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NOURISHING THE PLANET IN THE 21ST CENTURY

A CURRICULUM MODULE FOR
HIGH SCHOOL SCIENCE GRADES 9-12

SECOND EDITION

NUTRIENTS FOR LIFE FOUNDATION

BSCS
A SCIENCE EDUCATION CURRICULUM STUDY

NOURISHING THE PLANET
IN THE 21ST CENTURY
SECOND EDITION

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Figure 1	Agrium, Inc.
Figure 2	HolgerK
Figure 3	Potash and Phosphate Institute
Figure 4	BSCS
Figure 5	BSCS
Figure 6	BSCS
Figure 7	Nutrients for Life Foundation
Figure 8	The Mosaic Company
Figure 9	The Mosaic Company
Figure 10	The Mosaic Company
Figure 11	Nutrients for Life Foundation
Figure 12a	© PICSUNV / istockphoto.com
Figure 12b	© jorgesa / istockphoto.com
Figure 13	NOAA George E. Marsh Album
Figure 14	© Dole08 / istockphoto.com
Figure 15	CropLife Magazine
Lesson 1 opener	BSCS
Master 1.1	Agrium, Inc.
Master 1.2	BSCS
Master 1.3	BSCS
Master 1.4	BSCS
Master 1.5	Agrium, Inc.
Master 1.6	Agrium, Inc.
Lesson 2 opener	BSCS
Figure 2.1	BSCS
Figure 2.2	BSCS
Surface area cubes	BSCS
Soil triangle answer	BSCS, adapted from Soil Science Department. (n.d.). Soil Texture Animation. Retrieved from http://courses.soil.ncsu.edu/resources/physics/texture/soiltexture.swf
Master 2.2	BSCS
Master 2.5	BSCS, adapted from Soil Science Department. (n.d.). Soil Texture Animation. Retrieved from http://courses.soil.ncsu.edu/resources/physics/texture/soiltexture.swf
Lesson 3 opener	© alohaspirit / istockphoto.com
Figure 3.1a, b	BSCS
Figure 3.2	BSCS
Master 3.1	Agrium, Inc.
Master 3.2	BSCS
Master 3.3	BSCS
Master 3.4	BSCS
Master 3.5	NOAA George E. Marsh Album
Master 3.6	BSCS
Lesson 4 opener	The Mosaic Company
First experiment, before	BSCS
First experiment, after	BSCS
Second experiment, before	BSCS
Second experiment, after	BSCS
Master 4.2a–c	The Mosaic Company
Master 4.4a–d	The Mosaic Company
Master 4.5	BSCS
Master 4.7	BSCS
Master 4.9	BSCS
Lesson 5 opener	BSCS
Lesson 6 opener	© LokFung / istockphoto.com

CONTENTS

INTRODUCTION TO NOURISHING THE PLANET IN THE 21ST CENTURY

Over the past 50 years, the population of Earth has more than doubled, yet the amount of land devoted to farming has increased by just about 10 percent.[11] At the same time, the developed world has seen impressive gains in agricultural productivity. The so-called "Green Revolution" saw farmers in North America increase cereal production by about 120 percent between 1960 and 2012. During this time the amount of arable land in North America decreased by about 8 percent.[12] Farmers were able to increase their crop yields by breeding better plant varieties, adopting better water management practices, and using commercial fertilizers more wisely. Fertilizer management practices that ensure that the appropriate type of nutrient is used at the right time, applied in the proper amount that the plant needs, and placed where the plant can most easily use it play a large role in increasing crop production while minimizing nutrient losses to the environment. Today, at least one-third of the world's food supply is produced using commercial fertilizers that replace nutrients in the soil that have been removed through farming.

In early 2014, the world's population was approximately 7.1 billion people. It is estimated that the population will increase to 9.6 billion people by 2050.[23] How will we feed all these additional people? In the developed world, the increases in plant productivity supported by the Green Revolution are reaching their potentials. At the same time, and a world away, infrastructure and population growth pressures are forcing farmers in sub-Saharan Africa to grow crop after crop, "mining," or depleting, the soil of nutrients while giving nothing back. With little access to fertilizers, the farmers are forced to bring less-fertile soils on marginal land into production, at the expense of Africa's wildlife and forests.

Many Americans are generations removed from the farm and take their food supply for granted. They want their food to taste good, to be reasonably priced, and to be healthy and nutritious. At the same time, they want agricultural systems to be truly sustainable by protecting the environment and setting aside land for wildlife.

Difficult decisions will have to be made. Making more land available for farming also means having less land available for other uses such as housing, recreation, and wildlife habitats. Agricultural practices, if not carried out properly, can harm the environment by introducing excessive amounts of nutrients into rivers, lakes, and coastal waters. In agriculture, as in many other industries, science has determined best-management practices—practices that ensure efficient use of resources and minimize impacts on the environment. They enable profitability for farmers while guarding the public interest.

The public has an interest in policies that affect how the world's food is produced. To make rational decisions about these matters, the world's citizens need to recognize what options are available. It is important for young people to recognize the economic, social, and environmental consequences of the options they will confront as adults facing the challenge of nourishing Earth's growing population.

WHAT ARE THE OBJECTIVES OF THE MODULE?

Nourishing the Planet in the 21st Century has four objectives. The first is to help students understand some basic aspects of plant biology related to food production. Although school curricula address plant biology and food production, they usually focus on promoting an understanding of photosynthesis. The importance of soil and plant nutrition as it relates to food production is often not explored.

The second objective is to provide students with an opportunity to practice and refine their critical-thinking skills. Such abilities are important, not just for scientific pursuits, but for making decisions in everyday life. Our fast-changing world requires today's young people to be lifelong learners. They must be able to evaluate information from a variety of sources and assess its usefulness. They need to discriminate between objective science and information from sources outside the scientific community. Students must be able to use evidence to establish causal relationships.

The third objective is to convey to students the purpose of scientific research. Ongoing research affects how we understand the world around us and provides a foundation for improving our choices about personal health and the health of our community, including our environment. In this module, students participate in activities that give them experience with the major aspects of scientific inquiry. The lessons encourage students to think about the relationships among knowledge, choice, behavior, and human health in this way:

KNOWLEDGE (WHAT IS KNOWN AND NOT KNOWN) + CHOICE = **POWER**
POWER + BEHAVIOR = **ENHANCED HUMAN HEALTH**

The final objective of this module is to encourage students to think in terms of these relationships now and as they grow older.

WHY TEACH THE MODULE?

High school biology classes offer an ideal setting for integrating many areas of student interest. In this module, students participate in activities that integrate inquiry science, plant biology, and mathematics to meet curriculum objectives. The lessons interweave science, technology, and societal issues. The real-life context of the module's classroom lessons is engaging, and the knowledge gained can be applied immediately to students' lives.

WHAT'S IN IT FOR THE TEACHER?

Nourishing the Planet in the 21st Century meets many of the criteria by which teachers and their programs are assessed:

- The module is standards based and addresses important disciplinary core ideas, science practices, and crosscutting concepts found in the *Next Generation Science Standards.*[17] It pays particular attention to the standards that describe what students should know and be able to do with respect to scientific inquiry.
- It is an integrated module, drawing most heavily from the subjects of science, social science, mathematics, and health.

In addition, the module provides a means for professional development. Teachers can engage in new and different teaching practices such as those described in this module without completely overhauling their entire program. In *Designing Professional Development for Teachers of Science and Mathematics,* Loucks-Horsley, Hewson, Love, and Stiles write that supplements such as this one "offer a window through which teachers get a glimpse of what new teaching strategies look like in action." By experiencing a short-term module, teachers can "change how they think about teaching and embrace new approaches that stimulate students to problem-solve, reason, investigate, and construct their own meaning for the content."[15] The use of this kind of supplemental module can encourage reflection and discussion and stimulate teachers to improve their practices by focusing on student learning through inquiry.

IMPLEMENTING THE MODULE

The six lessons of this module are designed to be taught in sequence over seven to eight days (as a supplement to the standard curriculum) or as individual lessons that support and enhance your treatment of specific concepts in high school biology. This section offers general suggestions about using these materials in the classroom. You will find specific suggestions in the procedures provided for each lesson.

WHAT ARE THE GOALS OF THE MODULE?

Nourishing the Planet in the 21st Century helps students achieve **FOUR MAJOR GOALS** associated with scientific literacy:

- to understand a set of basic elements related to food production,
- to experience the process of scientific inquiry and develop an enhanced understanding of the nature and methods of science,
- to hone critical-thinking skills, and
- to recognize the role of science in society and the relationship between basic science and human health.

WHAT ARE THE SCIENCE CONCEPTS AND HOW ARE THEY CONNECTED?

The lessons are organized into a conceptual framework that allows students to move from what they already know about agriculture, or think they know, to gaining a more complete and accurate perspective on the topic.

LESSON 1: IN SEARCH OF ESSENTIAL NUTRIENTS - Students begin by comparing and contrasting the nutritional needs of plants and people.

LESSON 2: PROPERTIES OF SOILS - They then explore soils and investigate how the components of soil affect the movement of water in the soil .

LESSON 3: PLANT-SOIL INTERACTIONS - Students then turn their attention to plant anatomy. They explore the role of the root system as well as that of the xylem and phloem tissues. They conduct a hands-on activity that shows how nutrients move by diffusion.

LESSON 4: PLANT NUTRIENT DEFICIENCIES - They also consider how soil forms into layers called soil horizons that have distinct compositions and functions.

LESSON 5: FERTILIZERS AND THE ENVIRONMENT - students consider what happens when plants do not get adequate amounts of their essential nutrients. They play the role of plant doctor diagnosing the cause of a nutrient deficiency. Students then consider the role of fertilizer in a global context. They investigate how fertilizers can help feed people while protecting the environment. The consequences of misusing fertilizers also are considered.

LESSON 6: NOURISHING THE PLANET IN THE 21ST CENTURY - The module concludes with students reflecting on what they have learned about plant biology, fertilizers, and fertilizers' environmental effects in the context of making recommendations for agricultural practices for the future.

Most lessons include one or more optional extension activities that can enrich the learning experience if time permits. *Table 1* illustrates the scientific content and conceptual flow of the lessons.

TABLE 1. SCIENCE CONTENT AND CONCEPTUAL FLOW OF THE LESSONS

LESSON AND LEARNING FOCUS*	TOPICS COVERED AND MAJOR CONCEPT
1: IN SEARCH OF ESSENTIAL NUTRIENTS Engage: Students become engaged in how plants obtain their nutrition.	Plants and people require essential nutrients to complete their life cycles. Macronutrients are needed in larger amounts than micronutrients. Plants get their nutrients from water, air, and soil.
2: PROPERTIES OF SOILS Explore: Students consider what makes one soil better able to support plant growth as compared withand another.	Soils vary with regard to the amount of organic and inorganic matter they contain. Some soils hold and transmit water better than others do. Plants generally take up whatever is dissolved in soil water.
3: PLANT-SOIL INTERACTIONS Explain: Students conduct observations and experiments to investigate how plants obtain nutrients from the soil.	Plants extract nutrients from the soil. Nutrients enter the root system largely by diffusion. Water and food transport use the xylem and phloem tissues respectively.
4: PLANT NUTRIENT DEFICIENCIES Elaborate: Students deepen their understanding of the nutritional requirements of plants by diagnosing plant nutrient deficiencies.	Crop plants with nutrient deficiencies show specific symptoms. These deficiencies can be corrected by using fertilizers that restore nutrient balance to the soil.
5: FERTILIZERS AND THE ENVIRONMENT Explain-Elaborate: Students apply their understanding of fertilizers to a global scale and consider how fertilizer use affects the environment.	Fertilizers increase the amount of food and fiber produced per acre thereby reducing the amount of land needed for farming. Our growing population demands that more food be produced. Unless crop yields keep pace with the demand, more land will have to be used for agriculture.
6: NOURISHING THE PLANET IN THE 21ST CENTURY Evaluate: Students apply what they learned during the module to make recommendations for how to nourish the Earth's increasing population.	Human population growth challenges us to implement farming practices that can meet our nutritional needs while at the same time minimizing negative impacts such as nutrient run-off, erosion, and excessive land use.

*See How Does the BSCS 5E Instructional Model Promote Active, Collaborative, Inquiry-based Learning?, p. 12.

HOW DOES THE MODULE CORRELATE WITH STANDARDS?

Nourishing the Planet in the 21st Century supports teachers in their efforts to reform science education. The content is explicitly standards based. *Table 2* correlates the module content with the science practices specified in the *Next Generation Science Standards (NGSS)*.[17] *Table 3* correlates the content with relevant disciplinary core ideas from NGSS, and *Table 4* outlines how this module addresses the NGSS crosscutting concepts.

TABLE 2. ALIGNMENT OF NOURISHING THE PLANET IN THE 21ST CENTURY WITH SCIENCE PRACTICES IN THE NEXT GENERATION SCIENCE STANDARDS

SCIENCE PRACTICE	LESSON 1	LESSON 2	LESSON 3	LESSON 4	LESSON 5	LESSON 6
ASKING QUESTIONS AND DEFINING PROBLEMS			X			X
DEVELOPING AND USING MODELS		X	X			
PLANNING AND CARRYING OUT INVESTIGATIONS		X	X	X	X	
ANALYZING AND INTERPRETING DATA	X	X	X	X	X	X
USING MATHEMATICS AND COMPUTATIONAL THINKING		X	X	X	X	X
CONSTRUCTING EXPLANATIONS AND DESIGNING SOLUTIONS		X	X	X	X	X
ENGAGING IN ARGUMENT FROM EVIDENCE	X	X	X	X	X	X
OBTAINING, EVALUATING, AND COMMUNICATING INFORMATION	X	X	X	X	X	X

TABLE 3. ALIGNMENT OF NOURISHING THE PLANET IN THE 21ST CENTURY TO SELECTED DISCIPLINARY CORE IDEAS IN THE NEXT GENERATION SCIENCE STANDARDS

DISCIPLINARY CORE IDEA	LESSON 1	LESSON 2	LESSON 3	LESSON 4	LESSON 5	LESSON 6
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.			X			X
LS1.A: STRUCTURE AND FUNCTION: Systems of specialized cells within organisms help them perform the essential functions of life.		X	X			
LS1.C: ORGANIZATION FOR MATTER AND ENERGY FLOW IN ORGANISMS: The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen.		X	X	X	X	
LS1.C: ORGANIZATION FOR MATTER AND ENERGY FLOW IN ORGANISMS: The sugar molecules thus formed contain carbon, hydrogen, and oxygen; their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA) used, for example, to form new cells.	X	X	X	X	X	X
LS1.C: ORGANIZATION FOR MATTER AND ENERGY FLOW IN ORGANISMS: As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products.		X	X	X	X	X
LS2.B: CYCLES OF MATTER AND ENERGY TRANSFER IN ECOSYSTEMS: Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.		X	X	X	X	X
LS2.B: CYCLES OF MATTER AND ENERGY TRANSFER IN ECOSYSTEMS: The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and recombine in different ways.	X	X	X	X	X	X
LS2.C: ECOSYSTEM DYNAMICS, FUNCTIONING, AND RESILIENCE: Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overpopulation, and climate change—can disrupt an ecosystem and threaten the survival of some species.	X	X	X	X	X	X
LS4.D: BIODIVERSITY AND HUMANS: Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change.				X	X	X

TABLE 3. CONTINUED

ESS3.C: HUMAN IMPACTS ON EARTH SYSTEMS: The sustainability of human societies and the biodiversity that supports them require responsible management of natural resources.			X	X	X	X
ETS1.A: DEFINING AND DELIMITING ENGINEERING PROBLEMS: 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	X	X
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.			X	X	X	X

TABLE 4. ALIGNMENT OF NOURISHING THE PLANET IN THE 21ST CENTURY WITH CROSSCUTTING CONCEPTS IN THE NEXT GENERATION SCIENCE STANDARDS

CROSSCUTTING CONCEPT	LESSON 1	LESSON 2	LESSON 3	LESSON 4	LESSON 5	LESSON 6
PATTERNS	X		X	X		X
CAUSE AND EFFECT		X	X	X		X
SCALE, PROPORTION, AND QUANTITY		X			X	X
SYSTEMS AND SYSTEM MODELS		X	X		X	X
ENERGY AND MATTER IN SYSTEMS	X				X	X
STRUCTURE AND FUNCTION			X			
STABILITY AND CHANGE OF SYSTEMS		X		X	X	X

The suggested teaching strategies in all of the lessons support you as you work to meet the science standards outlined in the *Next Generation Science Standards*.[17]

TABLE 5. ALIGNMENT OF NOURISHING THE PLANET IN THE 21ST CENTURY TO SELECT COMMON CORE STATE STANDARDS

COMMON CORE STANDARD	LESSON 1	LESSON 2	LESSON 3	LESSON 4	LESSON 5	LESSON 6
ENGLISH LANGUAGE ARTS/LITERACY						
ANCHOR STANDARDS						
CCSS.ELA-LITERACY.CCRA.R.1	X	X	X	X	X	X
CCSS.ELA-LITERACY.CCRA.R.1			X	X	X	
CCSS.ELA-LITERACY.CCRA.R.2			X	X	X	
CCSS.ELA-LITERACY.CCRA.R.7		X	X	X	X	X
CCSS.ELA-LITERACY.CCRA.R.10		X	X	X	X	
CCSS.ELA-LITERACY.CCRA.W.1		X	X	X	X	X
CCSS.ELA-LITERACY.CCRA.W.2					X	X
CCSS.ELA-LITERACY.CCRA.W.4		X	X		X	X
CSS.ELA-LITERACY.CCRA.W.9		X	X	X	X	
CCSS.ELA-LITERACY.CCRA.SL.1	X	X	X	X	X	X
CCSS.ELA-LITERACY.CCRA.SL.2	X	X	X	X	X	X
CCSS.ELA-LITERACY.CCRA.SL.4		X	X	X	X	X
CCSS.ELA-LITERACY.CCRA.L.4			X	X	X	
CCSS.ELA-LITERACY.CCRA.L.6		X	X	X	X	X
MATH STANDARDS						
STANDARDS FOR MATHEMATICAL PRACTICE						
CCSS.MATH.PRACTICE.MP1		X			X	
CCSS.MATH.PRACTICE.MP2		X	X	X	X	
CCSS.MATH.PRACTICE.MP3		X			X	
CCSS.MATH.PRACTICE.MP4		X		X	X	
CCSS.MATH.PRACTICE.MP6		X			X	

The module also addresses many *Common Core State Standards,* as shown in *Table 5.* Please refer to the *Common Core State Standards* for grade-specific standards. The Nutrients for Life Foundation provides a search tool on their website, **http://nutrientsforlife.org,** allowing teachers to select their state and find soil science lessons that correlate with their state's science standards. The search tool can align this curriculum with science standards for all 50 states, *National Sciences Education Standards, Common Core State Standards,* and *Next Generation Science Standards.*

This module helps science teachers plan an inquiry-based science program by providing short-term objectives for students. It also includes planning tools for teaching the module, such as *Table 1, Science Content and Conceptual Flow of the Lessons* (page 7) and *Table 8, Suggested Timeline* (page 19). You can use this module to update your curriculum in response to students' interest. The focus on active, collaborative, and inquiry-based learning in the lessons helps support the development of student understanding and nurtures a community of science learners.

The structure of the lessons enables you to guide and facilitate learning. All the activities encourage and support student inquiry, promote discourse among students, and challenge students to accept and share responsibility for their learning. The use of the *BSCS 5E Instructional Model7*, combined with active, collaborative learning, allows you to respond effectively to students with diverse backgrounds and learning styles. The module is fully annotated, with suggestions for how you can encourage and model the skills of scientific inquiry and foster curiosity, openness to new ideas and data, and skepticism.

HOW DOES THE BSCS 5E INSTRUCTIONAL MODEL PROMOTE ACTIVE, COLLABORATIVE, INQUIRY-BASED LEARNING?

Because learning does not occur by way of passive absorption, the lessons in this module promote active learning. Students are involved in more than listening and reading. They are developing skills, analyzing and evaluating evidence, experiencing and discussing, and talking to their peers about their own understanding. Students work collaboratively with others to solve problems and plan investigations. Many students find that they learn better when they work with others in a collaborative environment than when they work alone in a competitive environment. When active, collaborative learning is directed toward scientific inquiry, students succeed in making their own discoveries. They ask questions, observe, analyze, explain, draw conclusions, and ask new questions. These inquiry-based experiences include both those that involve students in direct experimentation and those in which students develop explanations through critical and logical thinking.

The viewpoint that students are active thinkers who construct their own understanding from interactions with phenomena, the environment, and other individuals is based on the theory of constructivism. A constructivist view of learning recognizes that students need time to

- express their current thinking;
- interact with objects, organisms, substances, and equipment to develop a range of experiences on which to base their thinking;
- reflect on their thinking by writing and expressing themselves and comparing what they think with what others think; and
- make connections between their learning experiences and the real world.

This module provides a built-in structure for creating a constructivist classroom: the *BSCS 5E Instructional Model.*[7] The *5E Model* sequences learning experiences so that students have the opportunity to construct their understanding of a concept over time. The model leads students through five phases of learning that are easily described using words that begin with the letter **E: ENGAGE, EXPLORE, EXPLAIN, ELABORATE, AND EVALUATE.** The following paragraphs illustrate how the *5Es* are implemented across the lessons in this module

ENGAGE

Students come to learning situations with prior knowledge. This knowledge may or may not be congruent with the concepts presented in this module. The *Engage* lesson provides the opportunity for teachers to find out what students already know, or think they know, about the topic and concepts to be covered. The *Engage* lesson in this module, **LESSON 1: IN SEARCH OF ESSENTIAL NUTRIENTS,** is designed to

- pique students' curiosity and generate interest,
- determine students' current understanding about nutritional requirements,
- invite students to raise their own questions about essential elements,
- encourage students to compare their ideas with those of others, and
- enable teachers to assess what students do or do not understand about the stated outcomes of the lesson.

EXPLORE

In the *Explore* phase of the module, **LESSON 2, PROPERTIES OF SOILS,** students investigate the compositions of soils. Students perform experiments designed to provide a common set of experiences within which they can begin to construct their understanding. Students

- interact with materials and ideas through classroom and small-group discussions;
- acquire a common set of experiences so that they can compare results and ideas with their classmates;
- observe, describe, record, compare, and share their ideas and experiences; and
- express their developing understanding of testable questions and scientific inquiry.

EXPLAIN

The *Explain* lessons **(LESSON 3, PLANT-SOIL INTERACTIONS AND LESSON 5, FERTILIZERS AND THE ENVIRONMENT)** provide opportunities for students to connect their previous experiences with current learning and to make conceptual sense of the main ideas of the module. This phase also allows for the introduction of formal language, scientific terms, and content information that might make students' previous experiences easier to describe. The *Explain* lesson encourages students to explain concepts and ideas (in their own words) about how plants obtain nutrients and how fertilizers affect the environment;

- listen to and compare the explanations of others with their own;
- become involved in student-to-student discourse in which they explain their thinking to others and debate their ideas;
- revise their ideas;
- record their ideas and current understanding;
- use labels, terminology, and formal language; and
- compare their current thinking with what they previously thought.

ELABORATE

In *Elaborate* lessons, students apply or extend previously introduced concepts and experiences to new situations. In the *Elaborate* lessons in this module **(LESSON 4, PLANT NUTRIENT DEFICIENCIES AND LESSON 5, FERTILIZERS AND THE ENVIRONMENT)**, students

- make conceptual connections between new and former experiences, connecting aspects of their plant and soil investigations with their concepts of scientific inquiry;
- connect ideas, solve problems, and apply their understanding to a new situation;
- use scientific terms and descriptions;
- draw reasonable conclusions from evidence and data;
- deepen their understanding of concepts and processes; and
- communicate their understanding to others.

EVALUATE

The *Evaluate* lesson is the final phase of the instructional model, but it only provides a "snapshot" of what the students understand and how far they have come from where they began. In reality, the evaluation of students' conceptual understanding and ability to use skills begins with the *Engage* lesson and continues throughout each phase of the instructional model. When combined with the students' written work and performance of tasks throughout the module, however, the *Evaluate* lesson provides a summative assessment of what students know and can do.

The *Evaluate* lesson in this module, **LESSON 6, NOURISHING THE PLANET IN THE 21ST CENTURY,** provides an opportunity for students to

- demonstrate what they understand about plants and fertilizers and how well they can apply their knowledge to make recommendations for feeding our increasing population,
- defend their recommendations with evidence,
- share their current thinking with others,
- assess their own progress by comparing their current understanding with their prior knowledge, and
- ask questions that take them deeper into a concept.

