die at each station. Post the station instructions above each station.
2. Explain to students that many of the world's resources are not available for use by plants or animals. For example, only one percent of the Earth's water is actually drinkable. Have students brainstorm reasons why the other 99 percent might not be available

Matter of Fact

- Twenty gumdrops *(various colors)*

For each student:

- *Matter of Fact Notes* handout
- *What Goes Around, Comes Around* activity handout
- *Nitrogen Cycle* handout

for consumption. Record answers on the board. After some time, explain that 97 percent of water on Earth is salt water. Two percent of the water on earth is glacier ice at the North and South Poles.

3. Similar to the availability of water, some plant nutrients are not easily used by plants. For example, although 78 percent of the Earth's atmosphere is made of nitrogen—this form (N_2 or nitrogen gas) is unusable by plants. Today we're going to experience how nitrogen changes its molecular form during the nitrogen cycle and learn what forms can be assimilated by plants.

4. Distribute the *Matter of Fact Notes* handout on page 38. Complete the handout with the class. As you review the different forms of nitrogen, show students examples using molecular models. Identify the type of atoms in each molecule.

5. Show students the Nitrogen Cycle diagram. Review each step of the nitrogen cycle.

6. Introduce the activity *What Goes Around, Comes Around*. Explain to students that there are seven different stations around the classroom. Each station represents a "reservoir" for nitrogen in the nitrogen cycle. Tell students that in this activity they will act as nitrogen atoms moving through the nitrogen cycle. They will start as a pure form of nitrogen. In this form, they are a single atom. Hold up a single gumdrop. At each station students will role a die to determine how they will transform. Students will create a model of the different forms of nitrogen using the toothpicks and gumdrops provided at their starting station. They will take this model with them as they transform into different forms of nitrogen at each station. Have extra gumdrops on hand for construction of the models. Each color gumdrop will represent a different element, the toothpicks will represent chemical bonds. Students should record the information from each station on their *What Goes Around, Comes Around* chart. Students may use the *Nitrogen Cycle* handout to identify each process in the cycle.

   Briefly review each station and tell students that you will give the signal to switch stations every five minutes and that they should rotate to different stations as determined by the roll of the die at each of their stations.

7. Instruct students to return to their desks and complete the *Think About It* section of the handout. Students may work in pairs. Answer any questions before releasing students to begin the activity.

Matter of Fact

California Standards

Grade 8

Common Core English Language Arts

SL.8.1a
SL.8.1b
RST.8.3
RST.8 7
RST.8.9

Next Generation Science Standards

MS-PS1.A
MS-PS1.B
MS-LS2.A
MS-LS2.B
MS-LS2.C
MS-ESS3.C
MS-ETS1.B

Grades 9-12

Common Core English Language Arts

SL.9-12.1a
SL.9-12.1b
RST.9-12.3
RST.9-12.7

Next Generation Science Standards

HS-ESS2.E
HS-ESS3.A
HS-ESS3.C

8. As a class, review the *Think About It* section of the handout. Lead a class discussion to highlight the following "big picture" concepts:
    a. There is a limited amount of nitrogen in the environment. Nitrogen changes forms as it moves through different stages of the nitrogen cycle.
    b. Nitrogen does not move through the cycle as a single atom, but in stable compound and molecule forms.
    c. Bacteria play an important role in ammonification, denitrification, fixation, and nitrification. Without bacteria, the nitrogen cycle would cease to be a productive cycle.

Part II: Review

1. Prior to the review activity, divide the class into two equally sized groups based on an observable trait. For example, distribute paper streamers or divide the group by gender.
2. Introduce students to the review activity, *Molecular Shuffle*. Explain that in this activity, you will reveal different molecular formulas, including atoms, molecules, and compounds. After each chemical formula is revealed, students will scramble to create a group that accurately represents the atoms in the chemical formula.
3. For example, if the formula NO (nitric oxide) is revealed, a student with a green paper streamer will link arms with a student who has a blue paper streamer, to represent the two different elements bonded together. If the formula is H_2O (water) two green and one blue or two blue and one green will link together. If a student is unable to find a group they are "out" and can watch the activity from the sidelines. Any incomplete groups are also "out." If you announce a single atom, the students must stand at attention and yell "I'm an atom!"
4. Play the review activity, incorporating each form of nitrogen. Supporting presentation slides for the *Molecular Shuffle* may be downloaded from *www.LearnAboutAg.org/chemistry.*

Extensions

- Have students plan and construct a three-dimensional nitrogen cycle diagram using common household items or craft supplies.

- Watch an educational video that illustrates the nitrogen cycle. Search YouTube using the term "Nitrogen Cycle."
- Have students create a "mind map" to visually organize information. Several online tools, such as *www.mindmeister.com* and *www.mindomo.com* offer real-time collaboration in order to have a concept map that the whole class can edit at the same time.

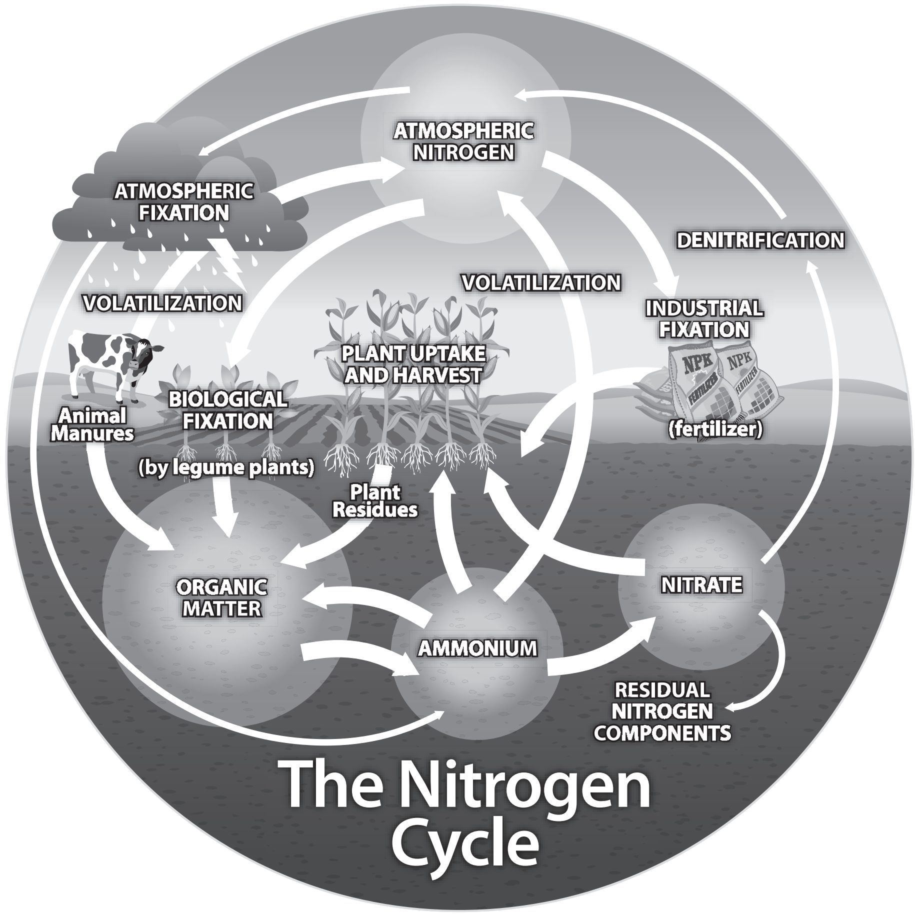
Variations

- Instruct students to use arrows and symbols to record their movement through the nitrogen cycle. Combine each student's unique path using different colors on a shared class diagram.
- Make the review activity, *Molecular Shuffle*, increasingly challenging. As students become familiar with the different forms of nitrogen, call out the name of the molecule only. Students must determine the chemical formula quickly before gathering into groups. Add oral responses for students to categorize elements as micro or macro nutrient, or increase the complexity of chemical formulas, using examples like calcium nitrate $Ca(NO_3)_2$.

ELL Adaptations

- The addition of the complex terms and science concepts can make learning even more difficult. Write down key terms so students can see them and connect them to the spoken word.
- Demonstrate activities in front of class to ensure that English language learners can see the procedures before engaging in an activity. Pair ELL students with partners who are English proficient and have a good understanding of topics being taught in class.

Nitrogen Cycle



- **Ammonification**: Bacteria or fungi convert organic forms of nitrogen (mostly from plant and animal waste) into ammonium NH_4^+, which can be used by plants.
- **Assimilation**: Living organisms take up nitrogen to be used for biological processes such as making chlorophyll, proteins, and enzymes.
- **Denitrification**: Under poor aeration, soil bacteria convert nitrate ions NO_3^- into nitrogen gas N_2, which cannot be used by plants and is lost to the atmosphere.
- **Fixation**: Bacteria convert nitrogen gas N_2 into ammonium NH_4^+ or nitrate NO_3^- that living organisms can assimilate. Rhizobium bacteria have the unique ability to fix nitrogen through metabolic processes. These bacteria form symbiotic relationships with plants in the legume family. Nitrogen gas can also be converted to forms that plants can use through the production of commercial fertilizers.
- **Nitrification**: Soil bacteria convert ammonium NH_4^+ into nitrate NO_3^- ions. Oxygen is needed for this process, therefore, nitrification takes place in the top layers of soil and flowing water. Nitrates can be used by plants.
- **Physical movement**: The physical movement of any form of nitrogen, which may include tilling (moving under the soil), leaching (moving through the soil), carrying (to transport via water), or runoff (the flow of water over land). No chemical process is involved in physical movement.

Matter of Fact Notes

Name: ______________________________

1. ________________ is anything that has ____________and takes up ________________.
2. An ____________________ is the smallest component of an element.

   Examples:

3. A ______________ is the smallest particle of a pure _________________ that has the properties of that substance. Also known as two or more atoms of the same type joined together by chemical bonds.

   Examples:

4. A __________________ is a substance made up of atoms of _________________ elements. There are relatively few chemical elements, but there are ______________ of chemical compounds.

   Examples:

5. All compounds are molecules, but not all molecules are compounds. Explain why you think this statement is true or false.

   ____

   ____

   ____

6. A ____________________ is a concise written description of the components of a chemical compound. It identifies the _________________ in the compound by their symbols and describes the number of atoms of each element with __________________. No subscript is used if one atom of an element is present.

   Example:

Matter of Fact Notes Answer Key

1. ______*Matter*__________ is anything that has ______*mass*______and takes up ________*space*_______.
2. An ________*atom*________ is the smallest component of an element.

Examples:

H *Hydrogen*	*N* *Nitrogen*	*Na* *Sodium*

3. A _____*molecule*_________ is the smallest particle of a pure ______*substance*______________ that has the properties of that substance. Also known as two or more atoms of the same type joined together by chemical bonds.

Examples:

N_2 *Nitrogen Gas*	H_2 *Hydrogen Gas*	O_2 *Oxygen Gas*

4. A ______*compound*____ is a substance made up of atoms of ____*at least two different*_______ elements. There are relatively few chemical elements, but there are ____*millions*_______ of chemical compounds.

Examples:

H_2O *Water*	NH_4^+ *Ammonium*	NO_3^- *Nitrate*

5. All compounds are molecules, but not all molecules are compounds. Explain why you think this statement is true or false.
Answers may vary. Oxygen gas O_2 and Nitrogen gas N_2 are not considered compounds because they are each composed of the same element. Water H_2O is a compound because it is composed of more than one element.

6. A _____*chemical formula*_______________ is a concise written description of the components of a chemical compound. It identifies the ________*elements*_____________ in the compound by their symbols and describes the number of atoms of each element with ________*subscripts*____________. No subscript is used if one atom of an element is present.

Example:

$C_6H_{12}O_6$ Glucose

What Goes Around Comes Around

Name: ____________________________

In this activity, you will take on the role of a nitrogen atom and experience how nitrogen cycles through the environment. Record each step of the journey in the chart below and assemble models out of gumdrops and toothpicks.

Station	Starting Location	Starting Form	Process	What Happened?	Ending Location	Ending Form	Atom, Compound, or Molecule?
Ex	Fertilizer	NO_3^-	Denitrification	Bacteria convert to nitrogen gas	Atmosphere	N_2	Molecule
1							
2							
3							
4							
5							
6							
7							

Think About It!

Complete all seven station rotations before answering the following questions.

1. How many different forms of nitrogen did you become in this cycle?

2. Explain how plants obtain nitrogen.

3. Explain how humans and animals obtain nitrogen.

4. Although you started as a single nitrogen atom (N) you never returned to a single nitrogen atom in this cycle. Why?

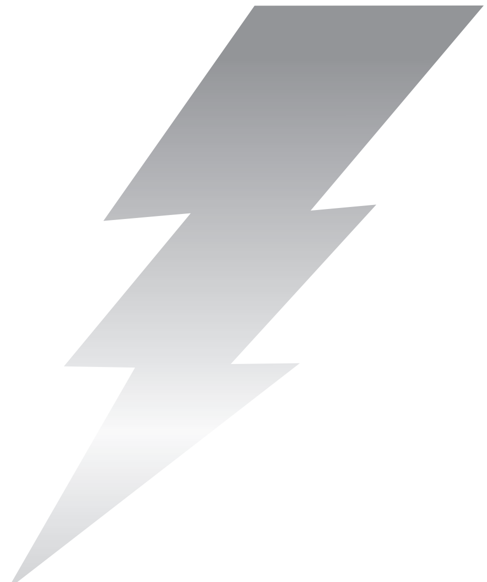
5. Explain the role of bacteria in the nitrogen cycle.

6. Predict what would happen if the bacteria population in an ecosystem decreased suddenly.

7. We know that matter cannot be destroyed. Hypothesize what happened to the atoms that were "lost" during some of the transformations.

8. How could human activity adversely or beneficially affect the natural cycling of nitrogen in the environment? Identify one realistic example and explain how the nitrogen cycle would be affected.

Atmosphere Station



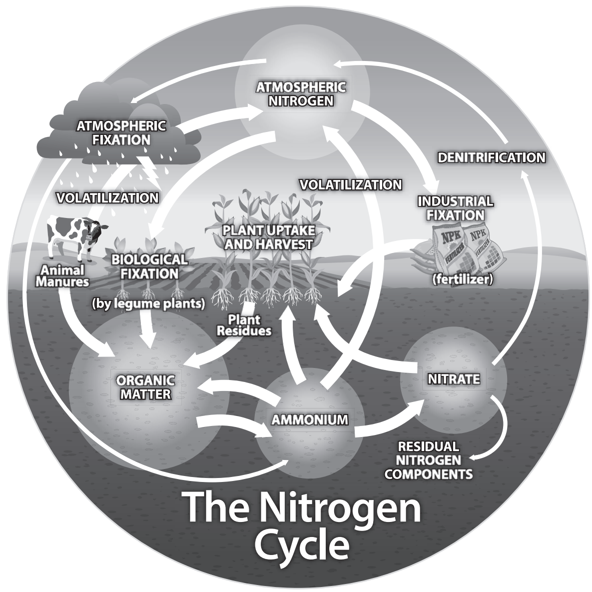
Starting Form: N_2

Dice Roll		Next Station
1 or 2	Lightning fixes atmospheric nitrogen N_2 in the atmosphere, which is carried by rain to a body of water NH_4^+.	Body of Water
3 or 4	Agriculture fixes millions of tons of atmospheric nitrogen N_2 for use as fertilizer NH_4^+.	Fertilizer
5 or 6	Bacteria in legumes convert nitrogen gas N_2 to a form plants can use NH_4^+, which is added to the soil.	Soil

Instructions

- Roll the die to select your path. Fill out your chart for that path.
- Use the toothpicks and gumdrops to make a model of the starting form of nitrogen and what it changed into. Take this model with you to your next station. You will use it to model the different forms of nitrogen throughout this lab.
- When time is up, move to the next station.

Soil Station



Starting Form: NH_4^+ or NO_3^-

Dice Roll		Next Station
1 or 2	Your neighbor doesn't follow the instructions when applying lawn fertilizer. Excessive watering after application leaches nitrate NO_3^- into the groundwater.	Groundwater
3 or 4	Bacteria in the soil convert ammonium NH_4^+ into nitrate NO_3^- and it remains in the soil.	Stay at soil
5 or 6	The nitrate in the soil NO_3^- is taken up by lettuce plants.	Plant

Instructions

- Roll the die to select your path. Fill out your chart for that path.
- Use the toothpicks and gumdrops to make a model of the starting form of nitrogen and what it changed into. Take this model with you to your next station. You will use it to model the different forms of nitrogen throughout this lab.
- When time is up, move to the next station.

Fertilizer Station

Starting Form: NH_4^+ or NO_3^-

Dice Roll		Next Station
1 or 2	The right amount of fertilizer is applied to the soil and taken up by plants NH_4^+ and NO_3^-.	Plant
3 or 4	High concentrations of pet waste in urban parks and neighborhoods may lead to nutrient movement into the groundwater (NO_3^-).	Groundwater
5 or 6	The fertilizer is consumed by soil bacteria, which, under anaerobic conditions, convert the nitrate into nitrogen gas N_2 which is released into the atmosphere.	Atmosphere

Instructions

- Roll the die to select your path. Fill out your chart for that path.
- Use the toothpicks and gumdrops to make a model of the starting form of nitrogen and what it changed into. Take this model with you to your next station. You will use it to model the different forms of nitrogen throughout this lab.
- When time is up, move to the next station.

Plant Station

Starting Form: Organic N

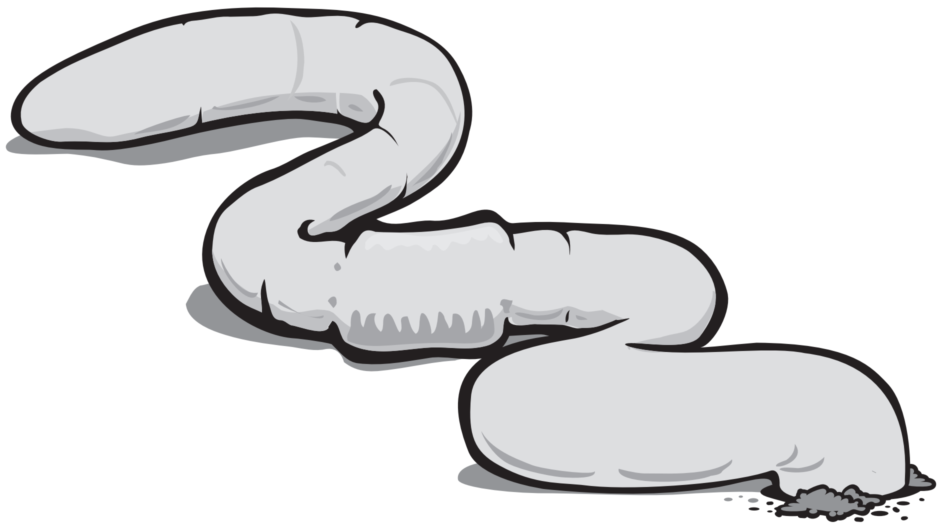
When NH_4^+ or NO_3^- is assimilated by a plant, we use the term "organic nitrogen" to describe the nitrogen compounds in the plant. These nitrogen compounds include many types of proteins, or by-products of protein digestion, such as urea and ammonium.

Dice Roll		Next Station
1 or 2	The inedible part of the plant is tilled into the ground, bacteria decompose the plant material NH_4^+.	Soil
3 or 4	A human eats the edible part of the plant, assimilates the nitrogen, and produces waste NH_4^+.	Waste/Decay
5 or 6	An animal eats the plant, assimilates the nitrogen, and produces waste NH_4^+.	Waste/Decay

Instructions

- Roll the die to select your path. Fill out your chart for that path.
- Use the toothpicks and gumdrops to make a model of the starting form of nitrogen and what it changed into. Take this model with you to your next station. You will use it to model the different forms of nitrogen throughout this lab.
- When time is up, move to the next station.

Waste/Decay Station



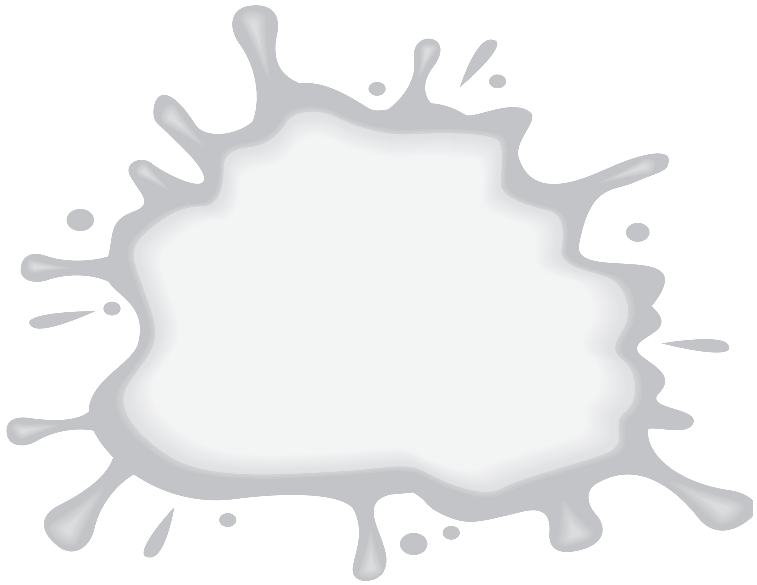
Starting Form: Organic N or NH_4^+

Dice Roll		Next Station
1 or 2	Waste and decaying materials (organic N) are composted by humans and used as fertilizer (NH_4^+)	Fertilizer
3 or 4	A malfunction at the city sewage treatment plant leads to run off into a body of water (NH_4^+).	Body of Water
5 or 6	Bacteria convert the nitrogen found in waste and decaying materials into ammonium, which remains in the soil (NH_4^+).	Soil

Instructions

- Roll the die to select your path. Fill out your chart for that path.
- Use the toothpicks and gumdrops to make a model of the starting form of nitrogen and what it changed into. Take this model with you to your next station. You will use it to model the different forms of nitrogen throughout this lab.
- When time is up, move to the next station.

Body of Water Station



Starting Form: NO_3^- or NH_4^+

Dice Roll		Next Station
1 or 2	Over time, nitrates NO_3^- from an old septic system may slowly leach into groundwater.	Groundwater
3 or 4	Nitrogen in the water is taken up by aquatic plants (NH_4^+).	Plant
5 or 6	Bacteria, in the process of denitrification under anaerobic conditions, convert nitrogen in a pond into atmospheric nitrogen N_2 which is released into the atmosphere.	Atmosphere

Instructions

- Roll the die to select your path. Fill out your chart for that path.
- Use the toothpicks and gumdrops to make a model of the starting form of nitrogen and what it changed into. Take this model with you to your next station. You will use it to model the different forms of nitrogen throughout this lab.
- When time is up, move to the next station.

Groundwater Station

Starting Form: NO_3^-

Dice Roll		Next Station
1 or 2	Underground aquifers carry the water underground until it reaches a body of water (NO_3^-)	Body of Water
3 or 4	Groundwater is pumped from underground through a well and applied to the soil (NO_3^-).	Soil
5 or 6	Bacteria, in the process of denitrification, convert nitrate NO_3^- in groundwater into atmospheric nitrogen N_2 which is released into the atmosphere.	Atmosphere

Instructions

- Roll the die to select your path. Fill out your chart for that path.
- Use the toothpicks and gumdrops to make a model of the starting form of nitrogen and what it changed into. Take this model with you to your next station. You will use it to model the different forms of nitrogen throughout this lab.
- When time is up, move to the next station.