To review the relationship of the 5E Instructional Model to the concepts presented in the module, see Table 1 (page 7).

When you use the *BSCS 5E Instructional Model*, you engage in practices that are different from those of a traditional teacher. In response, students learn in ways that are different from those they experience in a traditional classroom. The following charts, *Table 6, What the Teacher Does* and *Table 7, What the Students Do,* outline these differences.

TABLE 6. WHAT THE TEACHER DOES

PHASE	THAT IS CONSISTENT WITH THE 5E INSTRUCTIONAL MODEL	THAT IS INCONSISTENT WITH THE 5E INSTRUCTIONAL MODEL
ENGAGE	• Piques students' curiosity and generates interest. • Determines students' current understanding (prior knowledge) of a concept or idea. • Invites students to express what they think. • Invites students to raise their own questions.	• Introduces vocabulary. • Explains concepts. • Provides definitions and answers • Provides closure. • Discourages students' ideas and questions.
EXPLORE	• Encourages student-to-student interaction. • Observes and listens to the students as they interact. • Asks probing questions to help students make sense of their experiences. • Provides time for students to puzzle through problems.	• Provides answers. • Proceeds too rapidly for students to make sense of their experiences • Provides closure. • Tells the students that they are wrong. • Gives information and facts that solve the problem. • Leads the students step-by-step to a solution.
EXPLAIN	• Encourages students to use their common experiences and data from the Engage and Explore lessons to develop explanations. • Asks questions that help students express understanding and explanations. • Requests justification (evidence) for students' explanations. • Provides time for students to compare their ideas with those of others and perhaps to revise their thinking. • Introduces terminology and alternative explanations after students express their ideas.	• Neglects to solicit students' explanations. • Ignores data and information students gathered from previous lessons. • Dismisses students' ideas. • Accepts explanations that are not supported by evidence. • Introduces unrelated concepts or skills.
ELABORATE	• Focuses students' attention on conceptual connections between new and former experiences. • Encourages students to use what they have learned to explain a new event or idea. • Reinforces students' use of scientific terms and descriptions previously introduced. • Asks questions that help students draw reasonable conclusions from evidence and data.	• Neglects to help students connect new and former experiences. • Provides definitive answers. • Tells the students that they are wrong. • Leads students step-by-step to a solution.
EVALUATE	• Observes and records as students demonstrate their understanding of the concepts and performance of skills. • Provides time for students to compare their ideas with those of others and perhaps to revise their thinking. • Interviews students as a means of assessing their developing understanding. • Encourages students to assess their own progress.	• Tests vocabulary words, terms, and isolated facts • Introduces new ideas or concepts. • Creates ambiguity. • Promotes open-ended discussion unrelated to the concept or skill.

TABLE 7. WHAT THE STUDENTS DO

PHASE	THAT IS CONSISTENT WITH THE 5E INSTRUCTIONAL MODEL	THAT IS INCONSISTENT WITH THE 5E INSTRUCTIONAL MODEL
ENGAGE	• Become interested in and curious about the concept or topic. • Express current understanding of a concept or idea. • Raise questions such as, “What do I already know about this?” “What do I want to know about this?” “How could I find out?”	• Ask for the “right” answer. • Offer the “right” answer. • Insist on answers or explanations. • Seek closure.
EXPLORE	• Explore materials and ideas. • Conduct investigations in which they observe, describe, and record data. • Try different ways to solve a problem or answer a question. • Acquire a common set of experiences so that they can compare results and ideas. • Compare their ideas with those of others.	• Let others do the thinking and exploring (passive involvement). • Work quietly with little or no interaction with others (only appropriate when exploring ideas or feelings). • Stop with one solution. • Demand or seek closure.
EXPLAIN	• Encourages students to use their common experiences and data from the Engage and Explore lessons to develop explanations. • Asks questions that help students express understanding and explanations. • Requests justification (evidence) for students’ explanations. • Provides time for students to compare their ideas with those of others and perhaps to revise their thinking. • Introduces terminology and alternative explanations after students express their ideas.	• Propose explanations from “thin air” with no relationship to previous experiences. • Bring up irrelevant experiences and examples. • Accept explanations without justification. • Ignore or dismiss other plausible explanations. • Propose explanations without evidence to support their ideas.
ELABORATE	• Focuses students’ attention on conceptual connections between new and former experiences. • Encourages students to use what they have learned to explain a new event or idea. • Reinforces students’ use of scientific terms and descriptions previously introduced. • Asks questions that help students draw reasonable conclusions from evidence and data.	• Neglects to help students connect new and former experiences. • Provides definitive answers. • Tells the students that they are wrong. • Leads students step-by-step to a solution.
EVALUATE	• Make conceptual connections between new and former experiences. • Use what they have learned to explain a new object, event, organism, or idea. • Use scientific terms and descriptions. • Draw reasonable conclusions from evidence and data. • Communicate their understanding to others. • Demonstrate what they understand about the concepts and how well they can implement a skill. • Compare their current thinking with that of others and perhaps revise their ideas. • Assess their own progress by comparing	• Disregard evidence or previously accepted explanations in drawing conclusions. • Offer only yes-or-no answers or memorized definitions or explanations as answers. • Fail to express satisfactory explanations in their own words. • Introduce new, irrelevant topics.

HOW DOES THE MODULE SUPPORT ONGOING ASSESSMENT?

Because teachers will use this module in a variety of ways and at a variety of points in the curriculum, the most appropriate mechanism for assessing student learning is one that occurs informally at various points within the lessons rather than just once at the end of the module. Accordingly, integrated within the lessons in the module are specific assessment components. These embedded assessments include one or more of the following strategies:

- Performance-based activities, such as interpreting graphs or participating in a discussion about risks and benefits.
- Oral presentations to the class, such as reporting experimental results.
- Written assignments, such as answering questions or writing about demonstrations.

These strategies allow you to assess a variety of aspects of the learning process such as students' prior knowledge and current understanding, problem-solving and critical-thinking skills, level of understanding of new information,communication skills, and ability to synthesize ideas and apply understanding to a new situation.

HOW CAN TEACHERS PROMOTE SAFETY IN THE SCIENCE CLASSROOM?

Even simple science demonstrations and investigations can be hazardous unless teachers and students know and follow safety precautions. Teachers are responsible for providing students with active instruction concerning their conduct and safety in the classroom. Posting rules in a classroom is not enough; teachers also need to provide adequate supervision and advance warning if there are dangers involved in the science investigation. By maintaining equipment in proper working order, teachers ensure a safe environment for students.

You can implement and maintain a safety program in the following ways:

- Provide eye protection for students, teachers, and visitors. Require that everyone participating wear regulation goggles in any situation where there might be splashes, spills, or spattering.
- Know and follow the state and district safety rules and policies. Be sure to explain fully to the students the safety rules they should use in the classroom.
- At the beginning of the school year, establish consequences for students who behave in an unsafe manner. Make these consequences clear to students.
- Do not overlook any violation of a safety practice, no matter how minor. If a rule is broken, take steps to assure that the infraction will not occur a second time.
- Know and follow waste disposal regulations.
- Set a good example by observing all safety practices. This includes wearing eye protection during all investigations when eye protection is required for students.
- Know and follow waste disposal regulations.
- Be aware of students who have allergies or other medical conditions that might limit their ability to participate in activities. If a student has such a medical condition, then consult with the school nurse or school administrator to discuss whether or not participation is advisable.
- Anticipate potential problems. When planning teacher demonstrations or student investigations, identify potential hazards and safety concerns. Be aware of what could go wrong and what can be done to prevent the worst-case scenario. Before each activity, verbally alert the students to the potential hazards and distribute specific safety instructions as well.
- Supervise students at all times during hands-on activities.
- Provide sufficient time for students to set up the equipment, perform the investigation, and properly clean up and store the materials after use.
- Never assume that students know or remember safety rules or practices from their previous science classes.

HOW CAN CONTROVERSIAL TOPICS BE HANDLED IN THE CLASSROOM?

Teachers sometimes feel that the discussion of values is inappropriate in the science classroom or that it detracts from the learning of “real” science. The lessons in this module, however, are based upon the conviction that there is much to be gained by involving students in analyzing issues of science, technology, and society. Society expects all citizens to participate in the democratic process, and our educational system must provide opportunities for students to learn to deal with contentious issues with civility, objectivity, and fairness. Likewise, students need to learn that science intersects with life in many ways.

In this module, students are given a variety of opportunities to discuss, interpret, and evaluate basic science and health issues, some in the light of their values and ethics. As students encounter issues about which they feel strongly, some discussions might become controversial. The degree of controversy depends on many factors, such as how similar students are with respect to socioeconomic status, perspectives, value systems, and religious beliefs. In addition, your language and attitude influence the flow of ideas and the quality of exchange among the students.

The following guidelines may help you facilitate discussions that balance information with feelings:

- Remain neutral. Neutrality may be the single-most important characteristic of a successful discussion facilitator.
- Encourage students to discover as much information about the issue as possible.
- Keep the discussion relevant and moving forward by questioning or posing appropriate problems or
- hypothetical situations. Encourage everyone to contribute, but do not force reluctant students to enter the discussion.
- Emphasize that everyone must be open to hearing and considering diverse views.
- Use unbiased questioning to help students critically examine all views presented.
- Allow for the discussion of all feelings and opinions.
- Avoid seeking consensus on all issues. Discussing multifaceted issues should result in the presentation of divergent views, and students should learn that this is acceptable.
- Acknowledge all contributions in the same evenhanded manner. If a student seems to be saying something for its shock value, see whether other students recognize the inappropriate comment and invite them to respond.
- Create a sense of freedom in the classroom. Remind students, however, that freedom implies the responsibility to exercise that freedom in ways that generate positive results for all.
- Insist upon a nonhostile environment in the classroom. Remind students to respond to ideas instead of to the individuals presenting those ideas.
- Respect silence. Reflective discussions are often slow. If a teacher breaks the silence, students may allow the teacher to dominate the discussion.
- At the end of the discussion, ask students to summarize the points made. Respect students regardless of their opinions about any controversial issue.

USING THE STUDENT LESSONS

The heart of this module is the set of six classroom lessons. These lessons are the vehicles that will carry important concepts related to science practices to your students. To review the concepts in detail, refer to *Table 1* (page 7).

FORMAT OF THE LESSONS

As you review the lessons, you will find that all contain common major features.

AT A GLANCE provides a convenient summary of the lesson.

- **OVERVIEW** provides a short summary of student activities.
- **MAJOR CONCEPTS** states the central ideas the lesson is designed to convey.
- **OBJECTIVES** lists specific understandings or abilities students should have after completing the lesson.
- **TEACHER BACKGROUND** specifies which portions of the background section relate directly to the lesson. This reading material provides the science content that underlies the key concepts covered in the lesson. The information provided is not intended to form the basis of lectures to students. Instead, it enhances your understanding of the content so that you can more accurately facilitate class discussions, answer student questions, and provide additional examples.

IN ADVANCE provides instructions for collecting and preparing the materials required to complete the activities in the lesson.

- **PHOTOCOPIES** lists the paper copies and transparencies that need to be made from masters, which are found at the end of each lesson.
- **MATERIALS** lists all the materials (other than photocopies) needed for each of the activities in the lesson.
- **PREPARATION** outlines what you need to do to be ready to teach the lesson.

PROCEDURE outlines the steps in each activity of the lesson. It includes implementation hints and answers to discussion questions. Within the Procedure section, annotations provide additional commentary.

MASTERS required to teach the activities are located at the end of each lesson.

TIMELINE FOR THE MODULE

The following timeline outlines the optimal plan for completing the lessons in this module. This plan assumes that you will teach the activities on consecutive days. If your class requires more time for completing the activities or for discussing issues raised in this module, adjust your timeline accordingly.

TABLE 8. SUGGESTED TIMELINE (ASSUMES 45 MINUTE CLASS PERIODS)

TIMELINE	ACTIVITY
2 WEEKS AHEAD	Read all lessons. Obtain supplies for Lessons 2 and 3.
1 WEEK AHEAD	Copy masters. Gather materials. Prepare clay for Lesson 2. Germinate seeds for Lesson 3.
DAY 1 MONDAY	**LESSON 1** Activity 1: Essential Elements Activity 2: Sources of Essential Elements Note: The optional extension activity would require additional class time.
DAYS 2 AND 3 TUESDAY AND WEDNESDAY	**LESSON 2** Activity 1: Soil Separation Activity 2: Soil Columns Activity 3: Soil Is Complex Note: The optional extension activity would require additional class time.
DAYS 4 AND 5 THURSDAY AND FRIDAY	**LESSON 3** Activity 1: From Soil to Roots Activity 2: From Roots to the Plant Activity 3: Soil Formation and Horizons Activity 4: The Dust Bowl
DAY 6 MONDAY	**LESSON 4** Activity 1: When a Plant Needs "Food" Activity 2: Humanity Against Hunger Note: The optional extension activity would require additional class time.
DAY 7 TUESDAY	**LESSON 5** Activity 1: The Big Apple Activity 2: Using Land Wisely Activity 3: Fertilizers and the Future
DAY 8 WEDNESDAY	**LESSON 6** Activity 1: Nourishing the Planet in the 21st Century

TEACHER BACKGROUND

1.0 INTRODUCTION

We are fortunate to live in a society with abundant food. Most of us take for granted that we will always have enough to eat. If we do have any concerns about food, more than likely they relate to its nutritional value or to reducing the epidemic of obesity. Many of us have never visited a working farm, let alone tried to understand the techniques that farmers use to grow our food. A by-product of the success of modern agriculture is a society where the efforts of the few are adequate to feed the many. This situation allows the vast majority of people to engage in diverse occupations without worrying about the need to grow food to feed their families.

Of course, it has not always been this way. For most of human history, the world's population increased at a steady but slow rate. However, during the last 100 years, the rate of population growth increased to such an extent that more-efficient farming methods were not just desirable but essential to avoid massive famine. In 1950, the world's population reached 3 billion people. The population then doubled in just 50 years. The implementation of farming practices such as the increased use of commercial fertilizers to replenish soil nutrient deficiencies accompanied this rapid population growth. During this so-called Green Revolution, crop yields increased enough to keep pace with the demand for food.

In 1950, 1.7 billion acres of farmland were used to produce 692 million tons of grain. By 1992, essentially the same acreage produced 1.9 billion tons of grain.[10] Not only did the Green Revolution help feed our growing population; it also limited the amount of land that was cultivated to raise crops. If populous India had not used the high-yielding crops developed during the Green Revolution, then it would have had to farm additional acreage about the size of California to produce the same quantity of grain.[5]

However, the advances of the Green Revolution have almost reached their potential for increasing crop yields. At the same time, the human population shows no inclination to stop growing. It is estimated that by 2050, the world's population will increase from its present 7.1 billion people to approximately 9.6 billion people.[23] How will all of these people be fed? Most of the land suitable for farming is already being tilled. We have no choice but to explore other ways of increasing crop yields and sustaining the quality of our soil.

The challenge for the future is simple. We must feed a population that grows by 80 million people each year, using the same amount of farmland. Clearly, the farming practices of the past are not going to be able to sustain us in the future. Our response to this challenge involves making difficult decisions about land use, fertilizers, pesticides, and genetic engineering, among others. As a society, we will have to decide how agriculture can economically feed our growing population while at the same time help us protect our environment.

These issues will become increasingly important in the decades to come. As today's young people become adults and enter the workforce, they will be asked to make decisions regarding the use of natural resources such as farmland. Hopefully, they will make rational decisions about using technology to benefit society while minimizing its negative impacts. The aim of the *Nourishing the Planet in the 21st Century* module is to help prepare students to meet the challenges of the future. The lessons are designed to enhance students' basic understanding of plant biology and the process of scientific inquiry. They help develop critical-thinking skills in the real-world context of sustainably nourishing the planet's growing population. The module focuses on nutrients: exploring what they are, why they are important, where they come from, what their impacts are, and how they can be managed.

2.0 PLANTS AND THEIR ESSENTIAL ELEMENTS

All organisms must take in matter from their environment in order to survive. There are 92 naturally occurring elements on Earth. Living things need only a minority of them. For example, humans require about 21 different elements to be healthy.[8] Almost all of the mass of our bodies comes from just six of those elements **(CARBON, HYDROGEN, OXYGEN, NITROGEN, PHOSPHORUS,** and **CALCIUM).** These are the elements used to construct the carbohydrates, nucleic acids, proteins, and other molecules that make up our cells and carry out their chemistry. Other elements critical to our health are needed in very small amounts. Often, such elements are cofactors required by enzymes to catalyze specific chemical reactions. Regardless of whether elements are needed in large or small amounts, they must be obtained from the environment. Furthermore, it not enough that essential elements are present in the environment; they must be available in a chemical form that our bodies can use.

Not surprisingly, the situation in plants is similar. They, too, must carry out thousands of different chemical reactions, many of which are similar to those of humans. Scientists have identified 17 elements that are essential for plants *(see Table 9)*.[8] An element is described as being essential to the plant if the following conditions are met:

- The element must be required by the plant to complete its life cycle.
- The element cannot be replaced by another element.
- The element must be required for a specific biological function.[1]
- The element must be required by a substantial number of different plant species.

Essential elements can be classified as mineral or non-mineral nutrients. Carbon, hydrogen, and oxygen are classified as non-mineral nutrients because they are obtained from the atmosphere and water. Mineral nutrients can be further classified as being either macronutrients or micronutrients. As the name implies, macronutrients are needed in relatively large amounts. Nitrogen, phosphorous, and potassium are called primary macronutrients, while calcium, sulfur, and magnesium are called secondary macronutrients. The rest of the essential elements are called micronutrients because they are needed in small amounts. It is important to note that despite their name, micronutrients are just as essential to plant health as are macronutrients.

Plants absorb most of their essential elements from water in the soil. Usually the essential elements are taken up as a positively charged cation or a negatively charged anion.

TABLE 9. ESSENTIAL PLANT NUTRIENTS

ELEMENT TAKEN INTO THE PLANT	SYMBOL	CLASSIFICATION	CHEMICAL FORM
Hydrogen	H	Nonmineral nutrient	H_2O
Oxygen	O	Nonmineral nutrient	O_2 and CO_2
Carbon	C	Nonmineral nutrient	CO_2
Nitrogen	N	Primary macronutrient	NH_4+ and NO_3-
Phosphorus	P	Primary macronutrient	H_2PO_4- and $HPO_4{}^2-$
Potassium	K	Primary macronutrient	K^+
Calcium	Ca	Secondary macronutrient	Ca^{2+}
Magnesium	Mg	Secondary macronutrient	Mg^{2+}
Sulfur	S	Secondary macronutrient	$SO_4{}^2-$
Boron	B	Micronutrient	$B(OH)_3$
Chlorine	Cl	Micronutrient	Cl^-
Copper	Cu	Micronutrient	Cu^{2+}
Iron	Fe	Micronutrient	Fe^{2+} and Fe^{3+}
Manganese	Mn	Micronutrient	Mn^{2+}
Molybdenum	Mo	Micronutrient	$MoO_4{}^{2-}$
Nickel	Ni	Micronutrient	Ni^{2+}
Zinc	Zn	Micronutrient	Zn^{2+}

3.0 THE NITROGEN CYCLE

Although the atmosphere is about 78 percent nitrogen, plants cannot make use of nitrogen gas (N_2). Instead, plants need to obtain their nitrogen by taking up the cation ammonium (NH_4+) or the anion nitrate (NO_3–) in the soil. These ionic forms of nitrogen are generated by the breakdown of organic material in the soil or through a process called nitrogen fixation that is carried out by soil microbes. Some crop plants (legumes such as peas, beans, peanuts, and soybeans) live in close association with nitrogen-fixing bacteria that live in their roots and convert N_2 gas to a form that plants can use. Such crops have a steady source of nitrogen and do not require nitrogen-containing fertilizers.

The nitrogen cycle describes the processes by which nitrogen moves between its various chemical forms. Biological or physical processes can cause these chemical conversions. Four processes are essential to the nitrogen cycle.

- **NITROGEN FIXATION** refers to the process by which atmospheric nitrogen (N_2) is converted to nitrogen–containing compounds that are usable by plants. Nitrogen fixation can be accomplished through the action of lightning or bacteria in the soil.
- **AMMONIFICATION** refers to the process by which bacteria and fungi convert decomposed nitrogen-containing compounds into ammonium ions (NH_4+).
- **NITRIFICATION** refers to the process by which bacteria convert ammonium ions into nitrite (NO_2-). Other bacteria convert nitrite to nitrate (NO_3-). This is important because nitrites can reach levels that are toxic to plants.
- **DENITRIFICATION** refers to the process by which bacteria convert nitrates back to N_2.

So, let us summarize the nitrogen cycle. First, recall that plants cannot use the nitrogen in the air that is so plentiful. When plants and animals die and decompose, they add nitrogen to the soil. Bacteria in the soil convert the nitrogen into compounds that plants can use. Plants take in these nitrogen-containing compounds through their roots and use them to grow. Animals eat the plants, use the nitrogen, and return it to the soil when they die and decompose.

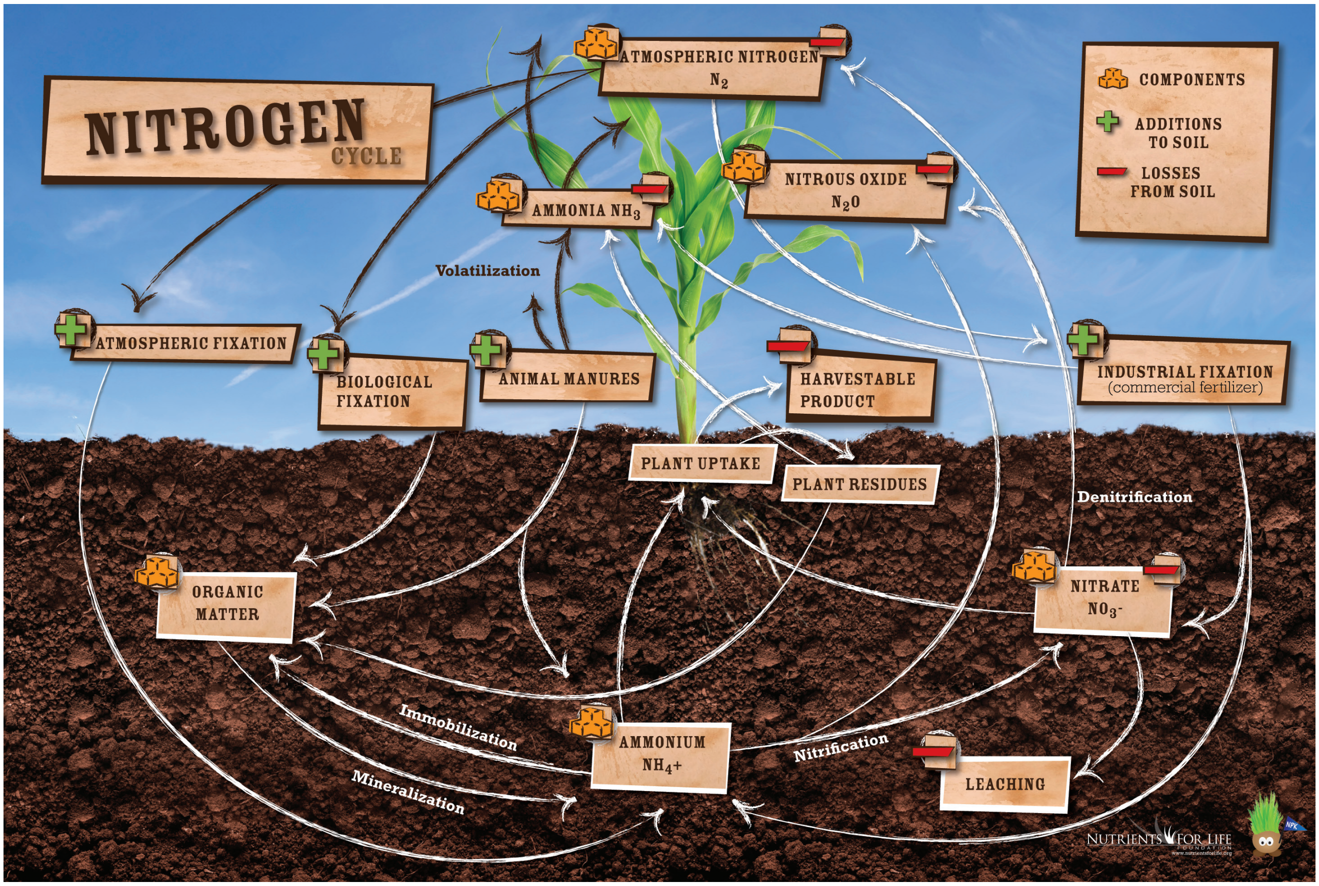

FIGURE 1. THE NITROGEN CYCLE DESCRIBES THE RELATIONSHIPS BETWEEN DIFFERENT FORMS OF NITROGEN IN THE ENVIRONMENT.