What Goes Around Comes Around Answer Key

Station	Starting Location	Starting Form	Process	Ending Location	Ending Form	Atom, Molecule, or Compound
Atmosphere 1	Atmosphere	N_2	Fixation	Body of Water	NH_4^+	Molecule to Compound
Atmosphere 2	Atmosphere	N_2	Fixation	Fertilizer	NH_4^+	Molecule to Compound
Atmosphere 3	Atmosphere	N_2	Fixation	Soil	NH_4^+	Molecule to Compound
Soil 1	Soil	NO_3^-	Physical Movement	Groundwater	NO_3^-	Compound to Compound
Soil 2	Soil	NH_4^+	Nitrification	Soil	NO_3^-	Compound to Compound
Soil 3	Soil	NO_3^-	Assimilation	Plants	Organic N	Compound to Compound
Fertilizer 1	Fertilizer	NH_4^+	Assimilation	Plants	Organic N	Compound to Compound
Fertilizer 2	Fertilizer	NO_3^-	Physical Movement	Groundwater	NO_3^-	Compound to Compound
Fertilizer 3	Fertilizer	NO_3^-	Denitrification	Atmosphere	N_2	Compound to Molecule
Plants 1	Plants	Organic N	Physical Movement	Soil	NH_4^+	Compound to Compound
Plants 2	Plants	Organic N	Assimilation	Waste/Decay	NH_4^+	Compound to Compound
Plants 3	Plants	Organic N	Assimilation	Waste/Decay	NH_4^+	Compound to Compound
Waste/Decay 1	Waste/Decay	Organic N or NH_4^+	Ammonification	Fertilizer	NH_4^+	Compound to Compound
Waste/Decay 2	Waste/Decay	Organic N or NH_4^+	Physical Movement	Body of Water	NH_4^+	Compound to Compound
Waste/Decay 3	Waste/Decay	Organic N or NH_4^+	Ammonification	Soil	NH_4^+	Compound to Compound
Body of Water 1	Body of Water	NO_3^-	Physical Movement	Groundwater	NO_3^-	Compound to Compound
Body of Water 2	Body of Water	NO_3^-	Assimilation	Plants	Organic N or NH_4^+	Compound to Compound or Molecule
Body of Water 3	Body of Water	NO_3^-	Denitrification	Atmosphere	N_2	Compound to Molecule
Groundwater 1	Fertilizer	NO_3^-	Physical Movement	Body of Water	NO_3^-	Compound to Compound
Groundwater 2	Fertilizer	NO_3^-	Physical Movement	Soil	NO_3^-	Compound to Compound
Groundwater 3	Fertilizer	NO_3^-	Denitrification	Atmosphere	N_2	Compound to Molecule

What's Your pH?

Purpose

In this lesson students will measure the pH of a soil sample and learn how pH affects the availability of nutrient uptake by plants. Students will determine if and how their soil pH should be modified through the application of soil amendments.

Time

Teacher Preparation:
45 minutes

Student Activities:
60 minutes

Materials

For the class:

- Sand
- Soil
- White vinegar (or 0.5 M solution of hydrochloric acid)
- Drain cleaner containing potassium hydroxide (or 0.5 M solution of sodium hydroxide)
- pH meters
- pH testing kit based on barium sulfate
- pH test strips (1-12 range) and litmus paper for quick acid/base indicators
- Distilled water

Background Information

Farmers are interested in the pH of their soils for a number of reasons. pH plays an important role in:

- The availability of essential plant nutrients.
- The activity of microorganisms in the soil.
- The solubility of some phytotoxic elements. For example, aluminum, iron, and manganese have greater solubility at pH values below 5.5. Sodium levels may become excessive when pH is above 8.5.

Soil moisture and organic matter also affect a plant's ability to take up nutrients from the soil. Before nutrients can be used by plants, they must be dissolved in the soil solution. Soil pH is an indication of the acidity or alkalinity of soil and is measured in pH units. The pH scale goes from 0 to 14 with pH 7 as the neutral point. Soil pH can be altered through the application of elemental sulfur or lime (calcium carbonate). Application of lime or elemental sulfur is not an instant fix for soil pH. Depending upon the soil properties, it may take months or even a year for measurable changes in pH to occur after an amendment has been added to the soil.

Soil pH and Interpretation

5.0	5.5	6.0	6.5	7.0	7.5	8.0
Strongly Acid	Medium Acid	Slightly Acid	Neutral	Neutral	Mildly Alkaline	Moderately Alkaline

Best Range for Most Crops

Acidic, neutral, or alkaline (basic) soil is determined by the concentration of hydroxyl ions OH^- and hydrogen ions H^+ in the soil. Neutral soil has an equal combination of both hydroxyl and hydrogen ions; alkaline soil has more hydroxyl ions; and acidic soil has more hydrogen ions. From pH 7 to 0, the soil is increasingly more acidic, and from pH 7 to 14, the soil is increasingly more alkaline. pH stands for "power of hydrogen." Since the pH scale is logarithmic, one unit of change represents a tenfold change in the pH. This means that a soil pH of 6 has 10 times more hydrogen ions than a soil with a pH of 7, and a soil with a pH of 5 has 100 times more hydrogen ions than a soil with a pH of 7.

What's Your pH?

- Internet access for research (this part may be done at home for homework)

For each group:

- Plastic 100 ml beaker
- 3 paper cups
- Spoon and stir stick
- Waterproof markers

For each student:

- *What's Your pH? Lab* worksheet

Biological processes such as nitrogen fixation and decomposition of dead plant matter is optimal when pH is close to neutral. The availability of nitrogen, phosphorus, and potassium is best when soil pH is between 6.5 and 7.0.

In the western U.S., acid soils may be found in areas with sandy soils, high rainfall, and high levels of organic material. The weathering of granite and sandstone rocks also results in acidic soils. Limestone may be added to raise the pH of acidic soils. It does this by removing hydrogen ions from the soil.

Alkaline soils may be a result of arid conditions, soils high in sodium or parent rock material that is rich in calcium carbonate ($CaCO_3$). Elemental sulfur may be added to alkaline soils to lower the pH. Elemental sulfur forms sulfuric acid (H_2SO_4) when it reacts with oxygen and water in the presence of soil microbes. This lowers the pH. In small gardens, the addition of peat moss is also an acceptable way to lower the soil pH.

Soil that has a high amount of clay or organic material has a higher buffering capacity to resist a change in pH when base or acid forming materials are added. Soil texture and buffering capacity should be considered when determining the amount of acid or base forming material needed to adjust the soil pH.

Preparation

- Before the lesson, prepare three soil samples. Samples should be close to 5.0, 6.5, 8.0 pH. This will require a little trial and error. Mix a little bit of soil with a lot of sand to make a soil mixture with little buffering capacity (the more clay and organic matter in soil, the higher the resistance to change in pH). The sandy texture of the soil will reduce the soil's resistance to changing pH when you add acid or base forming materials.
- White vinegar may be used to lower the pH of the soil sample. (You may also use 0.5 M solution of hydrochloric acid if you need a stronger acid to change the pH or if you don't want students to guess that the soil sample is acidic based on the vinegar odor.)
- A drain cleaner may be used to raise the pH of the soil sample. (You may also use 0.5 M solution of sodium hydroxide if you need a stronger base to change the pH.) *Note: Traditional agricultural methods of adding lime to raise the pH and adding elemental sulfur to*

What's Your pH?

California Standards

Grade 8

Common Core English Language Arts

SL.8.1a
SL.8.1b
RST.8.3
RST.8.7
RST.8.9
WHST.8.1b
WHST.8.4

Next Generation Science Standards

- MS-PS1.B
- MS-LS2.A
- MS-ETS1.B

Grades 9-12

Common Core English Language Arts

- SL.9-12.1a
- SL.9-12.1b
- RST.9-12.3
- RST.9-12.7
- WHST.9-12.1b
- WHST.9-12.4

Next Generation Science Standards

- HS-ESS2.E
- HS-ETS1.B
- HS-ETS1.C

lower the pH takes months to alter pH, so we use drain cleaner and vinegar in this lab to instantly adjust our soil samples to our desired pH.

- Use an electronic pH meter to periodically measure the pH of the soil as acid and base are added until the desired level of acidity or alkalinity is reached. Label each soil sample 1, 2, and 3. The soil pH should be known by you, but not by your students.

Introduction

1. Tell students that in this lab they will act as agronomists, testing soil pH and advising farmers on methods for amending the soil for maximum crop productivity.
2. Ask students if they know what pH is. Ask students if they can predict whether some common household items are acidic or alkaline. Do a demonstration to show students the pH levels of items such as lemon juice (pH 2.3), orange juice (pH 3.5), vinegar (pH 4.3), milk (pH 6.4), dish soap (pH 10), saliva (pH 6-8), or soda (pH 2-3).
3. Ask students for ideas on why it would be important for farmers to know the pH of their soil. Use lesson background information to discuss the definition and importance of soil pH.
4. Tell students that they will be testing soil samples that were sent in from three farms. Demonstrate to the students how to use each of the three pH testing methods.
   - Use a pH testing kit based on barium sulfate in powdered form, where a small sample of soil is mixed with distilled water which then changes color according to the acidity or alkalinity.
   - Use pH paper. A small sample of soil is mixed with distilled water into which a strip of pH paper is inserted. Show students how to compare results to the pH paper color chart.
   - Use an electronic pH meter, in which a rod is inserted into moistened soil and measures the concentration of hydrogen ions.
5. Instruct students to complete the information on their lab reports. When finished, discuss class results and have groups share their recommendations for each farmer based on the soil pH test.

What's Your pH?

Helpful Websites for Student Research

Colorado State University Extension

- Listing of yard and garden publications available for free download
  www.ext.colostate.edu/pubs/pubs.html
- Soil pH garden notes
  www.cmg.colostate.edu/gardennotes/222.html
- Fertilizer cost calculations
  www.ext.colostate.edu/pubs/crops/00548.html

Ohio State University Extension

- Soil acidification: How to lower soil pH
  www.ohioline.osu.edu/agf-fact/0507.html
- Soil acidity and liming for agronomic production
  www.ohioline.osu.edu/agf-fact/0505.html

University of California Agriculture and Natural Resources

- Listing of publications
  www.ucanr.edu/Publications_524
- Sample costs and profitability analysis of various crops
  www.ucanr.org/freepubs/freepubsub.cfm?cat=1&subcat=17

Extension

- Have students collect soil samples from your school garden. Test the pH of the soil samples and research the type of soil amendments that could be added to correct the pH level if needed. As a class, come up with a detailed plan to amend the soil pH, purchase and apply the soil amendment, and monitor the pH for any changes over the next couple of months. Soil samples should be cored from the first six inches of soil.

What's Your pH?

Variations

- Instead of preparing soil samples of varying pH values, have students collect soil samples from their home, neighborhood, or community (while being respectful of private property). Test the pH of the soil samples and investigate explanations for differences in pH.
- In addition to testing the soil pH of the samples that the students collect, also test the soil texture. This is an important factor in the amount of lime or elemental sulfur needed to change the soil pH. Here's a guide to soil texture by feel: *soils.usda.gov/education/resources/lessons/texture*

ELL Adaptations

- Write down key terms so students can see them and connect them to the spoken word. If appropriate, connect a visual to each term introduced.
- As a class, create a flow chart to illustrate the procedure for the lab. Address questions that come up during the illustration process and prior to starting the lab.

What's Your pH? Lab

Name: ___________________________________

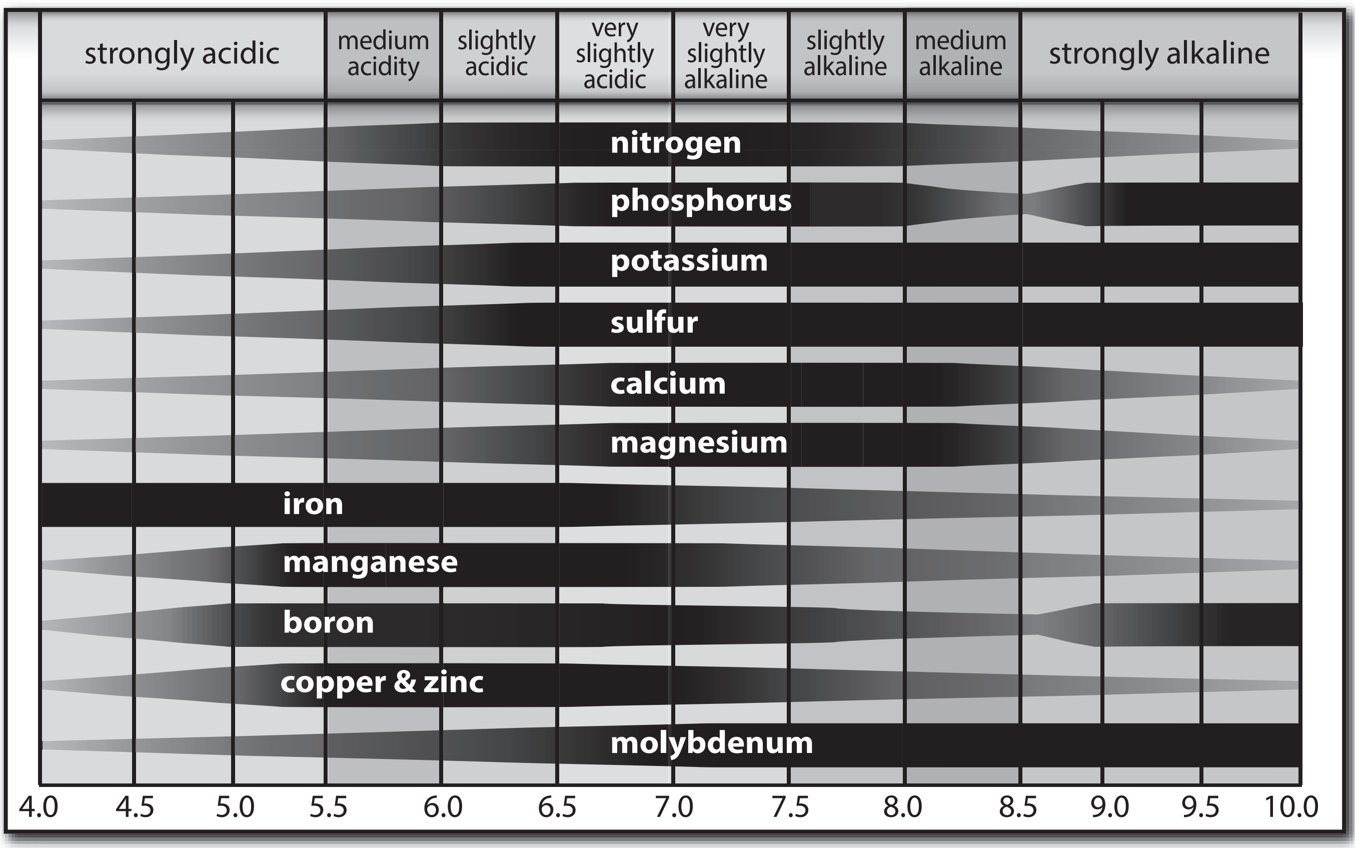
Introduction

Congratulations, you have a new job working as an agronomist for the University of California Cooperative Extension. Today, you are analyzing soil samples that were sent to you by local farmers. You will run a number of tests on the soil, but today you are concentrating on determining the soil pH. Soil pH is an important factor in the nutrient availability for plants. Once you know the pH of the soil from the farmers' fields, you will explain test results to farmers and will recommend the appropriate soil amendments to help each farmer maximize their crop production.

Procedure

1. Work in pairs. There are three soil samples in the lab. Soil sample one is from farmer Alice, soil sample two is from farmer Benny, and soil sample three is from farmer Carlotta. Mark each of your three cups with the appropriate name or number and place one spoonful of soil from each farmer's field in the respective cup.
2. Make a soil slurry by measuring out approximately twice the amount of distilled water as the amount of soil you have in your cup. Your goal is to have a soil slurry that is approximately two parts water to one part soil. Mix up the slurry with your spoon or stirring stick.
3. Select a method for testing your soil pH and follow the directions for using that test. For the most accurate results, use all three methods and take an average. Record your results on the chart.
4. Clean up your lab area.
5. Compare your test results to the nutrient availability chart on the back of this handout. Use classroom resources or the Internet to research information and fill out the report for each farmer.

Nutrient Availablity at Different Soil pH Levels



What's Your pH? Lab *(continued)*

Test Results

Farmer	Soil pH *using pH meter*	Soil pH *using pH test strip*	Soil pH *using soil pH test*	Average
Alice				
Benny				
Carlotta				

1. Based on a comparison to the nutrient availability chart:
   a. What nutrients might be limited in farmer Alice's field?
   ____
   b. What nutrients might be limited in farmer Benny's field?
   ____
   c. What nutrients might be limited in farmer Carlotta's field?
   ____

2. If needed, what method for amending soil pH would you advise for each farmer? When answering this question, consider the following factors: *(Internet research recommended)*
   - Cost of altering pH through addition of lime or elemental sulfur vs. cost of adding various nutrient amendments.
   - Cost of transportation and application of the amendment.
   - Options for growing crops best suited for existing soil pH.
   - Length of time needed for a measurable change in soil pH to occur.
   - Soil texture.
   - Form of the amendment: liquid, powder, or granular.

Farmer Alice

Add: ____

This recommendation is based upon the following facts:

____

____

____

What other information might you need to know about the soil in farmer Alice's 25 acre field to provide instructions on the type and amount of soil amendment needed to change the pH? List at least two questions.

____

____

____

____

What's Your pH? Lab *(continued)*

Farmer Benny

Add: ____

This recommendation is based upon the following facts:

____

____

____

What other information might you need to know about the soil in farmer Benny's 25 acre field to provide instructions on the type and amount of soil amendment needed to change the pH? List at least two questions.

____

____

____

____

Farmer Carlotta

Add: ____

This recommendation is based upon the following facts:

____

____

____

What other information might you need to know about the soil in farmer Carlotta's 25 acre field to provide instructions on the type and amount of soil amendment needed to change the pH? List at least two questions.

____

____

____

____

____

List at least five crops that do well in slightly acidic soil:

____

____

List at least five crops that do well in slightly alkaline soil:

____

____

What's Your pH? Lab Answer Key

Test Results

Farmer	Soil pH *using pH meter*	Soil pH *using pH test strip*	Soil pH *using soil pH test*	Average
Alice				5.0
Benny				6.5
Carlotta				8.0

1. Based on a comparison to the nutrient availability chart:

   a. What nutrients might be limited in farmer Alice's field?
   Nitrogen, phosphorus, potassium, sulfur, calcium, magnesium, molybdenum

   b. What nutrients might be limited in farmer Benny's field?
   Maybe calcium and magnesium, but others nutrients should be available based on the pH.

   c. What nutrients might be limited in farmer Carlotta's field?
   Phosphorus, iron, manganese, boron, copper, zinc

2. If needed, what method for amending soil pH would you advise for each farmer? When answering this question, consider the following factors: *(Internet research recommended)*

   - Cost of altering pH through addition of lime or elemental sulfur vs. Cost of adding various nutrient amendments
   - Cost of transportation and application of the amendment
   - Options for growing crops best suited for existing soil pH
   - Length of time needed for a measurable change in soil pH to occur
   - Soil texture
   - Form of the amendment: liquid, powder, or granular.

Farmer Alice

Add: *Lime to raise the soil pH*

This recommendation is based upon the following facts:
Adding lime would likely be more economical than adding all of the nutrients that may be lacking. This will raise the soil pH and make nutrients more available to crops.

Answers may vary. If you have the class time, students could spend another class period researching costs and doing calculations that correspond to the 25 acre fields of each farmer.
What other information might you need to know about the soil in farmer Alice's 25 acre field to provide instructions on the type and amount of soil amendment needed to change the pH? List at least two questions.

- *Meet with farmer Alice to walk her property and discuss the history of her farmland and management for clues on why her soil is acidic.*
- *Order a complete soil analysis to determine nutrient levels, texture, organic content, microbial activity, soluble salts.*
- *Test farmer Alice's irrigation water.*

What's Your pH? Lab Answer Key *(continued)*

Farmer Benny

Add: *First, do a soil test to determine if calcium and magnesium are lacking. If they are, research fertilizer choices that would supplement these nutrients.*

This recommendation is based upon the following facts:
The soil pH of 6.5 is near neutral and is suitable for many crops.

What other information might you need to know about the soil in farmer Benny's 25 acre field to provide instructions on the type and amount of soil amendment needed to change the pH? List at least two questions.

- *What crops does farmer Benny plan to grow?*
- *What supplements if any are being used on the farm now?*

Farmer Carlotta

Add: *Before adding anything, do a soil test to determine if the nutrients in question are in fact lacking. If they are lacking, analyze the cost between adding a fertilizer compound to supply those nutrients and adding elemental sulfur to lower the pH (adding elemental sulfur is often costly and may be more economical for horticultural production than agronomic crops).*

This recommendation is based upon the following facts:
Answers may vary. If you have the class time, students could spend another class period researching costs and doing calculations that correspond to the 25 acre fields of each farmer.

What other information might you need to know about the soil in Farmer Carlotta's 25 acre field to provide instructions on the type and amount of soil amendment needed to change the pH?

- *What crops does Carlotta plan to grow?*
- *Test the irrigation water at Carlotta's farm to see if this is a possible reason for the high soil pH.*
- *What types of fertilizer have been used in the past and present?*

List at least five crops that do well in slightly acidic soil:
Tomatoes, carrots, potatoes, sweet potatoes, blueberries, strawberries, soybeans, corn, squash, oats, cotton, or peanuts.

List at least five crops that do well in slightly alkaline soil:
Alfalfa, sugarbeets, cauliflower, spinach, celery, cabbage, turnips, Brussels sprouts, or mustard greens.

Know Your Nitrogen

Purpose

In this lesson, students will test for plant-available soil nitrogen and learn how farmers use this test to precisely match fertilizer application to meet crop needs and reduce the amount of nitrogen left in the soil in order to minimize nutrient loss and environmental impact.

Time

Teacher Preparation:
60 minutes

Student Activities:
Two 60-minute sessions

Materials

For the class:

- Two kitchen sponges
- Two clear bowls
- Two clear cups
- Water
- Food coloring, red
- Measuring cup
- Soil core sampling tubes (or use shovels to dig uniform cores from the first 6" of soil)
- A place to collect soil core samples
- Electronic scale

Background Information

Whether we are talking about your lawn, flower garden, or the wheat in your pasta dinner, plants need nutrients to grow. When crops are harvested the nutrients they utilized from the soil are removed with them. These nutrients must be replaced back into the soil so it remains fertile and can continue to grow crops in future years. Farmers and home gardeners use a variety of fertilizers to provide plants with essential nutrients. There are many different types of fertilizers that fit the needs of different crops and growing conditions. You may be familiar with fertilizers if you have applied compost, fish emulsion, animal manure, or other pre-packaged fertilizer to your lawn or garden. These fertilizers play an important role in growing beautiful flower gardens, green lawns, and providing affordable and nutritious food.

The use of any type of fertilizer comes with the responsibility to precisely follow instructions for storage, preparation, and application. From farms to home gardens and golf courses, we all must ensure that fertilizers are used correctly. Strict regulations, scientific research, and developments in new technology ensure that modern farming methods involve the selection of the appropriate fertilizer, application method, application timing, and monitoring of nutrients to provide crops with enough nutrients for optimum yield, while also protecting the environment. Applying too much fertilizer to crops can have adverse effects on the environment as well as the crop, and is an unnecessary expense. Replacing nutrients with fertilizer at the right time and in the right amount helps farmers grow enough food for an increasing world population as the amount of available farmland decreases. Achieving optimum yields without applying excessive nutrients is a goal of all farmers.

This lesson provides students with insight into one method farmers use to determine the amount of nitrogen fertilizer their crop may need. Of the primary nutrients, farmers are especially interested in nitrogen for several reasons. Nitrogen is required for plants to form proteins which make up much of their tissues, and nitrogen availability is often limited in the soil. While 78% of our atmosphere is nitrogen gas, most plants cannot use this form of nitrogen. Nitrogen is most available to plants when it is in the nitrate (NO_3^-) form or when it is in the ammonium (NH_4^+) form. Nitrogen can be made available in plant-usable forms of nitrogen through the action of nitrogen-fixing microbes found in the soil and the root nodules of some types of plants, such as legumes. These forms of nitrogen can also be supplied to plants through the use of various types of fertilizers.