4.0 SOIL FORMATION

Most people take soil for granted. In fact, "soil" has a negative connotation. We call it dirt and wash it off our clothes and our bodies. In reality, soil is essential to our survival and that of nearly every organism on Earth. Our planet is mostly made of rock with an iron-nickel core. Plants and animals, including us, occupy a thin veneer on its surface. Our existence is possible because of a thin layer of soil that comes between the planet's rocky interior and us.

Soils vary. They are natural expressions of the environment in which they form. Scientists recognize five main factors that influence soil formation: **1) PARENT MATERIAL, 2) CLIMATE, 3) LIVING ORGANISMS, 4) TOPOGRAPHY,** and **5) TIME.**[2]

PARENT MATERIAL
Parent material refers to both the organic and mineral material in which soil formation takes place. Mineral can include weathered rock, ash from volcanos, and sediments deposited by wind and water. Soil formation will happen more quickly in materials that are more permeable to water.

CLIMATE
Climate influences the amount of water available for weathering the parent material and the temperature at which it occurs. A warm, moist climate fosters plant growth and speeds up decomposition, both of which contribute to faster soil formation.

LIVING ORGANISMS
Plants supply soil with organic material and help prevent erosion. Deep-rooted plants have a greater impact on soil formation than shallow-rooted plants because they create larger channels for water movement. Insects, earthworms, fungi, and bacteria are important because they help decompose organic material releasing plant nutrients.

TOPOGRAPHY
The three dimensional shape of the land influences water movement and therefore the speed of soil formation. Since water flows downward due to gravity, soils on slopes are prone to erosion. Areas that are very wet or very dry may not be fertile and the resulting lack of plant growth can slow the rate of soil formation.

TIME
The weathering of rock slowly produces soils. Constant exposure to wind and rain cause the rocky crust to break slowly down into smaller particles. It can take centuries to produce fertile topsoil. As rainwater seeps into cracks, temperature extremes cause the water to freeze. The rock expands, contracts, and fractures. Organisms that live on and in the soil help these weathering actions along.

Of course, in addition to these five factors, human activity also can influence soil formation. Agricultural practices and urban development especially can interfere with the naturally occurring process of soil formation.

5.0 SOIL HORIZONS

The gradual process of soil formation produces a series of horizontal layers. A soil horizon is a layer generally parallel to the soil surface, whose physical and chemical characteristics differ from the layers above and beneath. A given type of soil usually has three or four horizons. Horizons are characterized by the obvious physical characteristics of color and texture. The formation of soil horizons is influenced by factors such as air, water, sunlight, and plant material.
The weathering of the parent material occurs first at the surface and then works its way downward. This means that the uppermost layers are changed (weathered) the most, while the deepest layers are the most similar to the original parent material.

To visualize the soil horizons, scientists dig a hole several meters deep to expose the layers. Most soils display a similar pattern of horizons. Each horizon is labeled with its own capital letter that identifies its place. A typical soil horizon sequence is described as **O-A-B-C-R.**[18]

- **O** refers to organic matter that is relatively undecomposed and lies on the surface.
- **A** refers to organic material mixed with mineral that makes up the surface soil.
- **B** refers to the subsoil. This layer reflects the chemical and physical alteration of the original parent material.
- **C** refers to the parent material
- **R** refers to the bedrock. The R layer is mostly composed of hard rock that cannot be excavated by hand.

FIGURE 2. PHOTO SHOWING SOIL HORIZONS

6.0 SOIL TRIANGLE

During soil formation, inorganic material is broken down by weathering into particles of various sizes. Soil texture refers to the relative proportions of different-sized particles found in the soil. Scientists classify soil particles into three categories. The smallest particles, which measure less than 0.002 millimeters, are called clay.[9] Clay is important in holding nutrients. Clay particles form plate-like structures that attract and hold nutrients through chemical bonds. These nutrients can be displaced off the clay by another nutrient, absorbed by a plant root or soil microbe, or chemically absorbed into the clay particle itself. The next-largest particles are called silt. Silt particles range in size from 0.002 millimeters to 0.06 millimeters. Sand refers to the largest particles. Sand grains range in size from 0.06 millimeters to 2 millimeters. Soils vary in their proportions of clay, silt, and sand. Soil scientists classify different soil types using the soil triangle. Each side of the soil triangle represents the amount of a particle of a certain size—clay, silt, or sand. The relative amounts of these three soil components intersect within the triangle and determine to what type of soil those proportions correspond.

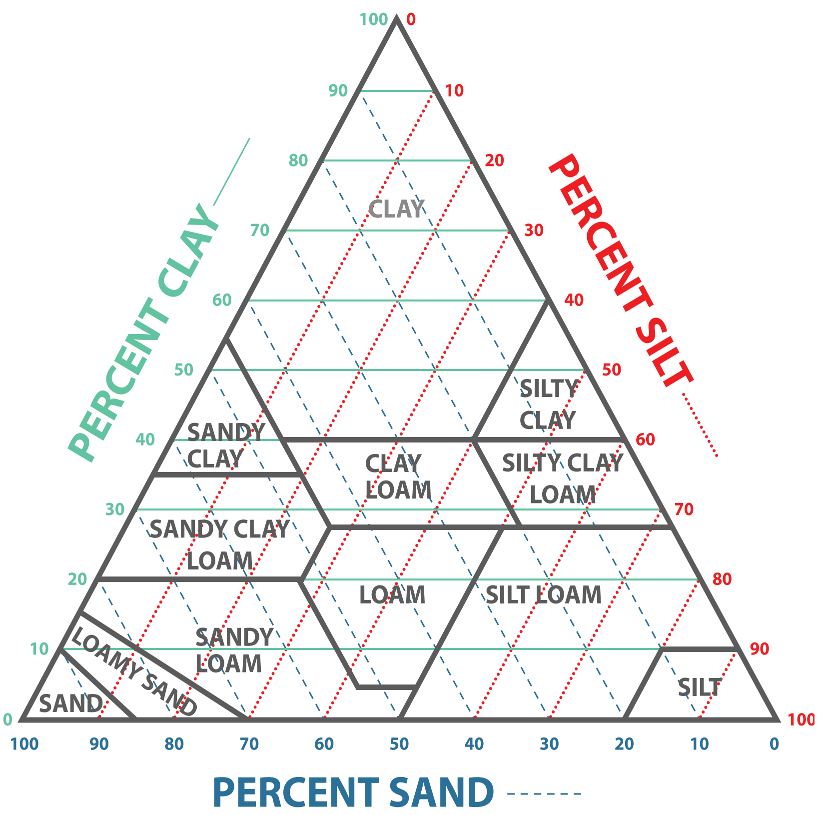

FIGURE 3. THE SOIL TRIANGLE IS USED TO CLASSIFY SOIL TYPES.

The ability of a soil to accept and retain water is largely determined by the relative amounts of clay, silt, and sand present. Porosity refers to spaces in the soil that can hold either air or water. Permeability is defined as the rate at which water can travel through soil. *Table 10* lists properties of particle size that relate to soils' interactions with water. Soils with desirable properties for farming are called loams. Loamy soils typically contain about 50 percent air space, which allows root systems to "breathe" (i.e., obtain O_2 for respiration). The solid half of loamy soils is about 90 percent minerals and 10 percent organic material. Usually, loamy soils have names that more accurately reflect their composition, such as clay loam or silt loam.

TABLE 10. PROPERTIES OF SOIL PARTICLES

PROPERTY	CLAY	SILT	SAND
POROSITY	Mostly small pores	Mostly small pores	Mostly large pores
PERMEABILITY	Slow	Slow to moderate	Rapid
WATER-HOLDING CAPACITY	Large	Moderate	Limited

Although the organic fraction of most soils is small in volume compared to the mineral fraction, it plays an important role in supporting plant growth. The organic material is composed of living organisms, plant roots, and plant and animal residue. A single gram of healthy topsoil may contain 100 nematodes (small roundworms), 1 million fungi, and 1 billion bacteria.[27] Earthworms and a wide variety of insects may be present in smaller numbers. Organic material contains a significant amount of nutrients, and it, together with plant roots, helps

- decrease erosion;
- increase water infiltration and storage;
- act as a pH buffer (to maintain an acid-base balance);
- decompose organic material, releasing nutrients;
- recycle carbon, nitrogen, and other nutrients; and
- retain available nutrients such as metal ions.

The soil is a "bank" for nutrients that are taken up by plants, and these nutrients must be replenished for continued plant growth. Before the advent of modern agriculture, farmers relied solely upon tillage to break down existing organic material and release existing soil nutrients. This practice is still used in many less-developed countries.

7.0 PLANT-SOIL INTERACTIONS

Plants use their root systems for structural support, stability, and nourishment. If you have ever seen a tree toppled by high winds, you have some idea of why trees are so stable. The primary function of the root system is to absorb water and nutrients from the soil. To do this, the root system is ever changing over the course of the plant's life, capable of growing year-round, if conditions for growth are met and there is not competition from the plant's top system. Roots also may serve as storage organs for starch or sugars. Carrots, beets, radishes, turnips, and potatoes are examples of storage roots.

FIGURE 4. A RADISH SEEDLING SHOWING ROOT HAIRS

The growth of roots is similar to the growth of shoots. However, there are important differences. In general, the more extensive a root system is, the more water and nutrients it can absorb. If you examine a root using a magnifying glass, you will see a large number of delicate root hairs growing out from the surface of the root *(see Figure 4)*. This system of root hairs greatly increases the surface area of the root available to contact and absorb water. A single rye plant 60 centimeters tall is estimated to have a root system with a total length of 480 kilometers. Its surface area is more than 600 square meters—twice that of a tennis court![6]

The tip of an actively growing root is called the root cap *(see Figure 5)*. The root cap produces a slimy secretion called mucilage that helps lubricate the root as it pushes its way through the soil. Just behind the root cap is the zone of active cell division, and behind it is a zone of cell elongation. The cells of the elongation zone grow by taking in water and swelling. The root cells contain salt and sugars. Because the root cells contain more solutes than the water in the soil, water flows into the cells by diffusion. This causes the cells to elongate, forcing the root deeper into the soil. Behind the elongation zone is the zone of cell differentiation. The cells in this area give rise to the cells of the vascular system, which transport water up the stem and sugars down from the leaves.

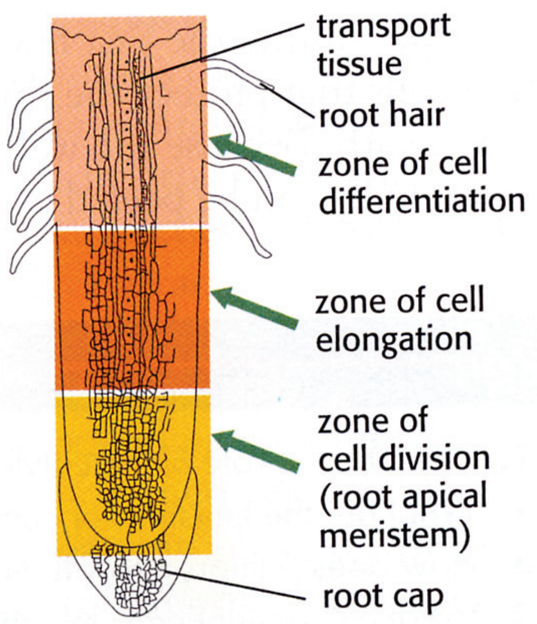

FIGURE 5. A LONGITUDINAL SECTION OF A ROOT TIP

Roots may stop growing during the winter not because they have become dormant like the buds at the top of the plant, but rather because the temperature is too cool to support growth. In order for roots to grow, they must have adequate moisture and temperature. Many people are under the misconception that roots grow in search of water. This is not the case. Roots can only grow where the conditions are suitable for growth. This means that roots grow where water is already present.

The transport of water and nutrients into, within, and out of a plant depends on three important processes:

DIFFUSION refers to the movement of a liquid or gas from a region of higher concentration to one of lower concentration. This movement is a natural consequence of random molecular movement and does not require added energy to accomplish. During photosynthesis, carbon dioxide moves down its concentration gradient to enter a leaf cell. At the same time, oxygen moves down its concentration gradient to exit the leaf cell.

OSMOSIS is a process similar to diffusion but refers to the movement of water. When water enters plant roots, it moves down its concentration gradient since the concentration of water is higher in the soil than in the root tip.

ACTIVE TRANSPORT refers to the movement of a liquid or gas from a region of lower concentration to an area of higher concentration. This movement against a concentration gradient can only be accomplished by using energy to help molecules move opposite the direction that diffusion would take them.

WATER is absorbed by the root hairs and brings along with it any chemicals, including nutrients that are dissolved in it. Most nutrients are present in higher concentration in the root hairs as compared with the soil water. Active transport is used to move the nutrients deeper into the root system until they reach cells of the vascular system. The importance of active transport can be demonstrated by exposing plants to a chemical that interferes with cellular respiration. Without a supply of energy-containing ATP molecules produced through respiration, the rate of nutrient movement slows greatly.

8.0 THE PLANT VASCULAR SYSTEM

Although plants do not have a circulatory system like humans, they still must transport material from one part of the organism to another. The plant stem contains a vascular system that connects the leaves to the roots. The plant's vascular system is composed of xylem tissue that transports water from the roots to the rest of the plant and phloem tissue that transports sugars produced in the leaves to the nonphotosynthetic parts of the plant *(see Figure 6).* The xylem is composed of dead cells that form long, empty tubes. Some tubes are wide, and others are narrow. The cell walls within the tubes are either missing or contain a series of holes that permits the passage of water. The cells that gave rise to the xylem lay down thick cell walls that contain a polymer called lignin. Lignin lends strength to the xylem and prevents it from collapsing under pressure.

The capability of xylem tissue is truly amazing. In the case of the tallest trees, water must be transported from the roots up, over 100 meters and against gravity, to the leaves. Water is thought to move through the xylem by a process known as cohesion-tension. According to this view, water can be pulled upward if the diameter of the tube is sufficiently small and that the column of water is continuous, that is, without air bubbles. A further requirement is that the tube be made of a material to which water molecules will adhere. Within each xylem tube, the water molecules are attracted to adjacent water molecules, forming an unbroken chain. The plant loses water through evaporation from its leaves by a process called transpiration. As water is lost, a negative pressure or tension is created that pulls water up from the xylem. Transpiration is the process that drives the transport of water from the roots up through the stems to the leaves.

While water is moving up the plant, sugars and amino acids must move from the leaves downward to the non-photosynthetic parts of the plant. Phloem tissue is composed of tubes made from living cells called sieve cells. Holes at the ends of their cell walls form sieve plates. The cytoplasm of one sieve cell connects with the cytoplasm of adjacent sieve cells through these holes, forming a continuous cell-to-cell sieve tube. As the sieve cells mature, they lose their nuclei and other organelles.

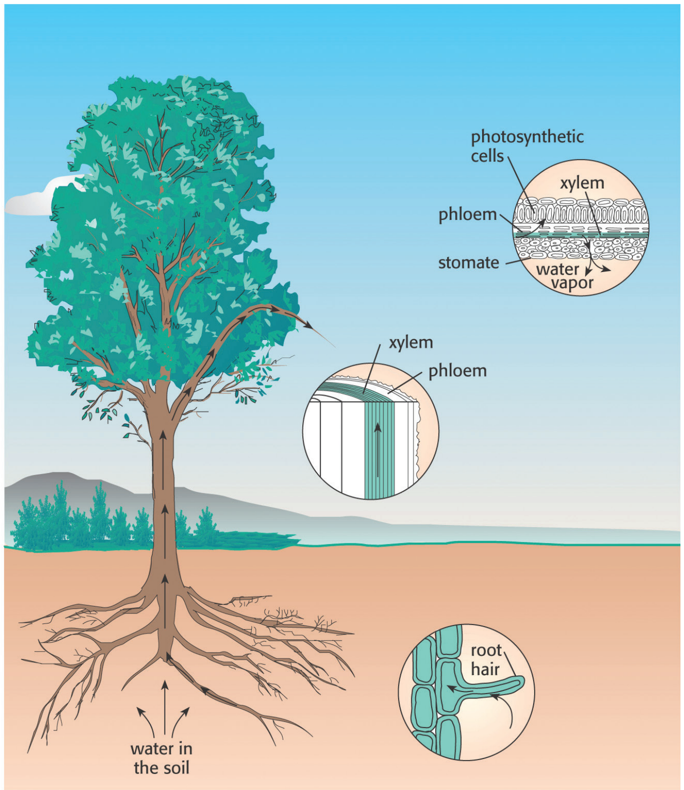

FIGURE 6. WATER TRANSPORT IN A TREE

Beside each sieve cell is a smaller companion cell that has a nucleus. The companion cells are thought to regulate the activity of the sieve cells.

Experiments have demonstrated that this movement occurs at a rate that is thousands of times faster than could be achieved by diffusion. Sugars are thought to move through the phloem by a process called pressure-flow. According to this view, water and dissolved sugars flow through sieve tubes from areas of higher pressure to ones of lower pressure. Sugars made in the leaves are transported into the phloem by active transport. The high concentration of sugar causes water to flow into the phloem cells, increasing what is called the turgor pressure within the cell. This high turgor pressure forces the sugar-water solution into the adjacent phloem cell, increasing its turgor pressure. This process repeats, moving from cell to cell until the solution reaches a cell where it will be used. Once at its destination, the sugar is removed from the phloem by active transport. Water, too, is removed from the phloem cell, regenerating the lower turgor pressure needed to keep the flow moving.

9.0 NUTRIENT DEFICIENCIES OF PLANTS

People and plants are very different types of organisms. For example, people have blood, while plants have sap. People are consumers, while plants are producers. Despite their many differences, both people and plants are made up of cells. In order for cells to be healthy, they must have certain nutrients. If a person is lacking a needed vitamin, mineral, or essential element, then a deficiency is the result. We are familiar with the results of some nutrient deficiencies. For example, if a person lacks iron, he or she becomes anemic, or if a person lacks calcium, his or her bones become brittle. As discussed in *Section 2.0, Plants and Their Essential Elements,* plants require a variety of elements to be present in different amounts in order to support healthy growth. A nutrient deficiency results if a particular nutrient is not available in sufficient quantity to meet the needs of the growing plant. Nutrient toxicity occurs when a nutrient is present in such an excess that it harms the plant. *Table 11* lists most of the essential plant nutrients and describes what happens when plants have too little or too much of them.

TABLE 11. SYMPTOMS OF PLANT DEFICIENCIES AND TOXICITIES

PLANT NUTRIENT	CONDITION	SYMPTOMS
NITROGEN	DEFICIENCY	Light green to yellow leaves; stunted growth; low protein level; poor fruit development
	TOXICITY	Dark green leaves; susceptible to drought, disease, and insects
PHOSPHORUS	DEFICIENCY	Purple coloration on leaves; stunted growth and delay in development; increased disease; reduced drought tolerance
	TOXICITY	Micronutrient deficiencies, especially zinc or iron
POTASSIUM	DEFICIENCY	Yellowing on edges of older leaves, dead leaves; irregular fruit development; reduced drought tolerance
	TOXICITY	Micronutrient deficiencies, especially zinc or iron
CALCIUM	DEFICIENCY	Poor fruit development and appearance; symptoms appear in new leaves and shoots
	TOXICITY	Deficiencies in magnesium or potassium (from precipitation in soil)
MAGNESIUM	DEFICIENCY	Yellowing on older leaves; poor fruit development
	TOXICITY	Growth reduction possibly due to imbalance with calcium and potassium
SULFUR	DEFICIENCY	Yellowing on younger leaves; otherwise similar to nitrogen deficiency
	TOXICITY	Premature dropping of leaves

TABLE 11. CONTINUED

IRON	**DEFICIENCY**	Yellow or white areas on young leaves, leading to spots of dead tissue
	TOXICITY	Bronzing of leaves with small brown spots
MANGANESE	**DEFICIENCY**	Yellowing or mottling on young leaves
	TOXICITY	Brown spots on older leaves
ZINC	**DEFICIENCY**	Yellowing on young leaves; stunted growth; delayed maturity
	TOXICITY	Possible iron deficiency
BORON	**DEFICIENCY**	Deformed and discolored leaves; death of growing points
	TOXICITY	Yellowed leaf tips, scorched appearance; premature leaf dropping
MOLYBDENUM	**DEFICIENCY**	Overall chlorosis, mottled spotting
	TOXICITY	Bright orange leaves

Adapted from Bennett, W. (Ed.). (1993). Nutrient deficiencies and toxicities in crop plants. St. Paul, MN: APS Press.

As shown in *Table 11*, when a plant is out of nutrient balance, it displays symptoms that are characteristic for that particular nutrient. A farmer concerned for the health of his or her crops must use scientific tools to prevent deficiencies and, if necessary, to examine these symptoms and diagnose problems, much like a physician does when encountering a patient with a dietary deficiency. Soil and plant tissue tests are used to detect nutrient imbalances. Once the problem has been identified, steps are taken to correct the imbalance. Farmers prescribe fertilizers for their crops in a manner similar to doctors prescribing vitamins for their patients.

10.0 NOURISHING CROPS WITH FERTILIZERS

As discussed above, plants grown in soil depleted of nutrients can display a wide variety of symptoms and greatly limit the quantity and quality of harvested crops. Fertilizer is essentially "plant food". It is added to replenish nutrients that people indirectly extract from the soil by harvesting plants. In non-agricultural ecosystems, the nutrients removed by plants are returned to the soil after the plants die and decompose. On farms, some of these nutrients are removed in the form of harvested crops, so it is often necessary to replace them with fertilizers. The essential components of most fertilizers are the macronutrients nitrogen, phosphorus, and potassium. All three of these elements play essential roles in allowing plants to access the free energy of the sun through photosynthesis and must be present in adequate amounts to ensure healthy crop growth.

TABLE 12. IMPORTANCE OF SOME ESSENTIAL MACRONUTRIENTS

NITROGEN	• Component of proteins and nucleic acids • Required for chlorophyll production
PHOSPHORUS	• Component of nucleic acids and some proteins • Required for energy transfer • Important for seed germination and water use
POTASSIUM	• Required as a regulator involved in - efficient use of water - transfer of food - protection against stresses
SULFUR	• Component of proteins • Required as a regulator involved in - efficient use of water - transfer of food - protection against stresses

Humans have been raising crops for nearly 10,000 years. Even ancient farmers fertilized their crops. The use of human and animal waste to increase soil fertility was recorded in China over 2,000 years ago. During the "golden age" of Greece from 800 to 200 BC, historians discussed methods for using sewage and classifying manures according to their value for crop production. Although these ancient cultures lacked our understanding of chemistry, they were observant and learned through trial and error how to help their crops grow. Mineral fertilizer in the form of saltpeter or potassium nitrate is mentioned by early Greek and Roman writers and in the Bible. Ancient Greeks also used salt brines to fertilize palm trees.[3]

Justus von Liebig (1803–1873) is known as the founder of the modern fertilizer industry. Using the contributions of other scientists and his own discoveries, Liebig formulated the "mineral theory," which held that crops "grow or diminish in exact proportion" to the amount of nutrient applied. Leibig stressed the value of replacing nutrients to maintain soil fertility. He also developed the "law of the minimum," which states that if one essential element is deficient, then plant growth will be lacking even when all other essential elements are abundant. If the deficient element is supplied, then growth will increase up to the point where the supply is no longer the limiting factor.[12]

The concept of the law of the minimum has been modified through the years as scientists have achieved a better understanding of the variables affecting plant growth. Moisture, temperature, insect control, weed control, light, plant population, and genetic capabilities of plant varieties are now part of this rule.