Know Your Nitrogen

- Food or aquarium grade calcium chloride
- One gallon of distilled water (add 6 grams of calcium chloride to 1 gallon of distilled water to make up the 0.01 M calcium chloride solution)

For each group:

- One, 10-500 ppm nitrate test strip.
- 50 ml centrifuge tube
- Quart-sized resealable bag
- Waterproof marker
- Nitrate test strip color chart (download from *LearnAboutAg.org/chemistry*)

For each student:

- *Summary of 2008-09 Large Scale Irrigation and Nitrogen Fertilizer Management Trials in Lettuce* (pages 69-70)
- *Nitrate Quick Test Procedure* (pages 71-72)
- *Know Your Nitrogen Lab* instructions and data handout (pages 73-74)

Before applying fertilizers, farmers test their soil to determine factors such as texture, pH, porosity, organic matter, nutrient content, and more. Farmers also test the tissues of the crops they are growing to compare with the nutrient components from the soil analysis. These factors are important in determining which nutrients to use, how much and when to apply, and how to irrigate. These considerations ensure the best utilization by plants for healthy and efficient crop production.

The California Department of Food and Agriculture's Fertilizer Research and Education Program (FREP) funds research on new techniques for managing agricultural nitrogen and develops workshops and training programs for farmers and ranchers. California state and regional water boards regulate, monitor, and provide financial assistance to protect water resources and achieve water quality objectives.

Procedure

1. Prior to the lesson, place a slightly damp, but not saturated, kitchen sponge above a clear bowl. The bowl should be small enough so that the sides of the sponge suspend it slightly above the bottom of the bowl. Repeat with a second sponge and clear bowl. Prepare two separate cups of water, one containing ½ cup of water and the other containing one cup of water. Also have one bottle of red food coloring on hand.
2. Tell students that in this example the sponge represents an agricultural field. Just like a sponge, soil can only hold a certain amount of water. Explain that in this demonstration the red food coloring represents a fertilizer solution.
3. Ask for two volunteers to come to the front of the room. The volunteers represent farmers who irrigate their crops differently. Instruct each student to place two drops of food coloring in the center of their sponge. Now instruct the student with ½ cup of water to slowly pour the ½ cup of water onto the center of one sponge. Instruct the other student to slowly apply one cup of water to the center of the other sponge. Have students record their visual observations about the process, and the amount of leachate that accumulates under the sponge, in a science journal or notebook.

Know Your Nitrogen

California Standards

Grade 8

Common Core English Language Arts

RI.8.1
RI.8.10
W.8.7
W.8.9
SL.8.1a
SL.8.1b
RST.8.3
RST.8.7
RST.8.9

Next Generation Science Standards

MS-LS2.A
MS-LS2.B
MS-ESS3.C
MS-ETS1.B

Grades 9-12

Common Core English Language Arts

RI.9-12.1
RI.9.10
W.9-12.7
W.9-12.9
SL.9-12.1a
SL.9-12.1b
RST.9-12.3
RST.9-12.7
WHST.9-12.1b
WHST.9-12.4

Next Generation Science Standards

HS-ESS2.E
HS-ESS3.A
HS-ESS3.C
HS-ETS1.A
HS-ETS1.B

A class discussion should bring up the following points:

a. The sponge, like soil, can only hold a certain amount of water. The phrase "water holding capacity" describes the ability of a particular type of soil to hold water against the force of gravity. Soil can only hold a limited amount of water.

b. After the sponge reached its water holding capacity, the water moved through the sponge carrying the fertilizer with it. Today's farmers and scientists work together to implement nutrient management practices that protect the environment and apply the precise amount of nutrients and irrigation needed by the crop.

c. Since water carries the fertilizer to the plant roots, it is important to understand how water travels through soil. California regulatory agencies, farmers, ranchers, and educational organizations are constantly working on research and monitoring projects to utilize the best nutrient management practices possible while growing healthy crops.

4. Explain that in this lesson, students will carry out the same nitrate soil test used by farmers to measure soil nitrate levels in order to match fertilizer application rates to the needs of their crops.

Variations

- Experiment with drainage in different soil types. Have students collect soil samples and determine the soil texture using a field test, laboratory analysis, or soil map. Allow students to use different soil types in their experimentation. Discuss the role of percolation and the soil's water holding capacity in drainage.

Extensions

- Introduce students to the 4Rs of nutrient stewardship—the right source, right rate, right time, and right place. "The Right Way to Grow: 4R Nutrient Stewardship" is an 11-minute video which gives an overview of the 4Rs and explains how stewardship applies to large-scale agriculture producers as well as small farms. The International Plant Nutrient Institute hosts a number of videos related to nutrient management on their YouTube channel, *www.youtube.com/plantnutritioninst*.

- Have students research best management practices used by farmers to protect water quality, including buffer zones, de-nitrification beds, and conservation tillage. Have student groups make a poster about individual best management practices and present it to the class.
- Prior to running the Nitrate Quick Test, teach a brief lesson on soil texture by using one of the following:

  1) *www.soils.org*
  2) soils4teachers.org/lessons-and-activities
  3) soils.usda.gov

ELL Adaptations

- Write down key terms so students can see them and connect them to the spoken word. If appropriate, connect a visual to each term introduced.
- As a class, create a flow chart to illustrate the procedure for the *Know Your Nitrogen* lab. Address questions that come up during the illustration process and prior to starting the lab.

Know Your Nitrogen Lab

Lab Procedure

1. As a class, read the *Summary of 2008-09 Large Scale Irrigation and Nitrogen Fertilizer Management Trials in Lettuce* by Michael Cahn and Richard Smith, Farm Advisors, Monterey County (pages 69-70). This is a technical document and students may have difficulty understanding the terminology. The reason for including this reading in the lesson is to help students understand that fertilizer application is complex and involves a great deal of science.

2. As a class, discuss the article. Were students surprised by the precision involved in modern agriculture? Make a list on the board of all the things these farmers needed to know about their crop and their soil. What skills would students need to run a lettuce farm like the one described in the article? Make a list on the board.

3. Tell students that they have earned a spot as an intern for the UC Cooperative Extension farm advisor in your county: "Your boss has given you an assignment to collect soil core samples from a local lettuce farm. You will need to collect numerous samples from the field and you have decided to enlist your classmates to help collect soil samples. Once you have collected your soil samples, you will return with them to the lab and will follow lab procedures that your boss has printed out for you."

4. Distribute the handouts for the *Know Your Nitrogen* lab and *Nitrate Quick Test Procedure*. Go over lab safety procedures and remind students to carefully read the instructions and gather the necessary materials before starting the lab. During the first day of the lab, demonstrate the correct method for soil sampling and draw a grid on the board to show where each group will sample the field. This will help ensure that a representative sample is collected. Lead students to the designated location to collect soil sample cores.

    - While students are collecting soil samples for the Nitrate Quick Test, you can do a quick assessment of the soil texture using this guide: *http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054311*

Know Your Nitrogen Lab

5. In addition to collecting soil samples, we are also interested in soil drainage. Soil texture, shallow soil with fractured bedrock, and soils with a water table close to the surface all affect soil drainage. There are precise laboratory methods for determining soil porosity and soil drainage, however, we can do a quick assessment with a shovel and some water.
    - Ask two students to volunteer to dig a hole that is one square foot wide by 12 inches deep, level on the sides and bottom.
    - Once the hole is dug, students should fill it with water and let it soak in for an hour or so. When all the water has drained, the hole should be refilled with water and students should note the amount of time it takes for the water to soak in. If the water drains faster than 4 inches per hour, the soil is highly porous. Soil with low porosity will drain less than one inch per hour.
    - Soil porosity is the amount of pore space occupied by water and gases in the soil. Ask students why farmers would be interested in soil prorosity and soil drainage.
6. On the second day of the lab, students will follow the lab procedures for carrying out the Nitrate Quick Test on their soil samples.
7. After students have completed the nitrate soil test, ask them to write their nitrate level on the board in their assigned soil grid space. Discuss the class findings and provide any guidance the students may need before moving on to the lab questions.

SUMMARY OF 2008-09 LARGE SCALE IRRIGATION AND NITROGEN FERTILIZER MANAGEMENT TRIALS IN LETTUCE

Michael Cahn and Richard Smith, Farm Advisors, Monterey County

In 2008 and 2009 five large scale trials were conducted to demonstrate practices to improve irrigation and nitrogen fertilizer management in romaine and iceberg lettuce in the Salinas Valley. Managements included 1) scheduling irrigations based on weather and soil based information, and 2) using the nitrate quick test to match fertilizer rates with the nitrogen needs of the crop at different growth stages. These practices can improve the efficiency of water and fertilizer application, reduce losses and provide tools for optimizing yield and quality of lettuce. The combined nitrogen and water management practices were referred to as the BMP (best management practices).

Procedures Trials were designed to compare the BMP and standard grower practices on large replicated strips in commercial fields located in the northern and southern parts of the Salinas Valley (Table 1). The management strips were 160 feet wide by the length of the field. Trials ranged from 15 to 27 acres in size. Soil textures ranged from silty clay to sandy loam at the trial sites. Trial No. 1 was irrigated with overhead sprinklers throughout the crop cycle; all other crops were irrigated with sprinklers for approximately the first 30 days of the crop followed by surface placed drip tape until harvest. Irrigations were scheduled from estimated consumptive water use for lettuce which was based on CIMIS evapotranspiration data and the water holding capacity of the soil. Applied water of the different management treatments was monitored using flow meters. Nitrogen fertilizer recommendations were based on weekly determinations of soil nitrate in the top foot of soil using the nitrate quick test. Soil moisture data and plant biomass was compared weekly between management treatments. Leachate during irrigation events was sampled using a suction lysimeter. Yields evaluations of trials were made in two ways: 1) small plots (two 100 ft² 13.3 ft plots) located within the management strips for all trials, and 2) cored lettuce using commercial equipment to harvest the center 12 beds of the management strips.

Summary of Results

Water and nitrogen fertilizer application was significantly reduced in the BMP treatment (Tables 2 and 3), averaging 121 lbs of N/acre and 11.2 inches of water for the BMP treatment and 176 lbs of N/acre and 13.7 inches of water in the grower standard treatment for all trial sites. The greatest reductions in nitrogen fertilizer and water were in Trial 1 and Trial 3, and 139 lbs of N/acre and 7.5 inches, respectively. Trial 2 had the least reduction in water and fertilizer because the grower standard practice was similar to the BMP treatment.

Monetary savings for applied fertilizer and water (Tables 2 & 3) were highest in Trial 1 site ($99/acre) and least for Trial 2 ($15/acre). Average savings in water and fertilizer for the 5 trials was $41/acre. Although average water savings were less than fertilizer savings ($9/acre for water and $33/acre for nitrogen fertilizer), careful water management is needed to prevent nitrogen fertilizer losses through leaching.

Evaluating root distribution and nitrate distribution by digging a pit down to 2.5 feet indicated that most roots were in the top foot of soil, but that most nitrate was lower in the profile (Figures 1 & 2). Monitoring of water use, soil moisture and nitrate concentration of leachate demonstrated that nitrate nitrogen leached below the 2 foot depth in both treatments. Nitrate-nitrogen concentrations in leachate sampled with a

Summary *(continued)*

suction lysimeter ranged from 105 to 178 ppm (Tables 4 & 5). During germination, there was less nitrate leached in the BMP treatment at one site where the germination water was carefully managed (Table 4), but the magnitude of savings were less at another site where more water applied to the BMP treatment during germination to compensate for hot weather conditions (Figure 3). However, after thinning and the installation of the drip system minimal losses of nitrate occurred in both the BMP and standard treatments because the applied water amounts were close to the crop evapotranspiration requirements. In contrast, following thinning and a sidedress application, higher leaching was observed in the standard treatment during a single sprinkler irrigation application (Table 5) because substantially more water was applied than the crop requirements.

Applying water rates closer to consumptive water use in the BMP treatment minimized nitrate leaching and reduced the economic loss of applied nitrogen to the crop.

Soil nitrate levels were higher in the BMP treatment over the course of the growing season in spite of the lower total nitrogen application. This observation indicates that by applying irrigation water at rates close to consumptive use of the crop, nitrate can be effectively maintained in the root zone and leaching losses can be minimized. This can save growers money (Table 2) and help to safeguard water quality.

Large scale commercial yield evaluations in four of the trials indicated that the BMP treatment yielded from 98 to 101% of the standard treatment (Table 6).