Today, commercial fertilizers are obtained from a variety of natural sources. The world's first commercial fertilizer was sodium nitrate mined from natural deposits in Chile and imported into Europe and the United States starting around 1830. Around the same time, ammonium sulfate, a by-product of the manufacture of coal gas used for illumination, was sold as a commercial fertilizer.

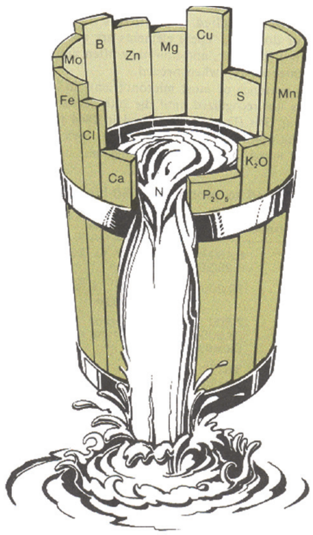

FIGURE 7. ACCORDING TO THE LAW OF THE MINIMUM, PLANT GROWTH WILL BE REDUCED IF JUST ONE ESSENTIAL ELEMENT IS LACKING.

10.1 NITROGEN (THE BUILDER)

NITROGEN (N) is a primary building block for all organisms. It is a component of every amino acid and therefore essential to making proteins. As part of the chlorophyll molecule, nitrogen helps keep plants green. Nitrogen, along with magnesium, is the only element in the chlorophyll molecule that the plant obtains from the soil.

Vigorous plant growth is associated with adequate nitrogen nutrition, in part because nitrogen plays a key role in cell division. If cell division is slowed or stopped, so is leaf growth, which affects the surface area of the leaf exposed to the Sun. A smaller surface area reduces the plant's ability to produce biomass (yield). In addition to increasing yield, nitrogen also improves crop quality by increasing its protein content. Crop plants generally require more nitrogen to grow at their full potential than non-crop plants.

In 1918, scientists Fritz Haber (1868–1934) and Carl Bosch (1874–1940) were awarded the Nobel Prize for developing nitrogen fertilizer by synthesizing ammonia from nitrogen gas and hydrogen. While this process has been modified several times, today the Haber-Bosch process remains the method by which nitrogen fertilizer is commercially produced. Some academics have even suggested that this process has been of greater fundamental importance to the modern world than the invention of the airplane, nuclear energy, space flight, or television.[22] The Haber-Bosch process has increased the amount of plant-available nitrogen produced on land by 60–70 percent compared to the natural processes of biological nitrogen fixation and lightning.[26] Ammonia can be used in a wide variety of field conditions and is a major source of nitrogen applied to crops in the United States. Ammonia contains 82 percent nitrogen and is an important component for most nitrogen-based fertilizers. Another nitrogen source is urea, which is made by reacting ammonia with carbon dioxide and is 45 percent nitrogen.

Organic sources of nitrogen have long been used as fertilizers. Between the years 1850 and 1900, the major natural organics were human excrement, cottonseed meals, fish scrap, and slaughterhouse wastes. In 1910, approximately 90 percent of the nitrogen used in the United States came from organic sources. As competition from commercial fertilizers grew, the contributions from organics decreased to 34 percent in 1920 and to 3.4 percent in 1950.[3]

A new form of fertilizer was developed in the 1950s called activated sewage sludge. This material is made by passing wastewater through filters and centrifuging it to remove debris, oil, grease, and grit. The wastewater is then oxygenated to help microorganisms break down the biomass. Excess water is removed, and the final product is a thick, fibrous cake that is dried in kilns at high temperature to kill any remaining microorganisms or pathogens.

FIGURE 8. THE CORN LEAF ON THE LEFT IS HEALTHY. THE LEAVES TO THE RIGHT HAVE INCREASING LEVELS OF NITROGEN DEFICIENCY.

10.2 PHOSPHORUS (THE ENERGY SUPPLIER)

PHOSPHORUS (P) is found in every living cell. In plants, it serves as both a structural element and as a catalyst for biochemical reactions. Phosphorus is a component of DNA and ATP (the cell's energy molecule). It also plays vital roles in capturing light during photosynthesis, helping with seed germination, and helping plants use water efficiently. Plants also use phosphorus to help fight external stress and prevent disease.

Animal and human bones contain insoluble calcium phosphate. As early as 2,000 years ago, Chinese farmers treated bones with lime and spread them on their fields. The lime treatment was necessary to convert the calcium phosphate into a more soluble form that plant roots could absorb. In the 1800s, fertilizer manufacturers wanted to produce phosphorus fertilizers that were more effective and plentiful than bones. They turned to natural deposits of phosphate rock in the fossilized remains of ancient marine life found in rock deposits around the world. The phosphate in these deposits exists in various forms of a very stable compound called apatite. To make the fertilizer called superphosphate, the phosphate rock is treated with acid or heat to render the phosphorus more soluble. Superphosphate production began in the United States in South Carolina in 1849.

FIGURE 9. CORN PLANTS DEFICIENT IN PHOSPHORUS HAVE SOME LEAVES WITH PURPLISH DIATION.

10.3 POTASSIUM (THE REGULATOR)

POTASSIUM (K) is essential to the workings of every living cell. Although potassium is not a part of any important plant structure, it plays critical roles in several physiological processes. Potassium activates enzymes that catalyze chemical reactions involved with growth. It plays an important role in water balance by regulating the opening and closing of stomates (the pores in leaves through which gases are exchanged). Potassium also helps regulate the rate of photosynthesis through its role in the production of ATP. Other aspects of plant health influenced by potassium include the growth of strong stalks, protection from extreme temperatures, and the ability to fight stress and pests such as weeds and insects.

Potassium used in the manufacture of fertilizers comes from sedimentary salt beds left behind following the evaporation of ancient seas and lakes. Nearly all potassium fertilizer is in the form of potassium chloride. The potassium fertilizer industry started in Western Europe, where there are significant deposits of such ores. North America has the world's largest reserves of potassium deposits. Other parts of the world containing potassium deposits include Brazil, China, Israel, Jordan, and Russia.

FIGURE 10. LEAF FROM A POTASSIUM-DEFICIENT CORN PLANT. THE DARK SPOTS ARE AREAS WHERE CELLS HAVE BEEN KILLED.

10.4 SULFUR (THE SYNTHESIZER)

SULFUR (S) is one of the most abundant elements in the soil and is one of the first elements scientists described. Like nitrogen, it is an essential component in the life of a cell. Sulfur is a component of the amino acids methionine and cysteine, which are used in the synthesis of proteins in all living things. Sulfur also is needed by enzymes associated with photosynthesis and chlorophyll synthesis. Sulfur is extracted from deep, naturally occurring underground deposits; from natural gas and crude oil; from the smelting of certain metal ores; and from gases produced by burning coal.

10.5 CALCIUM (THE SUPPORTER)

CALCIUM (Ca) plays a role in plants that is in some sense similar to that in humans. It is required for healthy growth and proper structural support. Calcium promotes proper cell elongation and is an essential part of the cell wall, helping to provide stability and bind cells together. In addition to its structural role, calcium participates in metabolic activities that help plants take up other nutrients and protect themselves against the effects of heat stress and infection by pathogens. Agricultural lime is used to supply plants with an external source of calcium. It is made from pulverized limestone or chalk, and the active ingredient is calcium carbonate.

10.6 MICRONUTRIENTS

Among the micronutrients, the following four types of deficiencies are commonly addressed with fertilizers:

- **BORON (B)** is an essential nutrient in the growth and development of new cells. In plants, boron helps regulate flowering, pollination, seed development, and sugar transport.
- **COPPER (Cu)** is a critical regulator of several plant enzyme systems and is necessary for protein synthesis and nitrogen metabolism.
- **MANGANESE (Mn)** is a part of several plant enzyme systems and plays a role in photosynthesis by regulating chlorophyll synthesis.
- **ZINC (Zn)** is an essential enzyme regulator involved with the synthesis of protein, starch, and growth hormones.

10.7 ORGANIC AND COMMERCIAL FERTILIZERS

During the past 30 years, the United States has witnessed a large growth in what is called organic farming. Although organic farming can be complicated to define, generally it relies on methods that use products that have been designated as "natural." Today, the organic foods industry has annual sales of approximately $21.1 billion, with organic products representing 3 percent of all U.S. grocery spending.[13]

Farmers who fertilize their crops have the choice of using either organic or commercial fertilizers, or a combination of the two types. As the name suggests, organic fertilizers come from once-living material, such as plants or animal manure. Commercial fertilizers consist of natural ingredients that have been subjected to a chemical process to make a fertilizer with increased and uniform nutrient content. Commercial fertilizers come either from natural mineral deposits or, in the case of nitrogen, from Earth's atmosphere. Chemically, there is no difference between the nitrogen atoms that come from fertilizer, animal manure, a compost pile, or the atmosphere; provided they are in the same form (e.g., ammonium, nitrate, or urea), they are the same as far as the plants are concerned. However, there are differences in the rate at which the nitrogen from each of these sources is made available to plants and in the ratio of nitrogen to other elements such as phosphorus.

A major distinction between organic fertilizers and commercial ones is the quantities of nutrients they contain and the farmers' knowledge about those quantities. Unlike commercial fertilizers, organic nutrient sources typically do not come with a guarantee of nutrient content. Organic material may supply high levels of one nutrient but low levels of another, creating an imbalance for crop plants. In contrast, commercial fertilizers contain known and often higher quantities of nutrients, which makes it convenient for farmers to apply them at rates that ensure that growing plants' needs are met and nutrient losses to the environment are minimized.

An advantage of plant-based organic fertilizers (e.g., compost) is that the nutrients are released slowly so they are less likely to be supplied faster than plants can use them. For this reason, they are often considered less damaging to the environment than commercial fertilizers. However, manure-based organic sources are typically more volatile—or subject to movement—in the environment than commercial fertilizers. If any nutrient—commercial or organic—is applied at a rate higher than plants can use them, the excess may run off the fields or disperse into the air and contribute to nutrient pollution *(see Section 12.1 Nutrient Pollution)*. Most organic fertilizers used on farms are manure based.

10.8 MEETING CROP'S NUTRIENT NEEDS

Fertilizers can be applied as liquids or solids or, as in the case of anhydrous ammonia, as a pressurized gas that is injected into the soil. Bagged fertilizers are sold in a wide variety of mixtures. It is easy to read their contents from the fertilizer label. The percentage by weight of the three macronutrients—–nitrogen, phosphorus, and potassium—is listed as the fertilizer's NPK ratio. For example, a label with an NPK ratio of 26-6-6 means that the fertilizer contains 26 percent nitrogen, 6 percent phosphorus, and 6 percent potassium. Some fertilizers also contain micronutrients, which are nutrients needed in smaller amounts for plant health and growth. Fertilizer labels also indicate the amounts of micronutrients as well as any inert ingredients such as sand that are included to provide bulk and make the fertilizer easier to apply.

Farmers use scientific methods to determine the appropriate nutrient balance for their crops. Because every farm field is different, farmers need to be able to select best-management practices (BMPs) that are suited to their growing conditions. Factors that may influence BMP selection include soil, climate, topography, and crop nutrient requirements. Often, farmers work with a certified crop adviser, a trained nutrient management professional, to assess growing and environmental conditions and develop a nutrient management plan.

The soil composition of farm fields varies greatly—often even on the same farm. Ensuring that crops get the precise amount of nutrients needed while minimizing nutrient losses to the environment involves consideration of a number of variables including the existing nutrient content of the soil and the crop nutrient needs. Soils can contain rich reserves of nutrients. Before fertilizing, farmers must measure the existing amounts of nitrogen, phosphorus, and potassium already in the soil. Then they can select a fertilizer that meets the needs of their crops. Sometimes, fertilizers are custom-blended to meet the farmer's needs. After the right product has been selected, the nutrient management plan must also take into account the criteria described in *Table 11.*

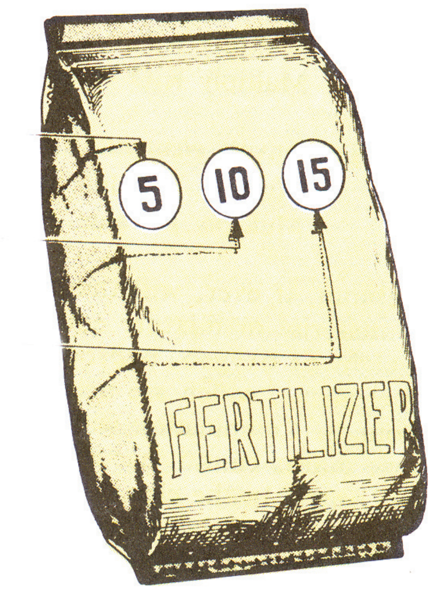

FIGURE 11. THIS IS A LABEL FOUND ON A BAG OF COMMERCIAL FERTILIZER. IT INDICATES THE PROPORTIONS OF NITROGEN, PHOSPHORUS, AND POTASSIUM.

TABLE 11. USE OF FERTILIZERS IN NUTRIENT MANAGEMENT PLANS

CRITERION	DESCRIPTION
RIGHT SOURCE	Farmers must ensure that the type of fertilizer used matches the crop's needs.
RIGHT RATE	Apply fertilizer at a rate that the plant can use. If the rate is too low, then optimal yields will not result. If the rate is too high, then fertilizer is wasted and can leak into the environment.
RIGHT TIME	Choose the best time to apply fertilizer. This means that the fertilizer should be applied when the crop needs the nutrients.
RIGHT PLACE	Farmers must ensure that nutrients are applied where plant roots can most easily access them. Careful application limits nutrient losses. Avoid environmentally sensitive areas such as those close to surface waters so nutrients will not run off or leach into surface and groundwater.

10.9 ORGANIC OR COMMERCIAL: WHICH IS BETTER?

A quick answer to the question of which fertilizer is better is that neither organic nor commercial nutrient sources are better for plants. Both have their places and should be used where appropriate, and each has its advantages and disadvantages. Farmers need to examine the relative merits and decide when and where each type of fertilizer should be used. Because most organic fertilizers used on farms are from livestock, we focus here on manure-based organic fertilizers.

Manure-based organic materials encourage the use of local natural resources. They use little or no synthetic additives. Manure fertilizers may be viewed as economic and agronomic nutrient supplements along with commercial fertilizers in the production of crops. They contain varying amounts of plant nutrients and provide organic carbon, which is part of any productive agricultural soil. They improve the biological, chemical, and physical properties of soils.

There are, however, some concerns associated with certain forms of manure-based organic fertilizer. First, when animal manures are produced in confined areas, excessive amounts of nutrients can accumulate in crop fields if the manure is over-applied near the site where it was produced. This can pose a threat of nitrate leaching to groundwater and phosphorus moving into surface waters through runoff and erosion. Second, the relatively fixed nutrient ratios of organic fertilizers can result in too much phosphorus being present in heavily manured soils because crops usually require much less phosphorus than nitrogen. In addition, significant amounts of ammonia gas (NH3) can be lost to the atmosphere.

By comparison, plant-based organic fertilizers are usually low in nutrient content. They contain some soluble nutrients, but most are released slowly as microbes in the soil break down the organic material into water-soluble forms that the plant roots can absorb. This feature may be an advantage when fertilizer is applied infrequently because it is less likely to overwhelm the system with soluble nutrients, which can result in nutrient loss to the environment. However, it also makes it difficult to time the release of nutrients to match the needs of the growing crop.

Commercial fertilizers contain precise, guaranteed levels of nutrients in forms that are readily available for plant uptake and use. It is possible to time their application to meet crop requirements, assuring efficient nutrient use and minimizing any potential impact on the environment. Because of their high nutrient content, commercial fertilizers are easy and economical to ship great distances from their point of production.

However, the high nutrient content of commercial fertilizers also means that the potential for overuse is greater. Farmers need to apply commercial fertilizers as specified by a nutrient management plan that is designed for the specific conditions of their fields. Nutrient management plans use data from soil and plant-tissue testing to help farmers use the proper amounts of nutrients at the optimal times. Nutrient management plans also keep farmers from wasting money by using too much fertilizer and from contributing unwanted nutrients to the air, groundwater, and local waterways. For example, although agriculture practices such as plowing can increase soil erosion, well-managed agricultural soils have less erosion than soils without an appropriate balance of nutrients. This is important because soil erosion in areas such as the Gulf of Mexico is an important contributor of nutrient pollution.[20]

FIGURE 12. ORGANIC FARMING RECYCLES NUTRIENTS BY USING COMPOST (A) AND MANURE (B).

11.0 THE DUST BOWL

The importance of maintaining healthy soil was made clear by the events of the so-called Dust Bowl that affected a large area of the Great Plains in the 1930s. During the late 1800s, an unusual amount of rain fell on the Great Plains. This led farmers and agricultural experts to overestimate how much rainfall the region could expect. This unusually wet period caused more people to settle in the area and begin farming. In 1930, an extended drought began, which caused crops to fail. High winds carried massive amounts of topsoil eastward. Throughout the 1930s, the area, including the Texas and Oklahoma panhandles as well as parts of New Mexico, Colorado, and Kansas, experienced a series of huge dust storms. Some of these storms blew dust all the way to Chicago and eventually to Cleveland, Buffalo, Boston, and New York City. During the winter of 1934–1935, red snow fell in New England.[19]

A number of factors worked together to create the Dust Bowl. Certainly, an extended period of high temperatures, wind, and drought were important. However, people too played a part. Early settlers used the land for grazing livestock. Later, as mechanized farming began to spread, many farmers used deep plowing techniques that eliminated the native grasses that held the soil together. High grain prices during World War I caused farmers to plant even more crops, which made the problem worse. Therefore, when the drought hit, the topsoil simply blew away.

To help prevent erosion, the federal government supported the planting of millions of trees from Canada to Texas. These trees helped to anchor and protect the soil. Farming practices too were modified. Farmers began to use a technique called contour plowing that helped the soil retain water. They also began to allow portions of their fields to lie fallow each year to help the soil regenerate.

FIGURE 13. A COMBINATION OF DROUGHT CONDITIONS AND POOR FARMING PRACTICES LED TO THE DUST BOWL OF THE 1930S

12.0 FERTILIZERS AND THE ENVIRONMENT

Nutrients provide the basic building blocks of life for all organisms. As has been discussed previously, proper nutrient application, through fertilizer, improves plant growth and crop yield. However, the nutrient cycle is very complex and humanity is still developing an understanding of the scientific details. Because nutrients occur naturally in the environment, fertilizer application augments nature's processes. Challenges arise when nutrients, through nitrogen-containing fertilizer, are applied improperly. If nutrients are applied at the wrong rate, in the wrong place, from the wrong fertilizer source, or at the wrong time, then the nutrients may be lost to the environment before the plant(s) can take them up and use them for growth. In such cases, nutrients can be lost from the field either through runoff (water) or through gasification and evaporation (air). In the case of runoff, nutrients can be lost to streams, rivers, lakes, and eventually the oceans. While the hydrologic cycle is very complex, excess nutrients in surface waters can promote growth of algae, which in turn can reduce oxygen concentrations in the water and degrade the overall water quality. In the case of gasification and evaporation, nitrogen is broken down by soil bacteria, is converted to N_2O, and moves into the atmosphere as a greenhouse gas.

12.1 NUTRIENT POLLUTION

Nutrients are a natural part of the environment and enter the biosphere from weathering and erosion processes. Nutrients can enter the environment through agriculture, sewage and wastewater treatment plants, coal-burning power plants, storm water runoff, and automobile exhaust. Nutrient sources vary greatly between urban and rural areas. Controlling nutrient loss means identifying its various sources and implementing policies that limit the loss of nutrients to the environment.

As discussed earlier, organisms require essential nutrients to survive, but they must be present in the proper amounts. Either too little or too much can adversely affect health. A similar situation exists with regard to the environment. The U.S. Environmental Protection Agency (EPA) estimates that almost 20 percent of the nation's lakes and 30 percent of streams have high levels of nitrogen and phosphorous pollution.[25] This type of nutrient pollution can cause massive overgrowth of algae. These so-called algal blooms also damage water quality. When large populations of algae die and decompose, they deplete the dissolved oxygen in the water. Marine animals that depend on this oxygen either die or leave the area.

Some species of algae emit toxins that can cause rashes, stomach aches and more serious problems for humans. The most severe acute health effect is methemoglobinemia, often called "blue baby syndrome". Recent evidence suggests that there is not a simple association between nitrate and blue baby syndrome, rather that nitrate is one of several interrelated factors that lead to methemoglobinemia. The disease is uncommon in the United States because potential exposure to high levels of nitrate is limited to a portion of the population that depends on groundwater wells, which are not regulated by the EPA. Public drinking water systems should contain nitrates at a level safe for consumption as nitrates can be removed by water filtration. Nitrogen pollution from cultivated soils, industry, and other sources contributes to global warming because a portion is released into the atmosphere as nitrous oxide (N_2O), a powerful greenhouse gas.

Excess nutrients can enter the environment through both natural and human-induced mechanisms. Sources of nutrient pollution are classified as being either point sources or nonpoint sources.

12.1a NUTRIENT POLLUTION POINT SOURCES

Point sources of nutrient pollution can be tied to specific locations. Typical point sources include factories, power plants, and wastewater treatment plants. In urban areas, wastewater treatment facilities can be the largest contributors to nutrient pollution. For example, in Long Island Sound off the East Coast, an estimated 60 percent of the nitrogen that enters the water comes from sewage discharge leaving New York City.

12.1b NUTRIENT POLLUTION NONPOINT SOURCES

Nonpoint sources of nutrient pollution are general sources such as agricultural areas, cities, and automobiles (golf courses, lawns, anything without a distinct discharge point). A major nonpoint source of nutrient pollution is urban development. For example, clearing of land for housing and industry creates sealed surfaces that do not absorb water and increase nutrient-laden runoff. A related nonpoint source of nutrient pollution is the septic systems that have proliferated as the suburbs extend beyond the reach of urban sewer systems. Automobile exhaust is another nonpoint source. This exhaust releases nitrogen into the atmosphere, but it returns to Earth's surface with the rain. Although definitive information is hard to come by, it has been estimated that up to 40 percent of the nitrogen entering aquatic environments in some areas can come from nitrogen in the air.[14] Agriculture is also a nonpoint source for nutrient pollution. Use of fertilizers can send excess nutrients into the environment, particularly when best practices are not used. To avoid introducing nutrient pollution, fertilizers must be applied using the right source, rate, time, and place. Increasingly, farmers are adopting nutrient management and precision agriculture measures that minimize the amount of this pollution.

12.1c REGULATION OF NUTRIENT POLLUTION

During the past 40 years, antipollution laws have been enacted to reduce the amounts of toxic substances released into our waters. States, territories, and tribes set water-quality standards. They classify a given water body according to the human uses the water quality will allow—for example, drinking water supply, contact recreation (swimming), and aquatic life support (fishing)—and the scientific criteria to support those uses. The Federal Clean Water Act mandates that if a water body is impaired by a pollutant, a total maximum daily load (TMDL) must be created. Total maximum daily load is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources. A TMDL is the sum of the allowable loads of a single pollutant from all contributing point and nonpoint sources. The calculation must include a margin of safety to ensure that the water body can be used for the purposes the state has designated, such as swimming and fishing.
The calculation must also account for seasonal variation in water quality.

Today, scientists and policy-makers are working with farmers to develop more-effective and extensive nutrient management strategies. Solving the nutrient pollution problem will involve establishing emission regulations, compliance incentives, and federal oversight.

12.2 MANAGING LAWN FERTILIZERS

Growing concern about algae in surface waters has led some local municipalities to begin regulating lawn fertilizers. Areas in Florida, Illinois, Maine, Maryland, Michigan, Minnesota, New Jersey, New York, Vermont, Virginia, Washington, and Wisconsin have enacted ordinances limiting the phosphorus in lawn fertilizers. In Ontario, Canada, the township of Georgian Bay passed a bylaw banning the application of fertilizer.[16] The merit of such legislation is still under debate. However, manufacturers are responding by offering fertilizer grades with lower amounts of phosphate. Will these approaches be effective in improving water quality in our rivers, lakes, and reservoirs? The principles of nutrient management that have been developed for agricultural fertilizers also apply to lawn fertilizers. With soil testing and wise application, such as more frequent applications at lower doses, nutrient losses can be reduced.

FIGURE 14. FERTILIZING LAWNS FREQUENTLY AT LOWER DOSES CAN HELP REDUCE NUTRIENT LOSSES

12.3 LAND USE

Perhaps surprisingly, fertilizers can have a positive impact on the environment with regard to land use. Land is a finite resource, and human societies use it for a variety of purposes. We need land for residential living, for industries, for recreation, for wildlife habitats, and of course, for growing food and fiber. Land cultivation worldwide has remain ed about the same for the past 50 years. Although subsistence farmers in developing countries have brought some additional land into production, land has also been lost to expanding cities in the developed countries. Even so, starting in the 1960s, farmers have increased food production about 400 percent. The Green Revolution was made possible largely by three innovations: better crop varieties, use of commercial fertilizers, and better water management practices. The economist Indur Goklany calculated that if we needed to feed today's population of over 6 billion people using the organic methods in use before the 1960s, it would require devoting 82 percent of Earth's land to farming.[11]

The United States produces a surplus of food, but the world does not. By 2050, the world's population is expected to number well over 9 billion people. Food production will need to keep pace. If the world's population used the world's farmland evenly, then each person would use 1.8 hectares. Instead, each person in North America uses 9.6 hectares and each European uses 5.0 hectares.[21]

13.0 TECHNOLOGY AND NUTRIENT MANAGEMENT

Clearly, if we are going to produce adequate food for our growing population, then crop yields will need to further increase. Strategies will have to be developed to meet the challenges of the future. Some farmers are using technology in a variety of ways to increase crop yields. While the utilization of these new technologies is growing, it is not occurring today on most of the nation's farms, although adoption is growing. The rest of this section describes some of these technologies.

GEOGRAPHIC INFORMATION SYSTEMS (GIS) allow farmers to use map-based information about natural resources, soils, water supplies, variability in crop conditions throughout the year, and crop yields to ensure the that amount of nutrients being used matches crop needs Even information about the amount of crop residue (which still contains nutrients) left at the end of the year and the amounts of nutrients removed by the crop can be "mapped" and stored in a GIS database. Once this information is gathered into one database, it can be integrated with other GIS databases such as rainfall records (taken from Doppler radar).

THE GLOBAL POSITIONING SYSTEM (GPS) is critical to the development of GIS databases and is used to identify the locations of equipment and people in the field. GPS is also useful in assessing general crop conditions and for scouting fields for problems such as nutrient deficiencies. GPS can help farmers return to the same field sites when problems are being addressed.

AUTO-GUIDANCE is a feature of mechanized agriculture. It ties together GPS, GIS, and robotics technologies, allowing a driver to sit and watch as the machine does the work. This technology is being used in various types of farm equipment such as tractors, combines, sprayers, and fertilizer applicators. For example, by using auto-guidance systems, farmers can ensure that applications of fertilizers are not on overlapping tracks. The best of these systems can apply fertilizer to an accuracy of less than one inch.

REMOTE SENSING uses satellite images of fields to help farmers know what is happening to their crops. The satellite images can be analyzed to detect variability in the reflection of visible, infrared, and other wavelengths of light. Some images show thermal (heat) radiation from the ground below, which helps estimate soil moisture conditions. These images and data, linked with the GIS data mentioned earlier, offer a means of detecting problems developing in the field and comparing successive images over time. The rate of change can be determined to illustrate how a problem is spreading.

ENHANCED EFFICIENCY FERTILIZERS help reduce nutrient losses and improve nutrient-use efficiency by crops while improving crop yields. These products provide nutrients at levels that more closely match crop demand leaving fewer nutrients exposed to the environment. Slow- and controlled-release fertilizers are designed to deliver extended, consistent supplies of nutrients to the crop. Stabilized nitrogen fertilizers incorporate nitrification inhibitors and nitrogen stabilizers, which extend the time that nitrogen remains in a form available to plants and reduces losses to the environment.

GENE MODIFICATION TECHNOLOGY is another strategy with potential implications for the future. One of the main factors that limit crop growth is the efficiency of nitrogen uptake and usage by the plant. If crop plants can be made to more efficiently use nitrogen, more fertilizer will be converted into biomass. This means less fertilizer will run off into the environment.

FIGURE 15. FARMERS CAN USE AUTO-GUIDANCE SYSTEMS TO APPLY FERTILIZERS ACCURATELY. SUCH SYSTEMS TIE TOGETHER GPS, GIS, AND ROBOTICS TECHNOLOGIES.

The ultimate goal of this research is to give nonlegume plants the ability to obtain their own nitrogen from the atmosphere (i.e., to "fix" nitrogen from the atmosphere) and not rely as heavily on added fertilizers. However, giving a corn plant the ability to fix nitrogen would involve adding a large number of genes not only from nitrogen-fixing bacteria but also from an appropriate host plant. The prospect of achieving this anytime soon is remote. Scientists have succeeded in helping plants better use nitrogen by increasing the expression of a single gene. For example, plants that highly express the enzyme glutamate dehydrogenase have been shown to grow larger than those that were not modified to do so. Of course, genetic scientists are not limiting their efforts to nitrogen fixation. A wide variety of crop plants have been engineered to grow faster, tolerate unfavorable environments, resist pests, and have increased nutritional value.

14.0 CONCLUSION

This curriculum helps students better understand the challenge confronting their generation as they seek to nourish the planet's people in the 21st century. Such an ambitious task cannot be fully addressed in the short time used to teach this material. We have therefore focused our attention on some core scientific concepts that underlie the growth of healthy crop plants and on issues of pollution and land use that have geographic, social, economic, ecological, legal, political, and ethical implications.

The classroom lessons are designed to introduce students to the notion of essential elements and relate them to the health of plants. Students will see that even though plants seem to be very different from us, their cells work in much the same way as ours do. Just as we need to obtain nutrients from a balanced diet, plants need to obtain a balance of nutrients from the air, water, and soil.

Students will learn to appreciate the soil as a precious natural resource that must be protected. They are instructed to regard the soil as a bank of nutrients that plants use to grow. Nutrients in the soil become dissolved in soil water and are taken up by the plant root system and distributed to the rest of the plant through the xylem tissue. Nutrients enter the roots through the passive process of diffusion and the energy-requiring process of active transport. The exploration of soils reveals that they differ in their composition and nutrient content. Physical properties of soils, such as the amount of air space and particle size, determine how much water a soil can hold and how easily the water moves through it.

The soil "nutrient bank" can only hold a limited amount of nutrients. In non-agricultural ecosystems, plants withdraw these nutrients then return them when they die and decompose. In agricultural ecosystems, some of the nutrients a crop extracts are harvested and taken offsite, which can eventually deplete the soil nutrient bank. As with people, when plants get too little (or too much) of a nutrient, their health suffers. Each type of nutrient deficiency has specific symptoms that scientists and farmers use to diagnose the problem. Fertilizer is 'food' for plants. When a nutrient deficiency is diagnosed, fertilizer can be used to restore nutrient balance to the soil.

Students will discover that only a portion of Earth's surface is used to grow the food we eat. They use estimates of population growth and land use to calculate how much additional land will have to be farmed to feed Earth's increasing population. The students will come to realize that growing enough food for everyone involves making some difficult decisions. They are challenged to put themselves in the position of a farmer and to consider the advantages and disadvantages of using organic or commercial fertilizers. At the same time, they must strive to reduce negative impacts on the environment by minimizing contributions to nutrient pollution.

As mentioned previously, *Nourishing the Planet in the 21st Century* is not intended to provide a comprehensive look at all the issues associated with food production and population growth. Hopefully, you will find the module serves as an engaging introduction to some of the important science concepts and societal issues associated with feeding our increasing population. The classroom lessons make explicit connections to the *Next Generation Science Standards* and can serve as the basis for a more detailed examination of agriculture and nutrition. You also may find that the module can set the stage for exploring other topics such as global warming and gene modification technology. In short, we hope that you find this module to be a valuable addition to your classroom.

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GLOSSARY

ACTIVE TRANSPORT: the movement of substance across a biological membrane against its concentration gradient; from a less-concentrated area to a more-concentrated area. Active transport requires the input of energy and uses specific transport proteins.

ATP: adenosine triphosphate; a compound that has three phosphate groups and is used by cells to store energy.

COMMERCIAL FERTILIZER: commercially prepared mixtures of plant nutrients that include nitrogen, phosphorus, and potassium applied to the soil to restore fertility and increase crop yields. Commercial fertilizers contain nutrients in known amounts that plants can immediately use.

CONCENTRATION GRADIENT: a difference in the concentration of certain molecules over a distance.

COVER CROP: crops such as rye, alfalfa, or clover can be planted immediately after a crop harvest to hold the soil in place, preventing erosion and nutrient loss. They also represent an important type of fertilizer because they provide nutrient value when they are eventually plowed into the soil. These plant-based fertilizers are used on a small scale in comparison to animal manure-based fertilizers.

CROP: food crops, lawns, garden, and ornamental plants such as flowers.

DIFFUSION: the movement of a substance down its concentration gradient from a more-concentrated area to a less-concentrated area.

DUST BOWL: The Dust Bowl drought was a natural disaster that severely affected much of the United States during the 1930s. The soil, depleted of moisture, was lifted by the wind into great clouds of dust and sand which were so thick they concealed the Sun for several days at a time. The "dust bowl" effect was caused by sustained drought conditions compounded by years of poor land management practices that left topsoil susceptible to the forces of the wind.

GENETICALLY MODIFIED FOOD: a food product containing some quantity of a genetically modified organism (GMO) as an ingredient. A GMO is any organism that has had a gene from another species added to it using recombinant-DNA technology.

GREEN REVOLUTION: a term used to describe the transformation of agriculture in some developing nations between the 1940s and 1960s. During the Green Revolution, already existing technologies such as pesticides, irrigation, and use of inorganic fertilizers spread to developing countries resulting in increased crop yields.

INFILTRATION: the process by which water penetrates into soil from the ground surface.

INORGANIC FERTILIZER: commercially prepared mixtures of plant nutrients that include nitrogen, phosphorus, and potassium applied to the soil to restore fertility and increase crop yields. Inorganic fertilizers contain nutrients in known amounts that plants can immediately use.

LIGNIN: a non-carbohydrate polymer that binds cellulose fibers together. It adds strength and stiffness to plant cell walls.

LOAM: a rich soil consisting of a mixture of sand and clay and decaying organic materials.

MACRONUTRIENT: a nutrient that must be present in a relatively large amount to ensure the health of the organism. Macronutrients are building blocks used to make essential biomolecules.

MICRONUTRIENT: a nutrient required in small quantities to ensure the health of the organism. Micronutrients are often used as cofactors for enzymatic reactions.

MICROORGANISM: an organism too small to be seen with the unaided human eye. Bacteria are an important type of microorganism.

NITROGEN FIXATION: a biological or chemical process by which elemental nitrogen, from the air, is converted to organic or available nitrogen.

NONPOINT SOURCE: nutrient pollution that results from runoff and enters surface, ground water, and the oceans from widespread and distant activities. Because it comes from a number of different sources, a nonpoint source is much harder to trace and quantify than a point source of nutrient pollution.

NUTRIENT: any of 17 essential mineral and nonmineral elements necessary for plant growth.

NUTRIENT DEFICIENCY: a condition where the amount of a nutrient essential to the health of an organism is lacking or present in an insufficient amount.

NUTRIENT POLLUTION: the presence of excessive amounts of nutrients such as nitrogen and phosphorus in waterways. These nutrients stimulate the growth of algae, thus robbing the waters of oxygen and suffocating some aquatic organisms. Nutrient pollution comes from both natural and human-induced sources.

NUTRIENT TOXICITY: the presence of an excessive amount of a specific nutrient, which is harmful to the organism.

ORGANIC FERTILIZER: a fertilizer that undergoes little or no processing and includes plant, animal, and/or mineral materials.

PERCOLATION: the process by which water moves downward through openings in the soil.

PERMEABILITY: the ability of soil to allow the passage of water.

PHLOEM: a portion of the vascular system in plants, consisting of living cells arranged into tubes that transport sugar and other organic nutrients throughout the plant.

POINT SOURCE: nutrient pollution that comes from a specific source that can be identified such as a factory or a wastewater treatment plant.

POROSITY: the percentage of soil volume that is not occupied by solids.

TRANSPIRATION: the loss of water to the atmosphere by a plant through the stomates in its leaves.

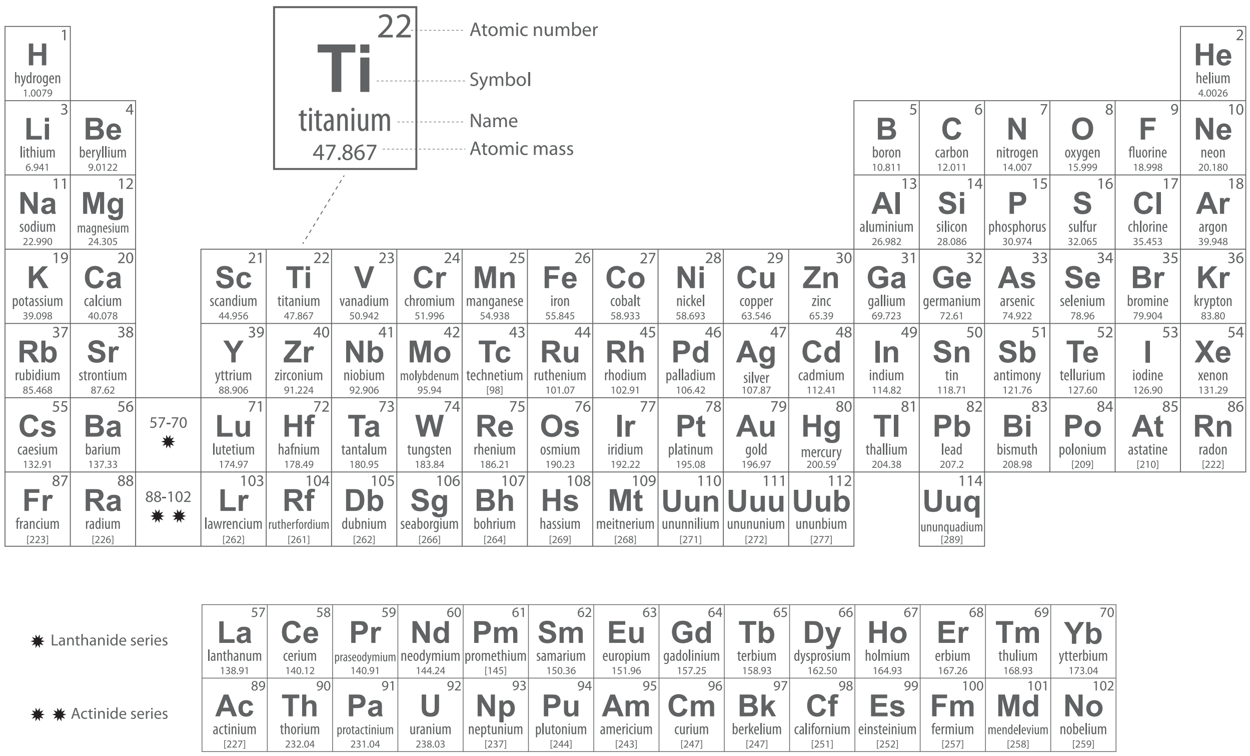
XYLEM: conducting tissue that transports water and dissolved nutrients in vascular plants.

LESSON 1

ENGAGE

IN SEARCH OF ESSENTIAL NUTRIENTS

AT A GLANCE



OVERVIEW

Students explore the meaning of essential elements. They use periodic tables to compare the elements that are essential to people and plants. Students make predictions as to where in the environment plants obtain each of their essential elements.

MAJOR CONCEPTS

- Plants require 17 essential elements to complete their life cycle.
- Plants and humans require similar sets of essential elements.
- Plants obtain their essential elements from air, water, and soil.

OBJECTIVES

After completing this lesson, students will be able to

- define an essential element,
- compare and contrast the essential element requirements of plants and humans,
- explain why plants cannot use elemental nitrogen found in the atmosphere, and
- identify the sources for each essential element needed by plants.

TEACHER BACKGROUND
Consult the following section in teacher background: **2.0 PLANTS AND THEIR ESSENTIAL ELEMENTS, 3.0 THE NITROGEN CYCLE**

IN ADVANCE

PHOTOCOPIES

ACTIVITY	MASTER	NUMBER OF COPIES
1	Master 1.1, Essential Elements	1 to project
	Master 1.2, The Periodic Table	1 per student and 1 to project
	Master 1.3, Essential Elements for Plants	1 to project
	Master 1.4, Essential Elements for Humans	1 to project
2	Master 1.5, Sources of Essential Elements	1 per student and 1 to project
	Master 1.6, Using Nitrogen	1 per student
OPTIONAL EXTENSION	Master 1.7, Food Label	1 per student

MATERIALS

ACTIVITY	MATERIALS
1	1 colored pencil per student
2	No materials except photocopies

PREPARATION

Make photocopies and prepare to project designated masters (using a document camera or similar device).

PROCEDURE

TEACHER NOTE
Remember, it is not important to discuss each essential element; rather, you should focus on those elements that are important in building proteins, nucleic acids, and carbohydrates.

ACTIVITY 1: ESSENTIAL ELEMENTS

In this activity, students use the periodic table to express their prior knowledge about what plants need to survive. Their predictions are compared to a list of essential elements known to be important to plant health.

1. BEGIN THE LESSON BY EXPLAINING THAT SCIENTISTS WHO ARE INTERESTED IN STUDYING HUMAN HEALTH MUST UNDERSTAND THE SPECIFIC NEEDS OF THE BODY. ASK STUDENTS, "WHAT DO HUMANS NEED TO LIVE?"

Accept all answers. Write student responses on the board or on chart paper. Direct the discussion to elicit air (oxygen), water, and food. Some students may realize that sleep is also required for survival. Other students may suggest environmental conditions such as temperature and pressure or material things such as clothing and shelter.

2. REMIND STUDENTS THAT LIFE REQUIRES ENERGY FOR ITS EXISTENCE. ASK STUDENTS, "WHAT DO PEOPLE TAKE INTO THEIR BODIES FROM THE ENVIRONMENT TO HELP THEM SURVIVE?"

Students should recognize that from the list generated in the previous step air, water, and food are obtained from the environment.

3. ASK STUDENTS, "WHY DO WE NEED EACH OF THESE (AIR, WATER, AND FOOD) TO SURVIVE?"

Students should

- report that oxygen in the air is needed for cellular respiration.
- be able to explain that our cells are mostly made of water. Water is the medium in which life has evolved. It is required for the chemistry of life.
- recognize that food has two critical functions: as a source of chemical energy and as a source of chemical building blocks needed by our cells.

4. REMIND STUDENTS THAT HUMANS (AND ANIMALS) EAT PLANTS AND OTHER ANIMALS TO OBTAIN CHEMICAL ENERGY AND PROVIDE THEM WITH THE BUILDING BLOCKS NEEDED BY THEIR CELLS. ASK STUDENTS, "WHAT ABOUT PLANTS; DO PLANTS NEED FOOD?"

Some students may respond that plants do not need food, because they can obtain energy from photosynthesis. Other students may mention that plants need water or that they obtain nutrients from the soil. If not mentioned by a student, remind the class that fertilizer can be considered "food" for plants, because it provides nutrients that plants need to live and grow.

TEACHER NOTE
In many things you may read online, the terms "essential elements" and "essential nutrients" are often used interchangeably. A nutrient is a substance that organisms need to live and grow. In this activity, the term essential elements will be the preferred term because students will be looking at the periodic table of elements. Elements often combine into larger molecules that living things use. For example, water is an important nutrient for organisms; water is made up of the elements hydrogen and oxygen.

5. EXPLAIN THAT THEY WILL NOW INVESTIGATE THE CHEMICAL ELEMENTS THAT ARE ESSENTIAL FOR PLANT GROWTH.

Project *Master 1.1, Essential Elements.* Ask different students to read aloud the criteria that describe an essential element.

6. PASS OUT TO EACH STUDENT A COPY OF *MASTER 1.2, THE PERIODIC TABLE.* INSTRUCT THE CLASS TO THINK ABOUT THE DEFINITION OF "ESSENTIAL ELEMENT" AND USE A COLORED PENCIL TO SHADE THOSE ELEMENTS ON THE PERIODIC TABLE THAT THEY THINK ARE ESSENTIAL FOR HEALTHY PLANT GROWTH. IF POSSIBLE, STUDENTS SHOULD THINK OF AN EXAMPLE OF HOW A GIVEN ELEMENT IS USED BY THE PLANT (SUCH AS THE PLANT USING NITROGEN TO MAKE PROTEIN OR PHOSPHORUS BEING USED TO MAKE ATP).

Give students about 10 minutes to complete this task. Students likely will not be able to suggest a function for elements needed in trace amounts. Many such elements are needed as cofactors for enzymes. It is not important to discuss the uses of each element, but it is important that students understand that these elements are needed to build cell structures and to carry out the cell's chemistry through enzymatic reactions.

This step gives you an opportunity to assess how well students can relate their knowledge of chemistry to biology. For example, students may respond that carbon is used to make carbohydrates, such as sugar.

7. PROJECT *MASTER 1.2, THE PERIODIC TABLE.* ASK A STUDENT VOLUNTEER TO READ ALOUD THE ELEMENTS SHADED ON HIS OR HER PERIODIC TABLE. HAVE THE VOLUNTEER EXPLAIN WHY THE SELECTED ELEMENTS WERE CHOSEN. HAVE ADDITIONAL STUDENTS ADD TO THE LIST WITH THEIR PREDICTIONS.

As the elements are read off, shade them in or circle them on the projected copy. Students are not expected to identify the complete list of essential elements. Their responses however, will reflect their relative knowledge about the biology of plants.

8. EXPLAIN THAT YOU ARE NOW GOING TO REVEAL WHICH ELEMENTS HAVE BEEN SHOWN TO BE ESSENTIAL FOR PLANT GROWTH AND COMPARE THEM WITH STUDENTS' PREDICTIONS. PROJECT *MASTER 1.3, ESSENTIAL ELEMENTS FOR PLANTS.*

Students likely will be surprised that so many elements are essential for plant growth. The comparison between the elements predicted by the students and the accepted ones should show some overlap. Students should be expected to identify **CARBON (C), HYDROGEN (H), NITROGEN (N), OXYGEN (O), PHOSPHORUS (P),** and **SULFUR (S)** because these elements serve as building blocks for biomolecules. If necessary, ask guiding questions to connect these elements to the synthesis of proteins, nucleic acids, and carbohydrates.

9. ASK, "DO YOU THINK THAT HUMANS REQUIRE THE SAME ESSENTIAL ELEMENTS AS PLANTS?"

Responses will vary. Some students may think that since humans and plants are very different from each other, they will need different sets of elements. Others may reason that since plants and humans are each made of cells that contain similar biomolecules, the essential elements needed by both will be similar.

10. PROJECT *MASTER 1.4, ESSENTIAL ELEMENTS FOR HUMANS.* ASK STUDENTS TO COMMENT ON HOW SIMILAR OR DISSIMILAR THIS PATTERN OF ELEMENTS IS COMPARED WITH THAT SHOWN PREVIOUSLY FOR PLANTS.

Students should notice that the two patterns are more alike than different. To make this point clearer, you can project copies of *Masters 1.3, Essential Nutrients* for Plants and *1.4, Essential Nutrients for Humans* side-by-side for students to compare.

ACTIVITY 2: SOURCES OF ESSENTIAL ELEMENTS

In this activity, students consider from where plants obtain essential elements.

1. EXPLAIN THAT YOU WILL CONCLUDE THE LESSON WITH A BRIEF ACTIVITY THAT EXPLORES WHERE PLANTS OBTAIN THEIR ESSENTIAL ELEMENTS.

2. PASS OUT TO EACH STUDENT A COPY OF *MASTER 1.5, SOURCES OF ESSENTIAL ELEMENTS.* EXPLAIN THAT THE HANDOUT LISTS THE 17 ESSENTIAL PLANT ELEMENTS. INSTRUCT STUDENTS TO THINK ABOUT WHERE A CORN PLANT OBTAINS THESE ESSENTIAL ELEMENTS. STUDENTS SHOULD INDICATE THE SOURCE—AIR, WATER, AND SOIL—FOR EACH ELEMENT (THAT IS, EACH CHEMICAL ELEMENT) BY CHECKING THE APPROPRIATE BOXES ON THE HANDOUT.

For the purpose of this activity, students should think about water as rainfall (before it reaches the ground). It therefore should not include those elements found in soil that may dissolve in water. Students are free to check more than one box for any element. Give students about 5 minutes to complete this task.