Conclusions

These trials demonstrated that careful water management and nitrogen fertilizer management can result in equivalent yields, save money and provide water quality benefits. In addition, reducing nitrate leaching could minimize nitrogen loading to our regional aquifer. The main tool for improving irrigation scheduling for lettuce is using CIMIS evapotranspiration data and soil water holding properties to estimate a reasonable irrigation schedule that will maintain yields and minimize percolation of nitrate. The nitrate quick test can provide guidance for management of fertilizer nitrogen. Taken together these techniques can provide growers with tools to help make decisions to improve the efficiency of lettuce production.

Nitrate Quick Test Procedure

Courtesy of University of California

Using the Pre-Sidedressing Soil Nitrate 'Quick Test' to Guide N Fertilizer Management April 2010
By T.K. Hartz, Extension Specialist, Department of Plant Sciences, University of California, Davis

In California vegetable fields nitrate-form nitrogen (NO_3^-) can build up to levels high enough to supply crop nitrogen demand for an extended period. Sampling the root zone soil for NO_3^- concentration before sidedressing can identify fields in which N application can be delayed or reduced without affecting crop productivity. Collection of a composite soil sample representative of the entire field is necessary to make an accurate determination of soil nitrate status. Eight to 12 soil cores from throughout the field is usually adequate. Sample depth should cover the active root zone, which for most vegetable crops is the top foot of soil. Collect the soil cores starting in a plant row and angling the core toward the bed center. Be sure not to sample the zone where a fertilizer band has been recently applied. Thoroughly blend the soil cores together. Laboratory analysis is the most accurate method of soil nitrate determination, but a semi-quantitative estimate of soil nitrate concentration can be made using the following on-farm 'quick test' procedure. The advantages of this procedure are:

- Results can be obtained in less than an hour for most soils
- No weighing or drying of soil is required, although you do need to estimate the soil texture and moisture content.

Procedure

1. Make the extracting solution by dissolving approximately 6 grams of calcium chloride (about one teaspoon) in a gallon of distilled water. The concentration of this solution is approximately 0.01 Molar. Your teacher will do this.
2. Fill a volumetrically marked tube or cylinder to the 30 ml level with the extracting solution. Any volumetrically marked tube or cylinder will work, but 50 ml plastic centrifuge tubes with screw caps are convenient and reusable.
3. Add the soil to the tube until the level of the solution rises to 40 ml; cap tightly and shake vigorously until all soil clods are thoroughly dispersed. It is critical that the soil you test is representative of the sample; for moist clay soils that are difficult to blend, pinch off several small pieces of each soil core. Testing duplicate samples will minimize variability.
4. Let the sample sit until the soil particles settle out and a clear zone of solution forms at the top of the tube. This may take only a few minutes for sandy soils, but as much as an hour or more for clay soils.
5. Dip an EM Quant® nitrate test strip into the clear zone of solution, shake off excess solution, and wait 60 seconds. Compare the color that has developed on the strip with the color chart provided. When the strip color is between two color samples on the chart, interpolate the nitrate concentration of the strip as closely as possible. The strip color will continue to darken with time, so make the determination between 60 and 70 seconds after dipping the strip.

Interpretation of Results

The nitrate test strips are calibrated in parts per million (ppm) NO_3^-. Conversion to ppm NO_3^- in dry soil requires dividing the strip reading by a correction factor based on soil texture and moisture content:

Strip reading ÷ Correction factor = ppm NO_3^- in dry soil

Correction Factor

Soil Texture	Moist Soil	Dry Soil
Sand	2.3	2.6
Loam	2.0	2.4
Clay	1.7	2.2

- Soil less than 10 ppm NO_3^- on a dry soil basis has limited N supply, and fertilization is usually justified.
- Soils between 10-20 ppm NO_3^- have enough N to meet immediate plant needs but a modest amount of sidedress N may be appropriate.
- In soil with NO_3^- greater than 20 ppm, additional N application should be postponed until retesting shows that residual soil NO_3^- has declined.

Know Your Nitrogen Lab

Name: ______________________________________

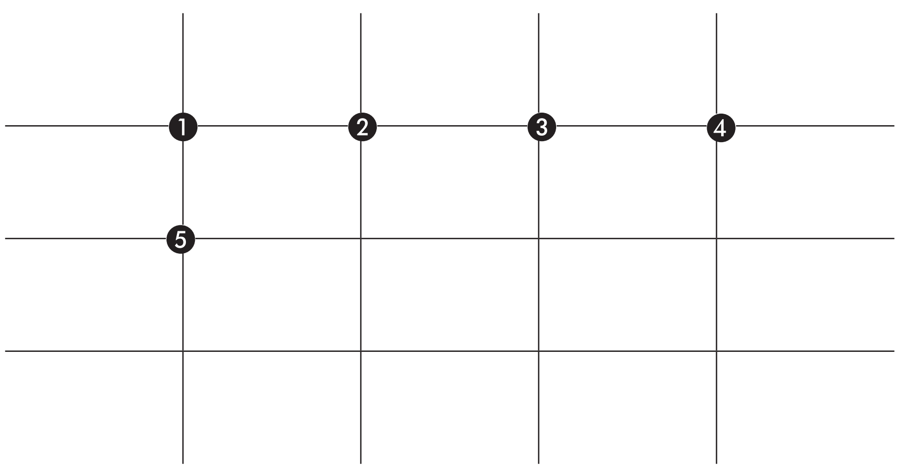
You have landed an intern position with your county farm advisor at the UC Cooperative Extension. Your boss has been teaching you about soils, plant nutrient requirements, fertilizers, and water quality monitoring. You are excited to receive the first job assignment that you will carry out on your own.

Your job is to perform nitrate tests on soil samples that you will collect from a local lettuce farm. Once you have the test results, you and your boss will work on a recommendation for the lettuce farmer that will maximize crop productivity while minimizing the risk of nitrate run off.

Nitrogen is a very important nutrient for plant growth. It is your job to help the farmer produce a healthy crop through the appropriate use of fertilizers while also protecting environmental quality.

Collecting Soil Samples

Your first step is to collect soil samples with your classmates. The following grid shows an example of how to collect representative soil samples from the field. Groups may collect soil samples from intersecting points on the transect lines, possibly intersecting every 15 feet (continue numbering the grid below and assign numbers to each group). Use a soil core sampler or shovel to dig a uniform soil core sample 6 inches deep. Place the soil sample in a plastic resealable bag and label it with the grid location with a waterproof marker.



Know Your Nitrogen Lab Data Sheet

Name: ______________________________________

Your boss informed you that the soil texture from the lettuce field is _________________________ and the soil moisture is _________________________ .

Use the correction factor from the chart on the Nitrate Quick Test Procedure hanout to convert your nitrate test strip reading to ppm.

1. Write your nitrate level from your core sample here ___________________________ in ppm and on the board in the grid spaces that you sampled from the field.
2. What is the average nitrate level from your compiled class data? _________________________________
   - Examine the soil sampling grid on the board. Discuss any variances in nitrate levels as a class. Could this be sampling error or is something else causing a difference in nitrate levels in the field?

Use the nitrate test interpretation guide to answer the following questions:

3. Does the lettuce farmer need to apply fertilizer containing nitrogen? ______________________________
4. Explain your reasoning:

   ____

   ____

   ____

   ____

5. Do some research and list three different fertilizer options that would add nitrogen to the soil.

   ____

   ____

6. Describe the results of your soil drainage test.

   ____

   ____

   - List at least three reasons why this would be of interest to the farmer.

     ____

     ____

     ____

7. Write a one-paragraph summary to the lettuce farmer explaining the results of the nitrate test and your recommendation for fertilizer application. Include three supporting facts to support your recommendation. Address precautions for reducing risk of nitrates moving off site from the lettuce field, soil drainage, and other data that needs to be collected from the farm.

Answers to Commonly Asked Questions

What is fertilizer?

A fertilizer is a substance that provides one or more chemical elements necessary for plant growth and development. There are two classes of fertilizers: organic fertilizer and inorganic, or commercial, fertilizer. Either type can be used by farmers and home gardeners to replace nutrients removed from the soil by previously harvested crops or to add nutrients that may be naturally lacking in the soil. Plants do not have a preference for either type. Some differences and similarities between these two types of fertilizers are described below.

Organic fertilizers are fertilizers that originate from living organisms and go through very little processing before being used on crops. Some organic fertilizers include fish and seaweed emulsions that are made by liquefying seaweed and fish. Other examples include compost, worm castings, bone meal, ground oyster shells, and steer and chicken manure. Organic fertilizers usually contain many different nutrients in low concentrations. Their nutrients are often in forms that must be broken down by microorganisms before they can be used by plants. The release of nutrients takes time, especially in cold weather when microorganisms in the soil are less active. In addition to adding nutrients to the soil, organic fertilizers also add organic matter that improves soil structure by increasing pore spaces, air circulation, and water holding capacity.

Some organic fertilizers can be labor and cost intensive to apply on large fields; with their low nutrient concentrations, large quantities may be needed to supply sufficient nutrients for growing crops. If manures are not composted before being used as a fertilizer, they can be a source of weed seeds or can damage plants if the manure has high salt content.

Inorganic or commercial fertilizers are fertilizers that are refined in factories from nitrogen gas from the atmosphere and other natural materials like rocks, minerals, petroleum, and animal products. Commercial fertilizers are prepared to contain exact amounts of nutrients in forms that can be immediately used by plants. They generally contain nitrogen, phosphorus, potassium, and a few trace minerals at concentrated levels. Some examples of commercial fertilizers are potassium sulfate and ammonium phosphate.

Nitrogen is the most abundant element in the Earth's atmosphere, but plants cannot absorb atmospheric nitrogen gas form the air. It must be in a special form to be used by plants. Inorganic nitrogen fertilizer is made by combining hydrogen and nitrogen form the air.

Inorganic phosphorus is made by mixing phosphate rock, mined from the earth, with sulfuric acid and water.

Potassium fertilizer is commonly called potash (pronounced "pot ash"). This name comes from the fact that the ashes left over from a campfire contain potassium and were, throughout history, put into fields. Inorganic potassium is usually obtained by mining. Potash is mined in New Mexico, Utah, and parts of Canada. Potassium can also be obtained from brine (salt) deposits on the Earth's crust. Brine deposits are places where large bodies of salt water used to exist and evaporated, leaving the salt behind. One example of a brine salt deposit are the salt flats near the Great Salt Lake in Utah.

Inorganic fertilizers are used by many farmers for a variety of reasons. They are easy to transport, store, and apply, and exist in a variety of formulas to meet the specific nutrient requirements of crops. Some of these fertilizers are formulated to be high in nitrogen while others are high in phosphorus or potassium.

Whether using organic or commercial fertilizer, farmers and home gardeners must take care to use fertilizers appropriately. Applying too much of either organic or commercial fertilizer can damage plants, waste money, and impact the environment. Farmers work closely with scientists to determine the best types of fertilizers for their crops, when to apply, how much to apply, and how to protect the environment. Home gardeners can take courses or obtain information about proper use of fertilizers from local garden clubs and university cooperative extension offices.

Why do plants need fertilizer?

Just like humans, plants require certain nutrients for survival. Plants require 17 chemical elements. These nutrients are used to build different plant components. For example, carbon, hydrogen, and oxygen are used to build plant foods of sugars and starches. Nitrogen is needed to make chlorophyll and plant proteins. Phosphorus provides energy for plants to grow and is important in root growth. Potassium helps plants fight stress and disease, and grow strong stems. If the necessary elements are available to the plants, fertilizers do not need to be added to the soil.

Answers to Commonly Asked Questions

As crops grow, they take up nutrients from the soil. When harvested, those crops take those absorbed nutrients with them. When nutrients are lacking in the soil, fertilizers are added to replenish the nutrients removed by previously grown crops.

What do the three numbers on a fertilizer label mean?

The three numbers on a fertilizer label stand for the percentages of nitrogen, phosphorus, and potassium in that particular fertilizer. These three elements are the major nutrients required by plants for growth and reproduction. For standardization, nitrogen (N) is always listed first, followed by phosphorus (P) and then potassium (K). When buying a fertilizer, one should consider the nutrients their plants need and buy a fertilizer containing the proper nutrient combination.