3. PROJECT *MASTER 1.5, SOURCES OF ESSENTIAL ELEMENTS.* ASK A STUDENT VOLUNTEER TO DESCRIBE WHICH ELEMENTS HE OR SHE LISTED AS COMING FROM WATER.

Put a “W” next to the elements named by the students. Of course, students should mention hydrogen and oxygen. Actually, rainwater may contain small amounts of other elements derived from atmospheric gases and dust particles. Other elements that could be mentioned include **C, Cl, N,** and **S.**

4. ASK ANOTHER VOLUNTEER TO DESCRIBE WHICH ELEMENTS HE OR SHE LISTED AS COMING FROM THE AIR.

Put an “A” next to the elements named by the students. Students should recognize that the corn plant obtains carbon and oxygen (via CO_2) from the air. Some students may know that most of the atmosphere is nitrogen. Most students will not realize that nitrogen gas is not available to the corn plant in a usable form. Do not correct this misconception yet. This issue will be addressed in *Step 7*. As with water, small amounts of other elements also may be present due to air pollution.

5. ASK ANOTHER VOLUNTEER TO DESCRIBE WHICH ELEMENTS HE OR SHE LISTED AS COMING FROM THE SOIL.

Put an “S” next to the elements named by the students. Students should list most if not all of the essential elements. The soil not only contains many elements that reflect its geological history, but it also contains organic material from once-living plants and animals as well as from the abundant life (both macro and micro) that resides there.

Answers to *Master 1.5, Sources of Essential Elements*

ESSENTIAL NUTRIENT	AIR	SOURCE WATER	SOIL
Boron (B)			S
Calcium (Ca)			S
Carbon (C)	A		S
Chlorine (Cl)			S
Copper (Cu)			S
Hydrogen (H)	A	W	S
Iron (Fe)			S
Magnesium (Mg)			S
Manganese (Mn)			S
Molybdenum (Mo)			S
Nickel (Ni)			S
Nitrogen (N)			S
Oxygen (O)	A	W	S
Phosphorous (P)			S
Potassium (K)			S
Sulfur (S)			S
Zinc (Zn)			S

6. ASK STUDENTS TO HELP YOU SUMMARIZE WHERE THE CORN PLANT GETS ITS ESSENTIAL ELEMENTS.

Students should report the following:

- **WATER: HYDROGEN AND OXYGEN.**
- **AIR: CARBON AND OXYGEN.**
- **SOIL: ALL ESSENTIAL ELEMENTS.**

Ask students to work individually or in pairs to write a short summary before holding a class discussion. This will allow students to gather their thoughts before speaking and for you to assess each student's understanding.

7. EXPLAIN THAT NITROGEN IS AN ESSENTIAL ELEMENT THAT PLANTS NEED IN RELATIVELY LARGE AMOUNTS. PASS OUT TO EACH STUDENT 1 COPY OF *MASTER 1.6, USING NITROGEN.* INSTRUCT STUDENTS TO READ THE DESCRIPTION AND ANSWER THE QUESTIONS.

8. AFTER STUDENTS HAVE COMPLETED THEIR TASKS, ASK THEM, "IN LIGHT OF WHAT YOU JUST READ, WOULD YOU CHANGE YOUR PREDICTION OF WHERE THE CORN PLANT OBTAINS ITS NITROGEN?"

Students should change their answer, if necessary, to indicate that the corn plant must obtain its nitrogen from the soil rather than from the air.

9. ASK FOR A VOLUNTEER TO READ HIS OR HER ANSWER TO QUESTION 1 ON *MASTER 1.6, USING NITROGEN.*

Answer to *Question 1:*

1. WHAT DO YOU THINK IS RESPONSIBLE FOR CONVERTING MOST OF THE NITROGEN USED BY PLANTS INTO A USABLE FORM?

Students should conclude that bacteria are responsible for fixing most of the nitrogen used by plants. Some nitrogen also is fixed by lightning and industrial processes, but these are much smaller amounts

10. ASK FOR A VOLUNTEER TO READ HIS OR HER ANSWER TO QUESTION 2 ON *MASTER 1.6, USING NITROGEN.*

Answer to *Question 2:*

2. WHY IS THIS ABILITY OF LEGUMES TO CARRY OUT THEIR OWN NITROGEN FIXATION IMPORTANT TO FARMERS?

Because the symbiotic bacteria in legumes fix additional nitrogen for plants to use, farmers can be less concerned with replenishing the soil using nitrogen-containing fertilizers.

11. EXPLAIN THAT TO GROW HEALTHY CROPS, FARMERS NEED TO KNOW WHICH ESSENTIAL ELEMENTS ARE FOUND IN THE SOIL AND HOW MUCH OF EACH IS PRESENT. ASK STUDENTS TO THINK OF WHERE THE ESSENTIAL ELEMENTS FOUND IN THE SOIL COME FROM.

Student responses will vary. At this time, accept all answers. If not mentioned, use guided questions to bring out the fact that essential elements in the soil come from multiple sources that include

- natural ones, such as the erosion of rocks;
- the action of lightning;
- the decomposition of plant and animal material;
- human-associated activities, such as runoff from fertilizers used by farmers and the public as well as from waste that humans produce; and
- emissions from industry and automobiles.

12. EXPLAIN THAT IN THE NEXT LESSONS THEY WILL INVESTIGATE THE COMPOSITION OF SOILS, SOIL FORMATION, AND THE INTERACTION OF PLANTS WITH SOIL.

OPTIONAL EXTENSION ACTIVITY: HUMANS, FOOD, AND ESSENTIAL ELEMENTS

This activity requires a variety of different food labels and access to the Internet if carried out in the classroom. Alternatively, it can be assigned as homework.

1. ASK STUDENTS TO RECALL THAT PLANTS GET THEIR ESSENTIAL ELEMENTS MOSTLY FROM THE SOIL. ASK, "WHAT ABOUT PEOPLE? FROM WHERE DO THEY GET THEIR ESSENTIAL ELEMENTS?

Students should respond that people get most of their essential elements from food, though water gives us hydrogen and oxygen just as it does for plants.

2. INSTRUCT STUDENTS TO OBTAIN A FOOD LABEL FROM A NUTRITIOUS FOOD FOR ANALYSIS.

Since this activity is concerned with diet and essential elements needed for good heath, food labels should come from healthy foods and not from snacks.

3. HAVE STUDENTS RETRIEVE THEIR COPIES OF *MASTER 1.4, ESSENTIAL ELEMENTS FOR HUMANS.* PASS OUT TO EACH STUDENT A COPY OF *MASTER 1.7, FOOD LABEL* AND INSTRUCT THEM TO FOLLOW THE DIRECTIONS ON THE HANDOUT.

Some elements, including sodium, calcium, and magnesium are listed on food labels. However, most of the ingredients listed on a food label are chemical compounds and not individual elements.

4. AFTER STUDENTS HAVE COMPLETED THEIR TASKS, ASK VOLUNTEERS TO LIST THE ESSENTIAL ELEMENTS FOUND ON THEIR FOOD LABELS. LIST THEM ON THE BOARD AS WELL AS THE CHEMICAL COMPOUND THEY COME FROM.

5. ASK IF OTHER STUDENTS FOUND ANY ADDITIONAL ESSENTIAL ELEMENTS TO ADD TO THE LIST. AS BEFORE, LIST THE INGREDIENT IN WHICH EACH ESSENTIAL ELEMENT IS FOUND.

6. ASK STUDENTS TO COMPARE THE LIST OF ESSENTIAL ELEMENTS FROM THEIR FOOD LABELS TO THOSE SHADED AS ESSENTIAL ON THE PERIODIC TABLE ON *MASTER 1.4.*

Students will see that the nutrition facts label on foods includes data about elements, such as calcium, iron, zinc, or manganese content. Students will see that food ingredients are the source of the 6 elements (**C, H, N, O, P,** and **S**) that are needed to make important biomolecules when they research the molecular formula. For example, they will see that carbohydrates and fats are made up of carbon, hydrogen, and oxygen.Proteins also contain nitrogen, phosphorus, and sulfur. Many of the other essential elements that are not structural components of biomolecules are needed as cofactors for enzymes and are present in very small amounts.

7. CONCLUDE THE ACTIVITY BY ASKING, "WHAT DID THIS EXERCISE TEACH YOU ABOUT HEALTH AND DIET?"

Students should recognize that their diet need to contain a variety of foods to supply all the essential elements. Plants, as well as people, need a "balanced diet."

LESSON 1 ORGANIZER

ACTIVITY 1: ESSENTIAL NUTRIENTS **WHAT THE TEACHER DOES**	**PROCEDURE REFERENCE**
Explain that health scientists must understand the needs of the body. Ask students, "What do humans need to live?"	Page 48 Step 1
Remind students that life requires energy. Ask students: • "What do people take into their bodies from their environment to help them survive?" • "Why do we need air, water, and food to survive?"	Page 48 Steps 2 and 3
Remind students that humans eat plants and animals to obtain chemical energy and the building blocks needed by their cells. Ask students, • "Do plants need food?"	Page 48 Step 4
Explain that they will investigate the chemical elements needed for plant growth. Project *Master 1.1, Essential Elements.* Have students read it aloud.	Page 48 Step 5
Give each student 1 copy of *Master 1.2, The Periodic Table.* Instruct students to shade those elements that they think are essential to plant growth.	Page 49 Step 6
Project *Master 1.2, The Periodic Table.* Ask a volunteer to read aloud the elements he or she shaded and to explain his or her reasoning. Solicit responses from other students.	Page 49 Step 7
Explain that you will reveal which elements are known to be essential for plant growth. Project *Master 1.3, Essential Elements for Plants.*	Page 49 Step 8
Ask, "Do you think that humans require the same essential elements as plants?"	Page 49 Step 9
Project *Master 1.4, Essential Elements for Humans.* Ask students how similar or dissimilar the pattern is compared with that shown previously for plants.	Page49 Step 10

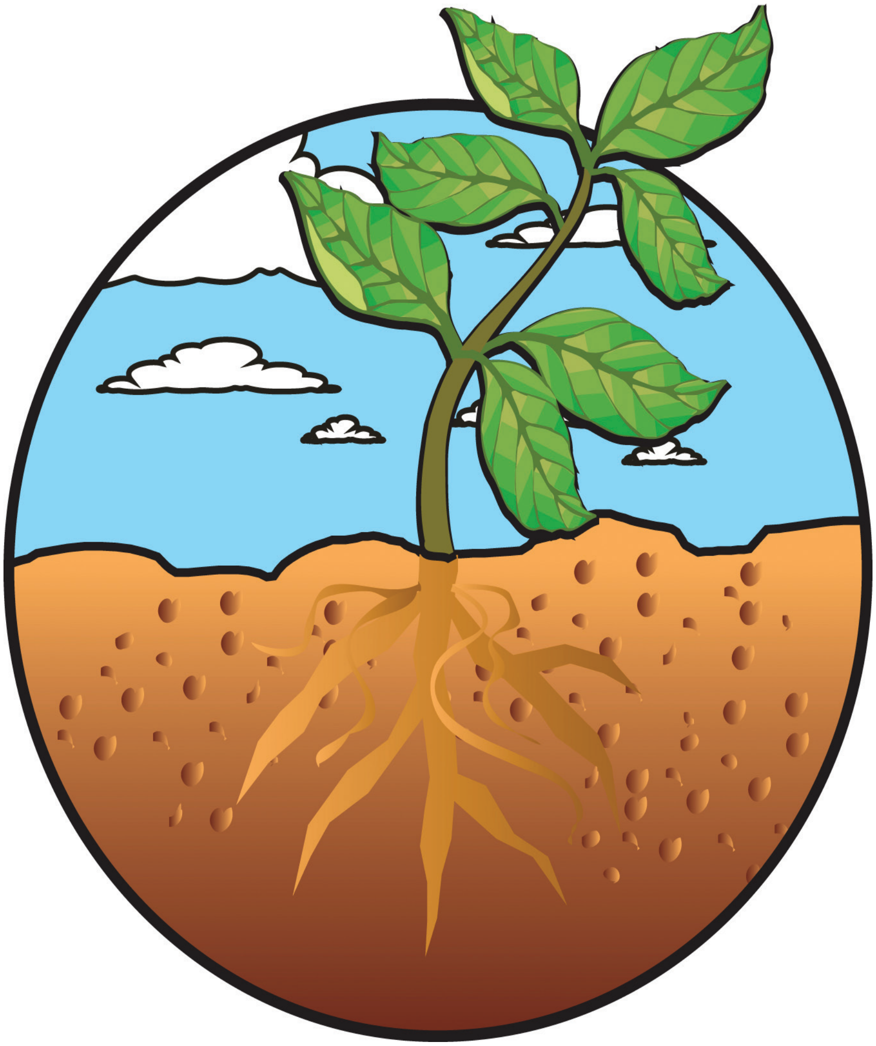
LESSON 1 ORGANIZER CONTINUED

ACTIVITY 2: SOURCES OF ESSENTIAL ELEMENTS **WHAT THE TEACHER DOES**	**PROCEDURE REFERENCE**
Explain to students that they will explore from where plants obtain their essential elements.	Page 50 Step 1
Give each student 1 copy of *Master 1.5, Sources of Essential Elements.* Instruct students to indicate on the Master from where (air, water, or soil) the plant gets each nutrient.	Page 50 Step 2
Project *Master 1.5, Sources of Essential Elements.* Ask a volunteer to describe which elements he or she listed as coming from water. Ask another volunteer which elements he or she listed as coming from the air. Ask a volunteer to describe which elements he or she listed as coming from the soil.	Page 50 Steps 3-5
Ask students to summarize where the corn plant gets its essential elements. Plants get carbon, hydrogen, and oxygen come from water and air, while the rest are only available from the soil.	Page 51 Step 6
Give each student 1 copy of *Master 1.6, Using Nitrogen.* Instruct students to read the description and answer the questions.	Page 51 Step 7
Ask students if they want to change their prediction of where the corn plant gets its nitrogen.	Page 51 Step 8
Ask a volunteer to read his or her answer to *Question 1.* Ask a volunteer to read his or her answer to *Question 2.*	Page 51 Steps 9 and 10
Explain that farmers must know which essential elements are found in their soil and in what amounts. Ask students where the essential elements in soil come from.	Page 51 Step 11
Explain that in the next lessons they will investigate the composition of soils, soil formation, and the interaction of plants with soil.	Page 51 Step 12

MASTER 1.1
ESSENTIAL ELEMENTS

NAME

DATE



AN ESSENTIAL ELEMENT

1. is required for a plant to complete its life cycle;
2. cannot be replaced by another element;
3. is directly involved in the plant's metabolism; and
4. is required by many different plants.

Adapted from Arnon, D., & Stout, P. (1939, July). The essentiality of certain elements in minute quantity for plants with special reference to copper. Plant Physiology, 14(3), 599–602.

MASTER 1.2

THE PERIODIC TABLE

NAME

DATE

22	Atomic number
Ti	Symbol
titanium	Name
47.867	Atomic mass

1 H hydrogen 1.0079																		2 He helium 4.0026
3 Li lithium 6.941	4 Be beryllium 9.0122												5 B boron 10.811	6 C carbon 12.011	7 N nitrogen 14.007	8 O oxygen 15.999	9 F fluorine 18.998	10 Ne neon 20.180
11 Na sodium 22.990	12 Mg magnesium 24.305												13 Al aluminium 26.982	14 Si silicon 28.086	15 P phosphorus 30.974	16 S sulfur 32.065	17 Cl chlorine 35.453	18 Ar argon 39.948
19 K potassium 39.098	20 Ca calcium 40.078		21 Sc scandium 44.956	22 Ti titanium 47.867	23 V vanadium 50.942	24 Cr chromium 51.996	25 Mn manganese 54.938	26 Fe iron 55.845	27 Co cobalt 58.933	28 Ni nickel 58.693	29 Cu copper 63.546	30 Zn zinc 65.39	31 Ga gallium 69.723	32 Ge germanium 72.61	33 As arsenic 74.922	34 Se selenium 78.96	35 Br bromine 79.904	36 Kr krypton 83.80
37 Rb rubidium 85.468	38 Sr strontium 87.62		39 Y yttrium 88.906	40 Zr zirconium 91.224	41 Nb niobium 92.906	42 Mo molybdenum 95.94	43 Tc technetium [98]	44 Ru ruthenium 101.07	45 Rh rhodium 102.91	46 Pd palladium 106.42	47 Ag silver 107.87	48 Cd cadmium 112.41	49 In indium 114.82	50 Sn tin 118.71	51 Sb antimony 121.76	52 Te tellurium 127.60	53 I iodine 126.90	54 Xe xenon 131.29
55 Cs caesium 132.91	56 Ba barium 137.33	57-70 *	71 Lu lutetium 174.97	72 Hf hafnium 178.49	73 Ta tantalum 180.95	74 W tungsten 183.84	75 Re rhenium 186.21	76 Os osmium 190.23	77 Ir iridium 192.22	78 Pt platinum 195.08	79 Au gold 196.97	80 Hg mercury 200.59	81 Tl thallium 204.38	82 Pb lead 207.2	83 Bi bismuth 208.98	84 Po polonium [209]	85 At astatine [210]	86 Rn radon [222]
87 Fr francium [223]	88 Ra radium [226]	88-102 * *	103 Lr lawrencium [262]	104 Rf rutherfordium [261]	105 Db dubnium [262]	106 Sg seaborgium [266]	107 Bh bohrium [264]	108 Hs hassium [269]	109 Mt meitnerium [268]	110 Uun ununnilium [271]	111 Uuu unununium [272]	112 Uub ununbium [277]		114 Uuq ununquadium [289]				

* Lanthanide series	57 La lanthanum 138.91	58 Ce cerium 140.12	59 Pr praseodymium 140.91	60 Nd neodymium 144.24	61 Pm promethium [145]	62 Sm samarium 150.36	63 Eu europium 151.96	64 Gd gadolinium 157.25	65 Tb terbium 158.93	66 Dy dysprosium 162.50	67 Ho holmium 164.93	68 Er erbium 167.26	69 Tm thulium 168.93	70 Yb ytterbium 173.04
* * Actinide series	89 Ac actinium [227]	90 Th thorium 232.04	91 Pa protactinium 231.04	92 U uranium 238.03	93 Np neptunium [237]	94 Pu plutonium [244]	95 Am americium [243]	96 Cm curium [247]	97 Bk berkelium [247]	98 Cf californium [251]	99 Es einsteinium [252]	100 Fm fermium [257]	101 Md mendelevium [258]	102 No nobelium [259]

MASTER 1.3

ESSENTIAL ELEMENTS FOR PLANTS

NAME

DATE

1 H hydrogen 1.0079																	2 He helium 4.0026
3 Li lithium 6.941	4 Be beryllium 9.0122											5 B boron 10.811	6 C carbon 12.011	7 N nitrogen 14.007	8 O oxygen 15.999	9 F fluorine 18.998	10 Ne neon 20.180
11 Na sodium 22.990	12 Mg magnesium 24.305											13 Al aluminium 26.982	14 Si silicon 28.086	15 P phosphorus 30.974	16 S sulfur 32.065	17 Cl chlorine 35.453	18 Ar argon 39.948
19 K potassium 39.098	20 Ca calcium 40.078	21 Sc scandium 44.956	22 Ti titanium 47.867	23 V vanadium 50.942	24 Cr chromium 51.996	25 Mn manganese 54.938	26 Fe iron 55.845	27 Co cobalt 58.933	28 Ni nickel 58.693	29 Cu copper 63.546	30 Zn zinc 65.39	31 Ga gallium 69.723	32 Ge germanium 72.61	33 As arsenic 74.922	34 Se selenium 78.96	35 Br bromine 79.904	36 Kr krypton 83.80
37 Rb rubidium 85.468	38 Sr strontium 87.62	39 Y yttrium 88.906	40 Zr zirconium 91.224	41 Nb niobium 92.906	42 Mo molybdenum 95.94	43 Tc technetium [98]	44 Ru ruthenium 101.07	45 Rh rhodium 102.91	46 Pd palladium 106.42	47 Ag silver 107.87	48 Cd cadmium 112.41	49 In indium 114.82	50 Sn tin 118.71	51 Sb antimony 121.76	52 Te tellurium 127.60	53 I iodine 126.90	54 Xe xenon 131.29
55 Cs cesium 132.91	56 Ba barium 137.33	57-70 *															
		71 Lu lutetium 174.97	72 Hf hafnium 178.49	73 Ta tantalum 180.95	74 W tungsten 183.84	75 Re rhenium 186.21	76 Os osmium 190.23	77 Ir iridium 192.22	78 Pt platinum 195.08	79 Au gold 196.97	80 Hg mercury 200.59	81 Tl thallium 204.38	82 Pb lead 207.2	83 Bi bismuth 208.98	84 Po polonium [209]	85 At astatine [210]	86 Rn radon [222]
87 Fr francium [223]	88 Ra radium [226]	88-102 **															
		103 Lr lawrencium [262]	104 Rf rutherfordium [261]	105 Db dubnium [262]	106 Sg seaborgium [266]	107 Bh bohrium [264]	108 Hs hassium [269]	109 Mt meitnerium [268]	110 Uun ununnilium [271]	111 Uuu unununium [272]	112 Uub ununbium [277]		114 Uuq ununquadium [289]				

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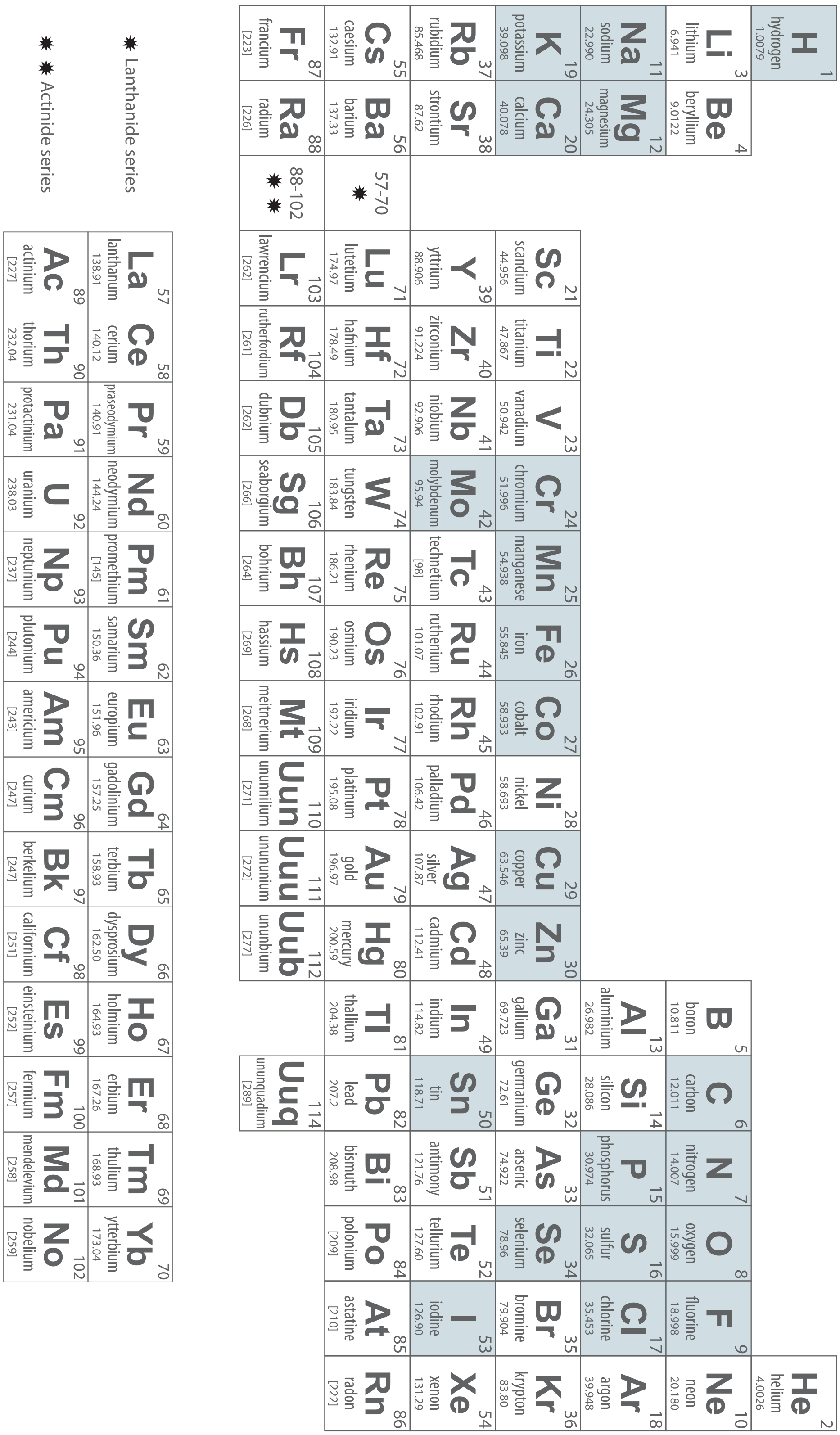
** Actinide series	89 Ac actinium [227]	90 Th thorium 232.04	91 Pa protactinium 231.04	92 U uranium 238.03	93 Np neptunium [237]	94 Pu plutonium [244]	95 Am americium [243]	96 Cm curium [247]	97 Bk berkelium [247]	98 Cf californium [251]	99 Es einsteinium [252]	100 Fm fermium [257]	101 Md mendelevium [258]	102 No nobelium [259]

MASTER 1.4

ESSENTIAL ELEMENTS FOR HUMANS

NAME

DATE



MASTER 1.5
SOURCES OF ESSENTIAL ELEMENTS

NAME

DATE

ESSENTIAL NUTRIENT	AIR	SOURCE WATER	SOIL
Boron (B)			
Calcium (Ca)			
Carbon (C)			
Chlorine (Cl)			
Copper (Cu)			
Hydrogen (H)			
Iron (Fe)			
Magnesium (Mg)			
Manganese (Mn)			
Molybdenum (Mo)			
Nickel (Ni)			
Nitrogen (N)			
Oxygen (O)			
Phosphorous (P)			
Potassium (K)			
Sulfur (S)			
Zinc (Zn)			

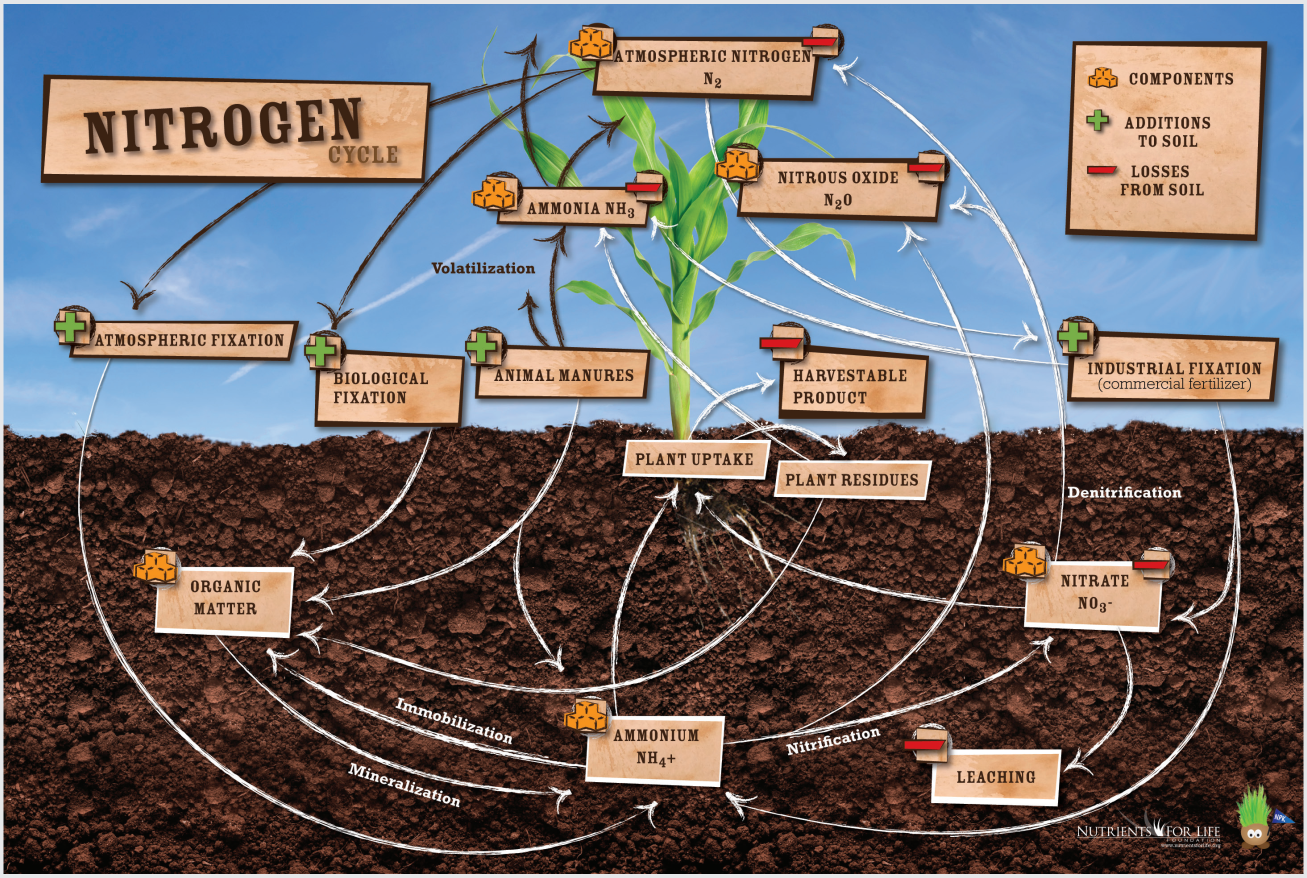
MASTER 1.6

USING NITROGEN

NAME

DATE

For many plants, the availability of nitrogen limits their growth. This fact is surprising since the air is nearly 80 percent nitrogen. However, neither plants nor animals can use the nitrogen gas (N_2) in the air. First, it must be fixed, or combined with other elements combined with other elements, such as hydrogen or oxygen, before plants can use it. Lightning strikes are one way that nitrogen can be fixed. In this case, nitrogen gas combines with oxygen to form NO_3-. Free-living bacteria in the soil convert the largest amounts of atmospheric nitrogen by combining it with hydrogen. When combined with oxygen or hydrogen, plants can take in and use the nitrogen in these forms as an essential element. Industrial processes also fix nitrogen to produce nitrogen-based fertilizers. Animals take in the nitrogen they need by eating plants. When animals expel waste, or when plants or animals die and decompose, the nitrogen returns to the soil. Other bacteria in the soil convert the nitrogen back to nitrogen gas (N_2) which then returns to the atmosphere. This completes the nitrogen cycle.



QUESTIONS

1. Look at the graphic of the nitrogen cycle. What do you think is responsible for converting most of the nitrogen used by plants into a usable form?

2. Plants of the legume family, such as peas and beans, live in a symbiotic relationship with bacteria that live in their roots. The bacteria use sugars from the plants to produce energy. In return, the bacteria take nitrogen from the air and convert it to a form that the plants can use. Why is this ability of legumes to use nitrogen this way important to farmers?

MASTER 1.7

FOOD LABEL

NAME
DATE

1. List any essential elements listed on the food label.
2. Most ingredients on food labels are chemical compounds composed of different elements. Select three ingredients on the food label and write them in the first column of the chart below.
3. Use the Internet to find the chemical formula for each of the three ingredients. Write the formula for each ingredient in the second column.
4. For each ingredient, list the essential elements that are part of its chemical structure.

INGREDIENT FROM FOOD LABEL	CHEMICAL FORMULA	ESSENTIAL ELEMENTS CONTAINED IN THE INGREDIENT

LESSON 2
EXPLORE

PROPERTIES OF SOILS

AT A GLANCE

OVERVIEW

Students examine different types of soil that have been mixed with water and allowed to settle. Next, they work with a soil model to investigate its components (sand, silt, and clay) and learn how the properties of these components affect the passage or retention of water through the soil and the amount of air in the soil.

MAJOR CONCEPTS

- The primary components of soil include sand, silt, and clay.
- The particle sizes of sand, silt, and clay affect how water moves through soil.
- Soils vary in their compositions.
- Soils contain both organic and inorganic matter.
- Soils contain differing amounts of air space.
- Soils are a bank of nutrients.

OBJECTIVES

- After completing this lesson, students will be able to
- list aspects of soil composition,
- explain the relationship between particle size and water movement through soil,
- appreciate that soils are living and dynamic,
- recognize that soils vary in composition,
- describe where nutrients in soil come from, and
- recognize that plants generally take up water and nutrients from the soil.

TEACHER BACKGROUND
Consult the following section in the Teacher Background: **4.0 SOIL FORMATION, 5.0 SOIL HORIZONS, 6.0 SOIL TRIANGLE**

IN ADVANCE

PHOTOCOPIES

ACTIVITY	MASTER	NUMBER OF COPIES
1	None	None
2	Master 2.1, Water and Soil Properties	1 per team of 3 students
	Master 2.2, Column Setup	1 to project
	Master 2.3, Making Sense of the Data	1 per student
	Master 2.4, Particle Size, Surface Area, and Water Movement	1 to project
3	Master 2.5, The Soil Triangle	1 to project
OPTIONAL EXTENSION	Master 2.6, Soil Particle Size	1 to project

MATERIALS

ACTIVITY	MATERIALS
1	**FOR THE CLASS:** • 10 oz each of potting soil and local soil • 2 clear 12–20-oz plastic bottles • Water
2	**FOR EACH DEMONSTRATION STRAW** (See Preparation for important details) • Plastic spoon • 1 bubble tea (also called smoothie or milkshake) straw* • 1 piece of coffee filter (approximately 3.5 cm^2) • Transparent tape • Permanent marking pen • Sand** • Clay*** • 1 cup (plastic, 8–10-oz cups [preferably clear] or beakers) • 1 plastic drink cup lid (size can vary)***** • 10 mL graduated cylinder • Disposable pipet • Stopwatch or timer • Ruler • Funnel (small end should fit inside straw; can be made by Rolling up 1/4 sheet of paper) • Water
	FOR EACH TEAM OF 3 STUDENTS: • 2 bubble tea or milkshake straws* • 2 pieces of coffee filter (approximately 3.5 cm^2) • Transparent tape, Permanent marking pen • 2 plastic spoons for scooping sand and baby powder • Sand** • Baby powder**** • 2 cups (plastic, 8–10-oz cups [preferably clear] or beakers), • 2 plastic drink cup lids***** • 10 mL graduated cylinder • Disposable pipet • Stopwatch or timer • Ruler • Funnel (small end should fit inside straw; can be made by rolling up 1/4 sheet of paper) • Water
3	None

* Bubble tea straws are optimal for this activity. You may also find them labeled as smoothie or milkshake straws. They have a larger diameter than a typical straw (3/8–1/2 inches [1–1.2 cm] diameter and 8–9 inches [20–28 cm] long). Some grocery stores carry these, and Asian food markets may be a good source. You can also purchase these online. If you have a choice, clear straws are best but may be harder to find. Clear with colored stripes also work. Colored straws can work (pastel colors are better than brighter colors), but it can be more challenging to see the water level in the straw because of the color. If you need to use the colored straws, sometimes a flashlight held behind straw can help make the waterline easier to see.

**Try to obtain coarse sand such as that used for home improvement products. Clean, fine sand may not allow water to pass as readily as most sands found in soils.

***One alternative is using Feldspar, a powdered clay found at some craft or hardware stores. If your school has an art program that includes ceramics, you may be able to get a small amount of clay from the art teacher. You will need less than 1 pound (about the size of a baseball) of a stoneware clay (not too gritty). Other options for obtaining clay include an art supply store, a hobby supply store, or a local potter/ceramic artist. Please note the polymer “clays” that you cure in an oven will not work for this activity. You need a natural clay.

IN ADVANCE
CONTINUED

****Baby powder is used as a substitute for silt because it is easily obtained and because it has particles approximately the same size as silt. Purchase plain baby powder—not the kind with cornstarch included.

*****The drink cup lids are the kind you find at fast-food restaurants or convenience stores for fountain sodas. The size is not critical because the lids do not need to fit the cups or beakers that you use. The lids simply need to be large enough to rest on top of the cup and hold the straw in a vertical position. The hole in the lid may not be large enough for a wide, bubble tea straw. If that situation arises, gently use your finger to enlarge the hole (being careful not to make it so large that it will not hold the straw).

PREPARATION

ACTIVITY 1: SOIL SEPARATION

- For this demonstration, clear plastic bottles (such as 12–20-oz water or soda bottles) work well. Fill one bottle about 2/3 full of potting soil.
- Fill the other bottle 2/3 full of local soil.
- Add water to near the top of each bottle.
- Place caps on the bottles and shake the contents well.
- Place the bottles in a location where they will not be disturbed.
- Prepare at least 1 day before making observations.

FIGURE 2.1. A. SOIL SEPARATION AFTER SITTING FOR ONE DAY

B. ORGANIC MATERIAL FLOATS ON THE SURFACE OF THE WATER

ACTIVITY 2: SOIL COLUMNS

CLAY COLUMN DEMONSTRATION

- Because it takes much longer for water to move through the clay, the procedure calls for doing the column with this soil component as a demonstration. You will be able to show students how to set up the straws and use it to collect data about clay for your class. You will add the water to the straw in Step 8. Prepare at least one column with clay as a demonstration to use in each class. You may want to prepare multiple clay columns that you can start at different times of day so that students can see them at different stages and to obtain multiple data points.
- You should start preparation of the clay 1-2 weeks before beginning this lesson. This procedure assumes that you will start with moist clay, which needs to dry, and then pulverized to a powder. To prepare the clay, break the moist clay into small chunks and cover with water. Allow to sit for a few days until the clay forms a homogeneous "slurry." Then pour onto a flat surface (such as a parchment-lined cookie sheet) so that it forms a thin layer and allow the clay to dry. When dry, place the pieces into heavy-duty zip-closure plastic bags with excess air squeezed out (you may want to double bag). Then use a heavy bottle or rolling pin (or other heavy item) to grind the clay into a powder. This process does not require a lot of "hands-on" time, but it will take some time for the clay to break down into a smooth slurry. It also takes some time for the clay to dry. The benefit of this process is that you can easily get thin sheets of dry clay that are easier to grind into a fine, more uniform powder for use in the columns.
- Practice preparing a column according to the diagram and instructions on *Masters 2.2* and *2.3* (without adding water).
- Practice adding water and timing the columns so you will be prepared to answer students' questions. For practice, you may want to start with sand and then move to baby powder and then clay. Using the pipet to add water can help minimize disruption of the column (especially baby powder and clay).

FIGURE 2.2: PHOTOGRAPH OF A COLUMN SETUP USING BABY POWDER AS A SUBSTITUTE FOR SILT. THIS COLUMN IS READY FOR WATER TO BE ADDED.

TEACHER NOTE

The layer of sand at the bottom of each straw improved the experimental results. Without that layer, the coffee filter seemed to clog with either clay or baby powder and blocked all water drainage. Students should be as consistent with that bottom layer as possible.

The amounts of sand, soil component, and water recommended on *Master 2.1, Water and Soil Properties*, worked well during field-testing of this activity. It may be important to test these quantities using the straws that your students will be using to make sure that any differences in size do not cause problems (such as not all the water will fit in the straw). If so, you can make some minor adjustments. For example, you can change the height of the column of soil component from 7 cm to 5 or 6 cm.

SOIL COLUMNS

Students will set up columns using sand and baby powder similar to the way the demonstration column was set up using clay.

ACTIVITY 3: SOIL IS COMPLEX
No materials needed.

PROCEDURE

ACTIVITY 1: SOIL SEPARATION

Students compare and contrast the appearance of local soil and potting soil that have been mixed with water and allowed to settle.

> **TEACHER NOTE**
>
> Be careful when moving the three bottles with the soils settled in water *(Step 4).* Excessive movement will cause the soil layers to mix. Try to keep the bottles undisturbed so that later classes can view them.

1. REMIND STUDENTS THAT IN THE PREVIOUS LESSON THEY INVESTIGATED ESSENTIAL PLANT ELEMENTS THAT ARE FOUND IN SOIL. ASK, "WHAT IS SOIL?" WRITE STUDENTS' RESPONSES ON THE BOARD OR CHART PAPER.

At this time, accept all answers. Student responses may include ideas about soil containing rocks, sand, clay, insects, worms, bacteria, bits of wood, and water. If necessary, point out that these materials contain many of the essential elements.

2. ASK STUDENTS, "HOW WOULD YOU CATEGORIZE THE COMPONENTS OF SOIL?"

Student responses will vary. Guide the discussion to bring out the fact that soil consists of nonliving inorganic material such as clay, silt, and sand as well as living and nonliving organic material such as dead plant material, bacteria, insects, and worms.

3. ASK STUDENTS, "HOW DOES SOIL HELP PLANTS TO GROW?" WRITE STUDENT RESPONSES ON THE BOARD.

Student responses will vary. Guide the discussion to bring out the following:

- Soil provides support for plants' root systems.
- Soil provides essential nutrients.
- Soil holds water and makes it accessible to plants.
- Soil contains air spaces, which is necessary for plant growth.

4. SHOW THE CLASS BOTTLES OF POTTING SOIL AND LOCAL SOIL THAT WERE PREVIOUSLY MIXED WITH WATER AND ALLOWED TO SETTLE. EXPLAIN HOW THEY WERE PREPARED. ASK STUDENTS TO GATHER AROUND THE BOTTLES AND MAKE OBSERVATIONS ABOUT THE DIFFERENT SOILS.

Students will observe that the different soils separate differently. At this point, students will not know what is found in each layer. They should record their observations and refer back to them later in the lesson.

- The potting soil will show a thick layer of dark material on the bottom, a thick layer of cloudy water, and a thinner layer of organic material on the top.
- Local soils may differ, but a typical soil will show layering similar to potting soil though there may be less organic material floating on the surface.

5. REMIND STUDENTS THAT SOIL CONTAINS BOTH ORGANIC AND INORGANIC MATERIAL. ASK, "CAN YOU IDENTIFY THE ORGANIC MATERIAL IN EACH CONTAINER?"

Responses will vary. If necessary, explain that the organic material is less dense than the inorganic material and floats on the surface of the water. If students are unfamiliar with the term "organic," explain that organic material includes decayed matter from plants, animals, and insects.

ACTIVITY 2: SOIL COLUMNS

Students investigate three components of soil to learn how the composition of soil affects the properties of the soil.

1. EXPLAIN TO STUDENTS THAT THE MAJOR COMPONENTS OF SOIL (IN ADDITION TO THE ORGANIC MATTER) ARE SAND, SILT, AND CLAY. INFORM STUDENTS THAT THEY ARE GOING TO BE INVESTIGATING THESE SOIL COMPONENTS AND THINKING ABOUT HOW THEY AFFECT THE PROPERTIES OF THE SOIL.

2. ASK STUDENTS TO WORK IN TEAMS OF 3. GIVE EACH TEAM 1 COPY OF *MASTER 2.1, WATER AND SOIL PROPERTIES*. BRIEFLY REVIEW THE INSTRUCTIONS ON THE MASTER WITH STUDENTS. DISPLAY A COPY OF *MASTER 2.2, COLUMN SETUP*, AND TELL STUDENTS THAT THIS DIAGRAM ILLUSTRATES HOW THEY WILL SET UP THEIR SOIL COLUMNS. INFORM STUDENTS THAT THEY WILL BE USING BABY POWDER AS A SUBSTITUTE FOR SILT.

Make sure that students understand the procedure they should follow. Unlike clay or sand, it is difficult to obtain silt. As students will later learn, baby powder particles are about the same size as silt, making an appropriate substitution.

3. HOLD UP A STRAW THAT IS SET UP ACCORDING TO THE SAME INSTRUCTIONS BUT CONTAINS CLAY RATHER THAN SAND OR BABY POWDER. DEMONSTRATE ADDING WATER AND BEGINNING TO TIME THE PROCESS.

The water will take quite a while to move through the clay. However, record the start time and allow students to watch for a few seconds before they move on. Make sure they understand that water will move more quickly through the other substances so they need to make sure that they pay attention when they start their experiments. Watch the clay column periodically to monitor the movement of water. Watch more closely when the water nears the bottom of the column so that you can record a finish time.

4. ALLOW TIME FOR TEAMS TO WORK THROUGH THEIR EXPERIMENTS.

As teams work, circulate around the room to answer questions or to help resolve any difficulties that may arise.

TEACHER NOTE

Students may feel that it is difficult to determine when all the water has moved through the column. For baby powder and clay, for example, water may collect at the bottom of the straw but not drip for up to several minutes. The important thing is for students to be consistent. For example, if drops have been falling at approximately 4-minute intervals and then nothing drips for about 10 minutes, students could use the time of the last drop as a cut-off point.

As an alternative, to gauge how long it takes the water to move through the column, you could have students note the time at which they cannot see any water remaining at the top of the column. If you take this approach, ask all members of the class to use this same strategy in their measurements. Although this measurement may provide interesting data, if students find it difficult, they can skip this data and focus on the other categories of data collection.

5. AFTER TEAMS COMPLETE THEIR INVESTIGATIONS, MAKE SURE THAT EACH TEAM ADDS THEIR DATA TO THE CLASS CHART. CALCULATE THE AVERAGES OF THE CLASS DATA FOR TIME AND WATER VOLUME. ADD DATA FOR THE CLAY COMPONENT AS WELL.

If you wish, you could have students work individually or in teams to calculate the averages.

The data in *Table 2.1* was collected during testing of this activity. You can use the data for the clay component for your class to analyze. The other data may provide interesting comparisons for your class data. It is important to note, however, that your data may be different because of differences between the straws, type of sand, and so forth.

TABLE 2.1, SAMPLE DATA FOR SOIL COLUMNS

Straw #	Substance	Time for first drop to fall	Time all water through straw	Total amount of water through (mL)	Amount water retained (mL)	Decrease in height of substance at experiment end (cm)
1	sand	28 sec	120 sec	5.9	4.1	4.1
2	sand	33 sec	202 sec	6.0	4.0	4.0
3	sand	35 sec	223 sec	6.0	4.0	4.0
4	sand	21 sec	84 sec	5.5	4.5	4.5
5	sand	34 sec	172 sec	5.8	4.2	4.2
6	sand	36 sec	205 sec	6.0	4.0	4.0
7	sand	38 sec	181 sec	6.0	4.0	4.0
Mean		**32.1 sec**	**169.6**	**5.9**	**4.1**	**4.1**
Straw #	**Substance**	**Time for first drop to fall**	**Time all water through straw**	**Total amount of water through (mL)**	**Amount water retained (mL)**	**Decrease in height of substance at experiment end (cm)**
8	baby powder	109 sec	15 min	4.2	5.8	0.8
9	baby powder	115 sec	4 min	4.4	5.6	1.5
10	baby powder	79 sec	12 min	4.8	5.2	1.2
11	baby powder	81 sec	14 min	4.6	5.4	1.5
12	baby powder	112 sec	10 min	4.4	5.6	1.7
13	baby powder	87 sec	8 min	4.6	5.4	1.8
14	baby powder	105 sec	12 min	4.7	5.3	2.0
Mean		**98.3 sec**	**10.7 min**	**4.5**	**5.5**	**1.5**
Straw #	**Substance**	**Time for first drop to fall**	**Time all water through straw**	**Total amount of water through (mL)**	**Amount water retained (mL)**	**Decrease in height of substance at experiment end (cm)**
15	clay	6 hr 50 min	~86 hr	2.5	7.5	0.2
16	clay	10 hr 35 min	>96 hr**	1.2	8.8	0.1
17	clay	7 hr 33 min	~60 hr	2.2	7.8	0.2
18	clay	5 hr 4 min	~48 hr	2.6	7.4	0.3
19	clay	5 hr 54 min	>96 hr**	2.0	8.0	0.3
20	clay	7 hr 26 min	>96 hr**	1.8	8.2	0.2
21	clay	10 hr 32 min	>96 hr**	1.0	9.0	0.0
Mean		**Approx. 7.7 min**	**83 hours**	**1.9**	**8.1**	**0.2**

*For the clay columns, it took between 2–3 hours for the water to reach the sand layer.

**The clay columns took a long time and there was a lot of variation among the replicates. Water continued to slowly drip from the straws even after 96 hours.

The sample data provided represent some patterns that you should expect to see in your class' data. For example, water moves through the sand more quickly than it does through baby powder. Water moves through both sand and baby powder much more quickly than it does through clay.