Why do some fertilizers require people to wear protective clothing such as masks or gloves?

Most commercial fertilizers are more concentrated than natural manures and composts. They are also applied in salt form. Large quantities of salt draw water out from cells and cause them to dehydrate. This can cause irritation to skin cells, eyes and lungs. For most household fertilizers, rinsing exposed areas with generous amounts of water will prevent damage. However, it is always better to be cautious when applying chemicals of any type.

Why do plants die if they get too much fertilizer?

Most fertilizers are applied as salts. Any type of salt is water-loving and attracts water. Fertilizers draw water from plant cells. If too much fertilizer is applied to a plant, the plant cells dehydrate and become brittle and sometimes discolored. This is called burning plants. The plants don't actually catch on fire, this term simply means that the plants lose moisture.

In what ways do manures benefit plant growth?

Manures are animal excrements. Manures contain nutrients that can be used by plants as well as organic matter that improves soil texture. Plants must not only have nutrients but must also grow in soil that has good aeration and can hold water. Animal manures vary in nutrient composition depending on the type of animal and the diet of the animal.

Answers to Commonly Asked Questions

How are fertilizers made?

Fertilizers can be natural or man-made. Natural fertilizers are substances such as manures and composts. Nitrogen can be made available to plants by the natural process of nitrification, where bacteria convert atmospheric nitrogen to nitrogen that can be used by plants. Many fertilizers are manufactured in factories using materials from the earth and atmosphere.

- Nitrogen gas makes up approximately 78% of our atmosphere. Nitrogen gas can be combined with natural gas in a complex factory process to change it into a form that plants can utilize.
- Phosphorus is usually made into fertilizer by mining phosphate rock and combining it with sulfuric acid (which comes from fossil fuels).
- Potassium often is obtained from salt deposits throughout the world like those of the Great Salt Lake in Utah.

What is hydroponics?

Hydroponics is a process in which plants are grown in water instead of soil. This is possible when the required nutrients are available in the water and the plants have some sort of support system to hold them up.

Why does manure smell?

Bacteria and other organisms decompose manure converting it to organic matter. During this process the bacteria release different gases as their waste products. Some of these gases smell. Ammonia substances are commonly given off as bacterial decomposition by-products.

Why do plants yellow if they do not have enough nutrients?

Yellowing is a sign of an unhealthy plant. There are many causes of yellowing, but generally it means that the process of chlorophyll formation is interrupted. Chlorophyll is the green substance in plants that absorbs energy from the sun and is used to convert carbon dioxide and water into sugars and starches. Certain elements are needed to build the chlorophyll molecule. If they are not available, chlorophyll cannot be produced and the plant turns yellow and eventually dies.

Answers to Commonly Asked Questions

What would happen to food prices without fertilizer?

A fertilizer is a substance that provides one or more chemical elements necessary for plant growth and development. This could include pre-packaged fertilizers bought from your local garden center, compost from kitchen waste, or animal manure. Both conventional and organic farmers use fertilizer to provide crops with the nutrients essential to supply consumers with nutritious, affordable food.

The United Nations projects that the world's human population will increase by at least two billion in the next 40 years. While the human population is growing, the amount of available farmland is not. Fertilizers make it possible to grow more food on less land. As crops grow, they take up nutrients from the soil and assimilate them into plant parts that people and livestock eat. These nutrients must be replaced back into the soil to maintain fertile farmland that is capable of producing crops year after year.

Without fertilizer, soil fertility and productivity drop. Prices go up when food is in short supply. People in the U.S. spend less on food than any other country in the world. U.S. farmers use science and technology to make the most efficient use of resources possible which helps keep food prices down while supplying safe, abundant, and nutritious food.

Is fertilizer harmful to the environment?

Fertilizers are an important tool in helping farmers produce enough food for our growing world population. Advances in science and agriculture techniques allow farmers to use a very high level of accuracy when applying nutrients to the soil in order to protect water, soil, and air resources.

With the use of fertilizer, farmers are able to grow more food on less land. This is important because the amount of available farmland decreases as cities and towns continue to grow with our increasing population.

Agricultural Organizations

General

American Farm Bureau Foundation for Agriculture
600 Maryland Avenue SW, Suite 1000W
Washington, DC 20024
Toll free: (800) 443-8456
E-mail: *foundation@fb.org*
Website: *www.agfoundation.org*

California Department of Food and Agriculture
1220 N Street
Sacramento, CA 95814
Phone: (916) 654-0466
Toll free: (800) 735-2929
Website: *www.cdfa.ca.gov*

California Farm Water Coalition
6133 Freeport Boulevard, 2nd Floor
Sacramento, CA 95822
Phone: (916) 391-5030
Fax: (916) 391-5044
Website: *www.farmwater.org*

California Foundation for Agriculture in the Classroom
2600 River Plaza Drive, #220
Sacramento, CA 95833
Phone: (916) 561-5625
E-mail: *info@LearnAboutAg.org*
Website: *www.LearnAboutAg.org*

National 4-H Cooperative Curriculum System, Inc.
405 Coffey Hall, 1420 Eckles Avenue
St. Paul, MN 55108-6068
Phone: (612) 624-4900
Toll free: (800) 876-8636
E-mail: *shopext@umn.edu*
Website: *www.n4hccs.org*

Agricultural Organizations

National Future Farmers of America Foundation
6060 FFA Drive
Indianapolis, IN 46268
Toll free: (888) 332-2668
E-mail: *kmumaw@ffa.org*
Website: *www.ffa.org*

University of California
Agriculture & Natural Resources Communication
Services Publications
1301 South 46th Street, Building 478
Richmond, CA 94804
Toll-free: (800) 994-8849
E-mail: *anrcatalog@ucdavis.edu*
Website: *anrcatalog.ucdavis.edu*

Teacher Resources and References

Gardening

California School Garden Network
Detailed step-by step instructions for creating a school garden. Includes a list of resources, training opportunities, and fundraising ideas.
Grades K-Adult
Free; available online

Website: *www.csgn.org*

Common Ground Garden Program
Information on many gardening topics, including tips, school and community gardens, composting, container gardening, saving water, and recycling.
Adult
Free; available online only

University of California Cooperative Extension
4800 East Cesar E. Chavez Avenue
Los Angeles, CA 90022
Phone: (323) 260-3407
E-mail: *ydsavio@ucdavis.edu*
Website: *celosangeles.ucdavis.edu/Common_Ground_Garden_Program*

National Gardening Association
Provides free educational gardening materials, grants, and resource to K-12 teachers.
Grades K-Adult
Free; available online

National Gardening Association
237 Commerce St., Suite 101
Williston, VT 05495
Phone: (802) 863-5251
Website: *www.garden.org*

Teacher Resources and References

Nutrients for Life
This organization provides free resources to teachers to teach a variety of topics on gardening including plant nutrients and soil properties.
Grades K-12
Free

Nutrients for Life Foundation
Capitol View
425 Third Street, SW, Suite 950
Washington, DC 20024
Phone: (800) 962-9065
E-mail: *info@nutrientsforlife.org*
Website: *www.nutrientsforlife.org*

Worms Eat My Garbage
This 176-page book, written by Mary Appelhof, is a guide to vermicomposting, a process using redworms to recycle food waste into nutrient-rich food for plants. ISBN 978-0-9778045-1-1
Grades K-Adult
$12.95 plus $3.50 s/h

Flowerfield Enterprises, LLC
10332 Shaver Road
Portage, MI 49024
Phone: (269) 327-0108
Email: *nancy@wormwoman.com*
Website: *www.wormwoman.com*

Soil

California Fertilizer Foundation
The California Fertilizer Foundation provides information about plant nutrients and agriculture. School garden grants are also available.
Grades K-12
Free online information

California Fertilizer Foundation
4460 Duckhorn Drive, Suite A
Sacramento, CA 95834
Email: *maryj@healthyplants.org*
Website: *www.calfertilizer.org*

Teacher Resources and References

Comparing Apples and… Earth?
A hands-on activity that uses an apple to explore how much of the Earth's surface is needed to grow food for a world of people.
Grades K-12
Free download, and video, at *www.LearnAboutAg.org/agbites*

California Foundation for Agriculture in the Classroom
2600 River Plaza Drive, #220
Sacramento, CA 95833
Phone: (916) 561-5625
Fax: (916) 561-5697
E-mail: *info@LearnAboutAg.org*
Website: *www.LearnAboutAg.org*

Soil Biology Primer
The Soil Biology Primer introduces the living component of soil and how it contributes to agricultural productivity and to air and water quality. The primer includes information on the soil food web and how the web relates to soil health.
Grades 8-Adult
$18 plus s/h

Soil and Water Conservation Society
945 SW Ankeny Road
Ankeny, IA 50023
Phone: (515) 289-2331 ext. 126
Toll-free: (800) THE-SOIL
Email: *pubs@swcs.org*
Website: *www.swcs.org*

Soils Sustain Life

Teacher Resources and References

Soil science is the study of Earth's land and water resources as they relate to agriculture, forestry, rangeland, ecosystems, urban uses, and mining and reclamation. This brochure defines soil science and its importance, identifies soil scientists and what they do, and provides information about career opportunities.
Grades 7-12
Free; online

Soil Science Society of America
677 South Segoe Road
Madison, WI 53711
Phone: (608) 268-4949
Email: *lmalison@soils.org*
Website: *www.soils.org*

Field Trip

The Center for Land-Based Learning
Two programs: the FARMS Leadership Program (statewide) and the SLEWS Program (Northstate, Sacramento Valley, Napa, and San Joaquin). Both are hands-on, experiential learning programs that take students out of the classroom and onto farms, ranches, wildlife areas, and post-secondary institutions to teach them about sustainable agriculture, conservation, and the environment. The headquarters in Winters is also an educational farm, which can host school classes for outdoor activities and field days.

Center for Land-Based Learning
5265 Putah Creek Road
Winters, CA 95694
Phone: (530) 795-9569
Website: *www.landbasedlearning.org*

Related Websites

California Department of Food and Agriculture
www.cdfa.ca.gov

California Foundation for Agriculture in the Classroom
www.LearnAboutAg.org

Fertilizer 101
www.fertilizer101.org

The Fertilizer Institute
www.tfi.org

International Plant Nutrition Institute
www.ipni.net

Natural Resources & Conservation Service
www.soils.usda.gov

Nutrients for Life
www.nutrientsforlife.org

Plants Database
www.plants.usda.gov

United States Department of Food and Agriculture
www.usda.gov

United States Environmental Protection Agency: Water Page
www.water.epa.gov

University of California Agriculture and Natural Resources
www.ucanr.org

Related Literature

Fertilizer 101. The Fertilizer Institute, 2010.
This book serves as a tool for fostering a better understanding of fertilizer and its role in world food production, the environment and the global economy. This new book answers readers' questions about different types of fertilizer, how fertilizers are used, information on the world's fertilizer industry, and answers to commonly asked questions about fertilizer's role in the environment.
www.fertilizer101.org

The New Sunset Western Garden Book: The Ultimate Gardening Guide. Sunset Magazine Editors, Oxmoor House, 2012.
This easy-to-use gardening book, written for gardeners of the western United States, provides general information on soils, pest control, planting techniques, and fertilizing, plus problem solving tips and plant selection guides. Available at most bookstores.
ISBN 978-0-376-03920-0

Western Fertilizer Handbook. Western Plant Health Association. Waveland Press, Inc., 2010.
This well-organized book provides information on the nutrient requirements of plants and nutrient management strategies.
ISBN 978-0-8134-3210-6

Matrix of Standards
8th Grade

California Standards	Description	One in a Million	Concentrate on the Solution	Matter of Fact	What's Your pH?	Know Your Nitrogen
Common Core English Language Arts						
RI.8.1 Reading Informational Text	Cite the textual evidence that most strongly supports an analysis of what the text says explicitly as well as inferences drawn from the text.					x
RI.8.10 Reading Informational Text	By the end of the year, read and comprehend literary nonfiction at the high end of the grades 6-8 text complexity band independently and proficiently.					x
W.8.7 Writing Standards	Conduct short research projects to answer a question, drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration.					x
W.8.9 Writing Standards	Draw evidence from informational texts to support analysis, reflection, and research.					x
SL.8.1a Speaking & Listening	Come to discussions prepared, having read or researched material under study; explicitly draw on that preparation by referring to evidence on the topic, text, or issue to probe and reflect on ideas under discussion.			x	x	x
SL.8.1b Speaking & Listening	Follow rules for collegial discussions and decision-making, track progress toward specific goals and deadlines, and define individual roles as needed.	x	x	x	x	x
RST.8.3 Reading Standards for Literacy in Science and Technical Subjects	Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.	x	x	x	x	x
RST.8.7 Reading Standards for Literacy in Science and Technical Subjects	Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually.	x	x	x	x	x
RST.8.9 Reading Standards for Literacy in Science and Technical Subjects	Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic.	x	x	x	x	x

Matrix of Standards
8th Grade

California Standards	Description	One in a Million	Concentrate on the Solution	Matter of Fact	What's Your pH?	Know Your Nitrogen
Common Core English Language Arts (cont.)						
WHST.8.1b Writing Standards for Literacy in History/ Social Studies, Science, and Technical Subjects	Support claim(s) with logical reasoning and relevant, accurate data and evidence that demonstrate an understanding of the topic or text, using credible sources.		x		x	
WHST.8.4 Writing Standards for Literacy in History/ Social Studies, Science, and Technical Subjects	Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.		x		x	

Matrix of Standards
8th Grade

California Standards	Description	One in a Million	Concentrate on the Solution	Matter of Fact	What's Your pH?	Know Your Nitrogen
Next Generation Science Standards						
MS-PS1.A: Structure and Properties of Matter	Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms.			x		
MS-PS1.B: Chemical Reactions	Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.			x	x	
MS-LS2.A: Interdependent Relationships in Ecosystems	Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors.			x	x	x
MS-LS2.B: Cycle of Matter and Energy Transfer in Ecosystems	Food webs are models that demonstrate how matter and energy is transferred between producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem.			x		x
MS-LS2.C: Ecosystem Dynamics, Functioning, and Resilience	Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations.			x		
MS-ESS3.A: Natural Resources	Humans depend on Earth's land, ocean, atmosphere, and biosphere for many different resources. Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. These resources are distributed unevenly around the planet as a result of past geologic processes.		x			
MS-ESS3.C: Human Impacts on Earth Systems	Typically as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise.		x	x		x
MS-ETS1.B: Developing Possible Solutions	There are systematic processes for evaluating solutinos with respect to how well they meet the criteria and constraints of a problem	x	x	x	x	x

Matrix of Standards
9th-12th Grade

California Standards	Description	One in a Million	Concentrate on the Solution	Matter of Fact	What's Your pH?	Know Your Nitrogen
Common Core English Language Arts						
RI.9-12.1 Reading Informational Text	Cite strong and thorough textual evidence to support analysis of what the text says explicitly as well as inferences drawn from the text.					x
RI.9-12.10 Reading Informational Text	By the end of the grade level, read and comprehend literary nonfiction in grades 9-12 text complexity band proficiently, with scaffolding as needed at the high end of the range.					x
W.9-12.7 Writing Standards	Conduct short as well as more sustained research projects to answer a question or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources of the subject, demonstrate understanding of the subject under investigation.					x
W.9-12.9 Writing Standards	Draw evidence from informational texts to support analysis reflection and research.					x
SL.9-12.1a Speaking & Listening	Come to discussions prepared, having read and researched material under study; explicitly draw on that preparation by referring to evidence from texts and other research on the topic or issue to stimulate a thoughtful, well-reasoned exchange of ideas.			x	x	x
SL.9-12.1b Speaking & Listening	Work with peers to set rules for collegial discussions and decision-making, clear goals and deadlines, and individual roles as needed.	x	x	x	x	x
RST.9-12.3 Reading Standards for Literacy in Science and Technical Subjects	Follow precisely a complex multistep procedure when carrying out experiments taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.	x	x	x	x	x
RST.9-12.7 Reading Standards for Literacy in Science and Technical Subjects	Translate quantitative or technical information expressed in words in a text into visual form and translate information expressed visually or mathematically into words. Integrate and evaluate multiple sources of information presented in diverse formats and media in order to address a question or solve a problem.	x	x	x	x	x

Matrix of Standards
9th-12th Grade

California Standards	Description	One in a Million	Concentrate on the Solution	Matter of Fact	What's Your pH?	Know Your Nitrogen
Common Core English Language Arts (cont.)						
WHST.9-12.1b Writing Standards for Literacy in History/ Social Studies, Science, and Technical Subjects	Develop claim(s) and counterclaims fairly, supplying data and evidence for each while pointing out the strengths and limitations of both claim(s) and counterclaims in a discipline-appropriate form and in a manner that anticipates the audience's knowledge level and concerns.		x		x	x
WHST.9-12.4 Writing Standards for Literacy in History/ Social Studies, Science, and Technical Subjects	Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.		x		x	x
Common Core Mathematics						
9-12.N-Q.1 Quantities	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.	x	x			
Next Generation Science Standards						
HS-PS1.A: Structure and Properties of Matter	The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.		x			
HS-ESS2.E: Biogeology	The many dynamic and delicate feedbacks between the biosphere and other Earth systems cause a continual co-evolution of Earth's surface and the life that exists on it.			x	x	x
HS-ESS3.A: Natural Resources	Resource availability has guided the development of human society. All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors.		x	x		x

Matrix of Standards 9th-12th Grade

California Standards	Description	One in a Million	Concentrate on the Solution	Matter of Fact	What's Your pH?	Know Your Nitrogen
Next Generation Science Standards (cont.)						
HS-ESS3.C: Human Impacts on Earth Systems	The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources. Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.			x		x
HS-ETS1.A: Defining and Delimiting Engineering Problems	Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities.		x			x
HS-ETS1.B: Developing Possible Solutions	When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs.	x	x		x	x
HS-ETS1.C: Optimizing the Design Solution	Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed.				x	

Glossary

Amendment: Any material added to soil to make it more productive. This could include fertilizer, or compost.

Ammonification: Bacteria or fungi convert organic forms of nitrogen into ammonium, which can be used by plants.

Aerobic: The presence of oxygen.

Anaerobic: The absence of oxygen.

Arable: Land that is capable of producing crops.

Aquifer: A geological formation containing ground water.

Assimilation: The conversion of absorbed nutrients into plant or body structures.

Atom: The smallest component of an element.

Buffer: Any substance or mixture of compounds that, added to a solution, is capable of neutralizing both acids and bases without changing the original acidity or alkalinity of the solution.

Chemical elements: Substances that cannot be broken down into simpler substances by chemical means, they are comprised of only one type of atom.

Chemical formula: A written description of the components of a chemical compound. It identifies the elements in the compound by their symbols and describes the number of atoms of each element.

Compost: A mixture made of decaying organic material used to fertilize plants and amend soils.

Compound: A substance made up of atoms of at least two different elements.

Concentration: The ratio of the mass or volume of a substance (solute) to the mass or volume of the solvent or solution.

Conservation: The wise use of resources, to conserve them for use by present and future generations.

Glossary

Crop rotation: The successive planting of different crops in the same field over a period of years to maintain or improve soil quality and reduce pest problems.

Decomposition: To break down into organic matter; this process is performed by bacteria, fungi, nematodes, earthworms, and others.

Deficiency: A substance that is lacking.

Denitrification: Under poor aeration, soil bacteria convert nitrate ions into nitrogen gas which cannot be used by plants and is lost to the atmosphere.

Dilution: The process of lowering the concentration of a solution by adding a solvent.

Fertilizer: A substance added to soil or water to provide plants with nutrients required for their growth.

Fertilizer analysis: The actual composition of a fertilizer as determined in a chemical laboratory using standard methods.

Fertilizer injector: A device used to apply water-soluble fertilizers, pesticides, plant growth regulators, wetting agents, and mineral acids to greenhouse crops.

Green manure: Vegetation that is plowed into the field to improve soil composition; normally a legume such as beans or alfalfa.

Groundwater: The water beneath the surface of the ground consisting mostly of surface water that has filtered down.

Heterogeneous: A heterogeneous mixture is not uniform in composition and components can easily be identified, as there are two or more phases present. "Hetero" is a Greek prefix for "different."

Homogeneous: Homogeneous mixtures are uniform in composition and particles are not typically seen. "Homo" is a Greek prefix for "same."

Hydroponics: To grow plants without soil, in a water-nutrient solution.

Ion: An electrically charged atom or group of atoms.

Glossary

Infiltration: To filter into or through; to move through the soil profile.

Leaching: Downward movement of materials in solution through the soil.

Legume: Normally a plant that has pods whose seeds split into two; often helps with nitrogen fixation. Examples include beans and alfalfa.

Macronutrients: Nutrients needed by plants in large quantities.

Manure: Solid animal waste products used for fertilizer. May contain some straw or other animal bedding material.

Matter: Anything that has mass and takes up space.

Micronutrients: Nutrients needed by plants in small quantities. Examples include boron, copper, and zinc.

Mixture: Combination of two or more different substances which are not chemically bonded and can be a solid, liquid, or gas.

Molecule: The smallest particle of a pure substance that has the properties of that substance. Also known as two or more atoms attached together by chemical bonds.

Mutualism: A symbiotic relationship where both living organisms benefit.

N-P-K: Nitrogen-Phosphorus-Potassium, the three chemical elements that must be represented on a bag of fertilizer.

Nitrate: The NO_3^- form of nitrogen that is readily used by plants.

Nitrification: To break down nitrogen compounds to nitrites and nitrates by bacterial action. Oxygen is needed for this process, therefore, nitrification takes place in the top layers of soil and flowing water. Nitrates can be used by plants.

Nitrogen: An element that makes up approximately 78% of our atmosphere and is needed by plants to produce, among other things, proteins, chlorophyll, DNA, and RNA.

Glossary

Nitrogen-fixation: The transformation of atmospheric nitrogen gas into forms available for plant growth (ammonium or nitrates) often performed by Rhizobium bacteria. Nitrogen gas can also be converted to forms that plants can use through the production of commercial fertilizers.

Nodule: A little knot or bump found in roots of legume plants; normally filled with a bacterium (Rhizobium) that performs nitrogen-fixation.

Nutrients: Elements needed by plants for proper growth.

Organic matter: Material in soil made from the decomposition of plants or animals. It increases the soil's ability to hold water and air.

Parts per million (ppm): A unit of measurement commonly used to describe the nutrient concentration in fertilizer solutions; can also be used to analyze contaminants in food, groundwater, air, and more. Compare to one drop of water in a swimming pool.

Periodic table: A chart in which the chemical elements are arranged based on atomic weights and chemical characteristics according to their atomic numbers.

pH: Power of hydrogen. A measure of the alkalinity or acidity of a substance.

Primary nutrients: Nutrients needed by plants in large amounts; this includes nitrogen, phosphorus, and potassium.

Root hairs: Tiny hair-like structures that are on the ends of roots and aide in nutrient and water absorption; they increase the surface area of root systems.

Saline: Another word for salt.

Salt: A product of an acid reacting with a base. Table salt, or sodium chloride, is only one type of salt.

Secondary nutrients: Nutrients needed by plants in medium quantities. Includes calcium, magnesium, and sulfur.

Sidedress: To place plant nutrients on or in the soil near the roots of a growing crop.

Glossary

Solution: A type of homogeneous mixture in which the particles of one or more substances (the solute) are distributed uniformly throughout another substance (the solvent).

Solute: The substance dissolved in a solvent to form a solution.

Solvent: A liquid in which substances (or solutes) are dissolved forming a solution.

Soil: The top portion of the Earth's surface that is used to grow plants; consists of organic and inorganic substances.

Soil porosity: The amount of pore spaces between soil particles that are filled with water and gases.

Soil texture: The proportions of sand, silt, and clay in a soil.

Stomata: A small opening in the epidermis of plant leaves, through which gases are exchanged.

Sustainable agriculture: An agricultural system that remains viable and environmentally sound over a long period of time.

Water holding capacity: The amount of water that a soil can hold before nutrients begin to leach out.

Yield: The amount of crop harvested per unit area over a given amount of time.