6. GIVE EACH STUDENT A COPY OF *MASTER 2.3, MAKING SENSE OF THE DATA*. ALLOW TIME FOR STUDENTS TO WORK IN THEIR TEAMS TO ANSWER THE QUESTIONS.

Sample answers to questions on *Master 2.3, Making Sense of the Data*

1. HOW DOES THE SIZE OF SAND GRAINS COMPARE WITH THE SIZE OF BABY POWDER PARTICLES? WHAT IS YOUR EVIDENCE?

Sand grains are larger than particles of baby powder. The evidence of this is both the ability to see particles of sand whereas you cannot see individual particles of baby powder.

2. WHICH SUBSTANCE ALLOWED WATER TO MOVE THROUGH MORE QUICKLY?

Water moved through the column of sand more quickly than through the column of baby powder.

3. BASED ON YOUR DATA FROM YOUR EXPERIMENT USING SAND AND BABY POWDER, WRITE 1–2 SENTENCES ABOUT PARTICLE SIZE AND THE MOVEMENT OF WATER THROUGH THE COLUMN.

Water moves through a column of larger particle sizes more quickly than through a column of smaller particle sizes. Water moves more slowly through a column containing smaller particle sizes than it does through a column containing larger particle sizes.

4. THE DATA FROM THE COLUMN CONTAINING CLAY SHOW THAT IT TOOK THE LONGEST FOR THE WATER TO MOVE THROUGH THE COLUMN. IF THE STATEMENT YOU WROTE FOR QUESTION 3 IS CORRECT, HOW DOES THE SIZE OF A PARTICLE OF CLAY COMPARE WITH A PARTICLE OF SAND OR BABY POWDER?

If smaller particle sizes cause slower movement through the column, clay particles should be smaller than baby powder particles and much smaller than sand particles because it took longer for the water to move through the column.

5. WHICH SUBSTANCE RETAINED THE MOST WATER IN THE STRAW? WHICH SUBSTANCE RETAINED THE LEAST?

The clay column retained the greatest amount of water. The sand column retained the least.

6. WRITE A SENTENCE THAT SUMMARIZES THE RELATIONSHIP BETWEEN WATER RETENTION AND PARTICLE SIZE?

A column containing small particles retains more water than a column containing larger particles.

7. AT THE BEGINNING OF THE EXPERIMENT, YOUR COLUMN OF SAND, BABY POWDER, OR CLAY (IN THE DEMONSTRATION) WAS 7 CM IN HEIGHT. WHAT DIFFERENCES DID YOU SEE IN THE HEIGHT AT THE END OF THE EXPERIMENT?

Answers will vary somewhat in the specific information, but the responses should indicate that the sand and clay columns did not change a great deal in height but the baby power decreased in height. Baby powder generally will show the greatest decrease in height.

8. WHAT ACCOUNTS FOR THE DIFFERENCES IN HEIGHT AT THE END OF THE EXPERIMENT?

The amount of air contained in the column between particles accounts for the difference. The baby powder generally compacts the most after water passes through. The clay, depending on how fine the initial powder put into the straws was, will vary. If the clay had some small chunks, it will likely compact more after water passes through the column than if it was already ground into a very fine powder that would pack tightly while dry. Smaller particles will compact more tightly reducing the amount of air in the column.

These questions should help students recognize a relationship between particle size of soil components and the way that water interacts with soil. In the next step, they will find out more about why particle size is important.

7. CONTINUE THE DISCUSSION BY ASKING STUDENTS WHY THEY THINK PARTICLE SIZE WOULD CHANGE THE WAY THAT WATER MOVES THROUGH SOIL OR THE AMOUNT OF WATER RETAINED IN THE SOIL.

Student responses may vary. This is an opportunity to gauge student's current thinking.

8. ASK STUDENTS IF THEY KNOW OF ANY RELATIONSHIP BETWEEN PARTICLE SIZE AND SURFACE AREA. ASK, "HOW DOES THE SURFACE AREA OF A LARGE PARTICLE LIKE A SAND GRAIN COMPARE WITH THE SURFACE AREA OF A SMALL PARTICLE LIKE CLAY?"

9. TO ILLUSTRATE THE RELATIONSHIP BETWEEN SURFACE AREA AND PARTICLE SIZE, WORK THROUGH AN EXAMPLE WITH STUDENTS ABOUT SURFACE AREA OF A CUBE.

Calculating surface area of a cube is simpler than calculating surface area of a sphere, but the basic principle is the same.

Draw a cube on the board and indicate that each side is 10 cm long. The surface area of the cube is calculated using the formula

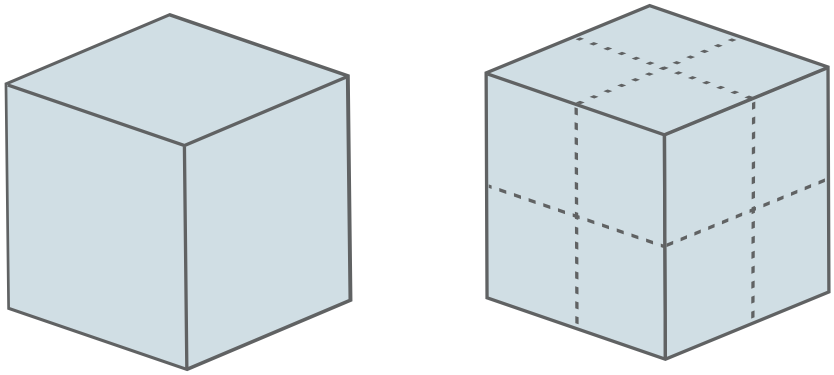
SURFACE AREA = **LENGTH x WIDTH x NUMBER OF SIDES**

FOR A CUBE THAT IS 10 CM SQUARE, THE SURFACE AREA WOULD BE 10 x 10 x 6 = 600 CM^2

Now imagine that the same cube was cut into 8 smaller cubes (same total volume). Each cube would have sides 5 cm in length. The surface area of each small cube would be 5 x 5 x 6 = 150 cm^2. However, when you calculate the total surface area for all 8 smaller cubes, you have a surface area equal to 150 x 8 = 1200 cm^2. This means that the surface area to volume ratio increases as the size of the cube (or other particle) decreases.

Sides = 10 cm

Sides = 5 cm

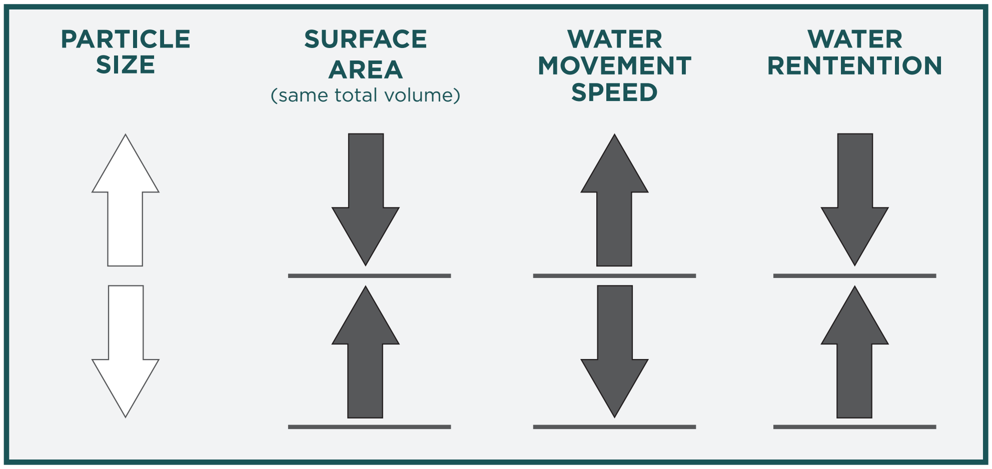


Similar to cubes, a collection of smaller spheres would have a greater total surface area than a single large sphere. However, calculating the surface area of a cube is easier than calculating the surface area of a sphere. (Surface area of sphere = $4\pi r^2$.)

Students may have considered other examples of surface area related to other areas of science. For example, students may have thought about why single-celled organisms are small and why large organisms are multicellular. In large part, this is due to issues related to surface area. Large organisms must be multicellular (made up of many small cells) because very large cells would not have adequate surface area for processes such as gas exchange, and so forth.

10. HELP STUDENTS CONTINUE TO BUILD THEIR UNDERSTANDING BY SUMMARIZING WHAT THEY KNOW SO FAR. FROM THEIR EXPERIMENTS, THEY LEARNED THAT PARTICLE SIZE WAS IMPORTANT FOR ISSUES RELATED TO WATER MOVEMENT AND RETENTION IN SOIL COMPONENTS. THEY ALSO NOW KNOW THAT THERE IS A RELATIONSHIP BETWEEN PARTICLE SIZE AND SURFACE AREA. DISPLAY A COPY OF *MASTER 2.4, PARTICLE SIZE, SURFACE AREA, AND WATER MOVEMENT.* AS A CLASS, WORK TOGETHER TO INDICATE THE RELATIONSHIPS BETWEEN THESE FACTORS.

Answers to *Master 2.4, Particle Size, Surface Area, and Water Movement*



If students are having difficulty with this summary, draw their attention back to the straw activity and the cube surface area problems.

To assess each student's understanding, you could ask them to complete the information on *Master 2.4* individually before having a class discussion. This could also give them a different way to synthesize what they have learned and be better prepared for a class discussion.

11. NOW THAT STUDENTS UNDERSTAND THE RELATIONSHIP BETWEEN PARTICLE SIZE, SURFACE AREA, AND WATER MOVEMENT IN THE SOIL COMPONENTS, EXPLAIN THAT A KEY FACTOR IN THE MOVEMENT OF WATER THROUGH SOIL IS FRICTION. THE FORCE OF GRAVITY PULLS THE WATER DOWNWARD, BUT THE FRICTION, WHICH IS RELATED TO SURFACE AREA, CAUSES RESISTANCE. THEREFORE, WATER MOVES MORE SLOWLY THROUGH SOILS WITH SMALLER PARTICLE SIZES (SILT OR CLAY).

ACTIVITY 3: SOIL IS COMPLEX

Students consider how soil is usually a mixture of the three major components, and the amounts of each component influences plant growth.

1. REMIND THE STUDENTS OF THE WAYS IN WHICH SOIL HELPS PLANTS TO GROW.

- Soil provides support for plants' root systems.
- Soil provides essential nutrients.
- Soil holds water and makes it accessible to plants.
- Soil contains air spaces, which are necessary for plant growth.

2. ASK, "BASED ON WHAT YOU LEARNED ABOUT SOIL COMPONENTS (SAND, SILT, AND CLAY), WOULD ANY OF THESE BE IDEAL FOR HELPING PLANTS GROW?"

This is an opportunity to assess what students remember from the previous activity. Students' responses should indicate that some soil components (e.g., sand) do not hold as much water, which could be detrimental to plants. On the other hand, clay does not let water move through very quickly which could also be a problem if there is too much water in the soil for healthy plants. In addition, clay (once it is wet) does not contain much air space, which also could be problematic for plants; sand contains a great deal of air space, which in extreme cases could mean that there is not enough support for a plant's roots.

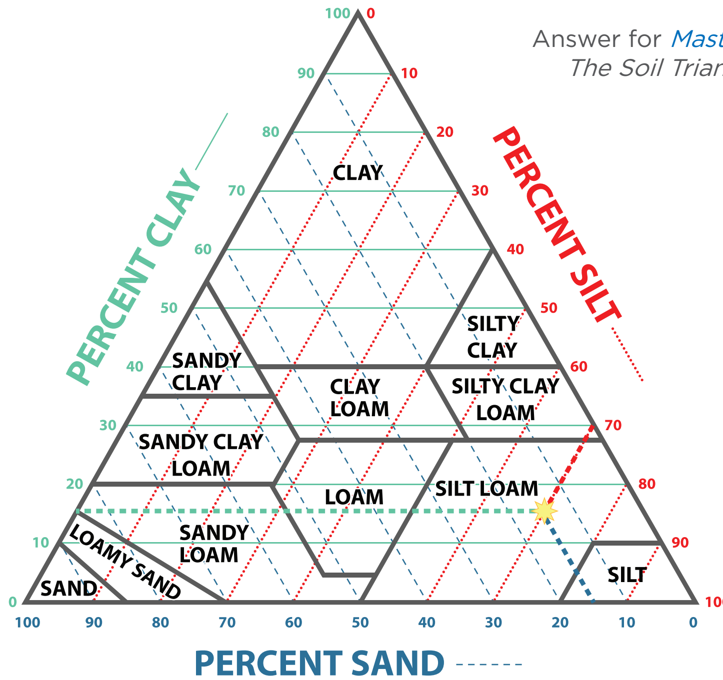
3. **EXPLAIN THAT SOILS ARE NOT AS SIMPLE AS THE INDIVIDUAL COMPONENTS THEY USED IN THEIR INVESTIGATION. SOILS ARE MADE UP OF A MIXTURE OF SAND, SILT, CLAY, AS WELL AS ORGANIC MATTER. DISPLAY A COPY OF *MASTER 2.5, THE SOIL TRIANGLE.* EXPLAIN THAT IT IS USED TO CLASSIFY THE DIFFERENT TYPES OF SOIL. POINT OUT THAT THE SOIL TRIANGLE DIAGRAM IS DIVIDED INTO 12 SOIL CLASSIFICATIONS BASED ON THE AMOUNT OF SAND, SILT, AND CLAY IN THE SOIL.**

   You may want to point out the term "loam" to students. Loam is another word for a soil that includes an ideal mix of sand, silt, and/or clay for many crop plants. On the soil triangle, there are 12 categories of loam that are differentiated by the amount of each component the soil includes.

4. **HELP THE STUDENTS LEARN TO USE THE SOIL TRIANGLE BY GIVING THEM A HYPOTHETICAL SOIL TO CLASSIFY. ASK, "HOW WOULD YOU CLASSIFY A SOIL THAT CONTAINS 20 PERCENT CLAY, 70 PERCENT SILT, AND 10 PERCENT SAND. DEMONSTRATE ON THE PROJECTED COPY OF *MASTER 2.5* HOW STUDENTS WOULD DETERMINE THAT THIS SOIL SAMPLE WOULD FALL INTO THE SILT LOAM CLASSIFICATION.**

   Start by finding 20 percent clay on the left side and drawing a line horizontally across the triangle. Then find 70 percent silt on the right side of the triangle and draw a line for that percentage.
   Finally, draw a line for 10 percent sand from the bottom of the triangle. The intersection of these 3 lines will determine the soil classification.

Answer for *Master 2.5, The Soil Triangle*



5. **ASK, "IN WHICH CATEGORY ON THE SOIL TRIANGLE DO YOU THINK CROP PLANTS WOULD GROW BEST AND WHY?" ALLOW VOLUNTEERS TO SHARE THEIR ANSWERS BUT MAKE SURE THEY SUPPORT THEIR ANSWERS WITH INFORMATION ABOUT SOIL PROPERTIES THAT THEY LEARNED PREVIOUSLY.**

   Answers will vary with respect to the specific type of loam that would be best, but they should include ideas that reflect what they have learned about water movement through soil, water retention, and air space. For example, an appropriate response might be "Soil with some sand would allow water to move through the soil and it would have more air space than clay or silt, but having some clay or silt would help the soil retain some water and provide more structure for the roots." Students may realize that plants living in different environments or types of soil have different root structures.

6. **CONCLUDE THE ACTIVITY BY ASKING STUDENTS HOW THE SOIL TRIANGLE COULD BE HELPFUL TO SOMEONE WHO IS GROWING PLANTS (EITHER ON A SMALL SCALE SUCH AS AN INDIVIDUAL GARDENER OR ON A LARGER SCALE SUCH AS A FARMER).**

   If students have difficulty getting started, you might ask them to think about the situation of someone who wants to grow a plant in their garden but the plant does not do well because the soil is very hard and compacted. What does this mean about the soil and how might it be changed? Another situation relates to irrigation. In one location, a crop may need a certain amount of water to thrive. In a different location, irrigating with the same amount of water may be either insufficient or excessive because the properties of the soil are different.

   If you wish, this could be assigned for homework to allow students to do more research about situations in which knowledge of soil properties and the soil triangle may be beneficial.

EXTENSION ACTIVITY: PARTICLE SIZE (OPTIONAL)

In this lesson, students used sand, baby powder, and clay for their columns and began to think about particle size. However, it can be very difficult for students to grasp the variation in size among these different particles.

Display a copy of *Master 2.6, Soil Particle Size.* Use a ruler to emphasize that things over 75 mm are classified as rock and things over 2 mm in diameter are classified as gravel. Point out that it is more difficult to appreciate the size of the smaller particles since you cannot see individual particles. Ask students to come up with a way to represent the difference in sizes among clay, silt, and sand (smaller particle sizes of sand). Encourage students to use their creativity to think about how to visualize these relationships. For example, if a basketball represented a sand grain, what is something they could use to represent the size of a silt or clay particle? Ask students to include the calculations they used to identify objects that would be appropriately scaled.

EXTENSION ACTIVITIES: DIGGING DEEPER INTO SOIL (OPTIONAL)

Students could use what they have learned in this lesson to design their own experiments to learn more about soil texture and its relationship to water movement through soil or to plant growth. Students could design additional experiments using the straw columns. For example, students could use this setup to investigate their local soil or potting soil. They could also design experiments in which they mix the sand, silt (baby powder), and clay to see how water movement changes. Students should make sure that they design (plan) their experiments carefully and include appropriate controls. They should also be clear about the data that they want to collect.

Another option would be to investigate how plant growth is affected by soil. For example, they could try growing plants in sand, silt (if available), or clay and compare with growth in local soil or potting soil. Again, students should design their experiments before they begin to ensure that the data will be meaningful (e.g., number of replicates, conditions in which plants will be kept, use of appropriate controls, and so forth).

If students pursue either of these options, make sure they have a testable question and that the experiment will be tied to the concepts developed in this lesson. You can require students to have their experimental designs approved by you before they can begin.

LESSON 2 ORGANIZER

ACTIVITY 1: SOIL SEPARATION **WHAT THE TEACHER DOES**	**PROCEDURE REFERENCE**
Remind students that they investigated essential plant nutrients that are found in soil. Ask, "What is soil?" Write students' responses on the board or chart paper.	Page 71 Step 1
Ask students, "How would you categorize the components of soil?" Also, ask, "How does soil help plants to grow?" Write responses on the board.	Page 71 Steps 2 and 3
Show the class bottles of potting soil and local soil that were previously mixed with water and allowed to settle. Explain how they were prepared. Ask students to gather around the bottles and make observations about the different soils.	Page 71 Step 4
Remind students that soil contains both organic and inorganic material. Ask, "Can you identify the organic material in each container?"	Page 71 Step 5

ACTIVITY 2: SOIL COLUMNS **WHAT THE TEACHER DOES**	**PROCEDURE REFERENCE**
Explain to students that the major components of soil (in addition to the organic matter) are sand, silt, and clay. Inform students that they are going to be investigating these soil components and thinking about how they affect the properties of the soil.	Page 72 Step 1
Ask students to work in teams of 3. Give each team 1 copy of *Master 2.1. Water and Soil Properties*. Briefly review the instructions on the master with students. Display a copy of *Master 2.2, Column Setup*. Inform students that they will be using baby powder as a substitute for silt.	Page 72 Step 2
Hold up a straw that is set up according to the same instructions but contains clay rather than sand or baby powder. Demonstrate adding water and beginning to time the process.	Page 72 Step 3
Allow time for teams to work through their experiments.	Page 72 Step 4
After teams complete their investigations, make sure that each team adds their data to the class chart. Calculate the average times and water volumes for the class data. Add data for the clay component as well.	Page 72 Step 5
Give each student a copy of *Master 2.3, Making Sense of the Data*. Allow time for students to work in their teams.	Page 74 Step 6
Continue the discussion by asking students why they think particle size would change the way that water moves through soil or the amount of water retained in the soil.	Page 75 Step 7
Ask students if they know any relationship between particle size and surface area. Ask, "How does the surface area of a large particle like a sand grain compare with the surface area of a small particle like clay?"	Page 75 Step 8
To illustrate the relationship between surface area and particle size, work through an example about surface area of a cube.	Page 75 Step 9
Help students continue to build their understanding by summarizing what they know so far. From their experiments, they learned that particle size was important for issues related to water movement and retention in soil components. They also now know that there is a relationship between particle size and surface area. Display a copy of *Master 2.4, Particle Size, Surface Area, and Water Movement*. As a class, work together to indicate the relationships between these factors.	Page 76 Step 10
Explain that a key factor in the movement of water through soil is friction. The force of gravity pulls the water downward, but the friction, which is related to surface area, causes resistance. Therefore, water moves more slowly through soils with smaller particle sizes (silt or clay).	Page 76 Step 11

LESSON 2 ORGANIZER CONTINUED

ACTIVITY 3: SOIL IS COMPLEX **WHAT THE TEACHER DOES**	**PROCEDURE REFERENCE**
Remind students of the ways that soil helps plants grow.	Page 76 Step 1
Continue the discussion by asking students, “Based on what you learned about soil components (sand, silt, and clay), would any of these be ideal for helping plants grow?”	Page 76 Step 2
Explain that soils are not as simple as the individual components they used in their investigation. Soils are made up of a mixture of sand, silt, clay, and organic matter. Display a copy of *Master 2.5, The Soil Triangle*. Point out that the soil triangle is divided into 12 soil classifications based on the amount of sand, silt, and clay in the soil.	Page 77 Step 3
Ask students if they could figure out how a soil sample would be classified if it contained 20 percent clay, 70 percent silt, and 10 percent sand. Demonstrate on the projected copy of *Master 2.5* how students would determine that this soil sample would fall into the silt loam classification.	Page 77 Step 4
Ask, “In which category on the soil triangle do you think plants would grow best and why?” Allow volunteers to share their answers, but make sure they support their answers with information about soil properties that they learned previously.	Page 77 Step 5
Conclude the activity by asking students how the soil triangle could be helpful to someone who is growing plants (either on a small scale such as an individual gardener or on a larger scale such as a farmer).	Page 77 Step 6

MASTER 2.1

WATER AND SOIL PROPERTIES

NAME

DATE

SETTING UP THE EXPERIMENT

1. Using the marking pen, draw a line on each straw 2 cm from the bottom. Draw a second line 7 cm above the first line.

2. Cover one end of each straw with a piece of coffee filter and tape the coffee filter to the straws. Do not cover the bottom of the straws with tape.

3. Using the plastic spoon and the funnel, add sand to each straw up to the level of the lower line. The level of sand should be the same in each of your team's straws.

4. Add baby powder to one straw until it reaches the upper line mark you drew on the straw. Be careful not to disturb the bottom layer of sand. To the other straw, add additional sand until it reaches the mark.

5. Insert the straws through the plastic lids. (Insert the top end so you will not tear the coffee filter.) Rest the lids on top of the cups making sure the straws do not touch the bottom of the cup.

MATERIALS FOR THE TEAM

2 plastic spoons
2 straws
2 pieces of coffee filter (3.5 cm^2)
Transparent tape
Permanent marking pen
Sand
Baby powder
2 cups
2 plastic drink cup lids
10 mL graduated cylinder
Disposable pipet
Stopwatch or timer
Ruler
Funnels made by rolling up paper

EXPERIMENTAL PROCEDURE

1. Decide what role each team member will play during the experiment. One student should be in charge of measuring and adding water. Another student will be responsible for timing the experiment and the third student will record data.

2. Measure 10 ml of water in the graduated cylinder. Use the pipet to add the water to the top of the sand in the straw. (Using the pipet will cause the least disturbance to the sand.) Begin timing.

3. Record the time when the first drop of water falls into the cup. Continue timing.

4. Stop the timer when the last drop of water falls into the cup. Measure the water in the cup.

5. Record your team's data in the chart below. Calculate the amount of water retained in the straw at the end of the experiment (10 mL – amount entered in column 5). Also, measure the decrease in height of the substance at the end of the experiment.

SUBSTANCE	TIME FOR FIRST DROP TO FALL	TIME FOR ALL WATER TO PASS THROUGH STRAW	TOTAL AMOUNT OF WATER THROUGH STRAW (mL)	AMOUNT OF WATER RETAINED IN STRAW (mL)	DECREASE IN HEIGHT OF SUBSTANCE AT END OF EXPERIMENT (CM)
SAND					
BABY POWDER					

6. Repeat Steps 2–5 using the straw containing baby powder.

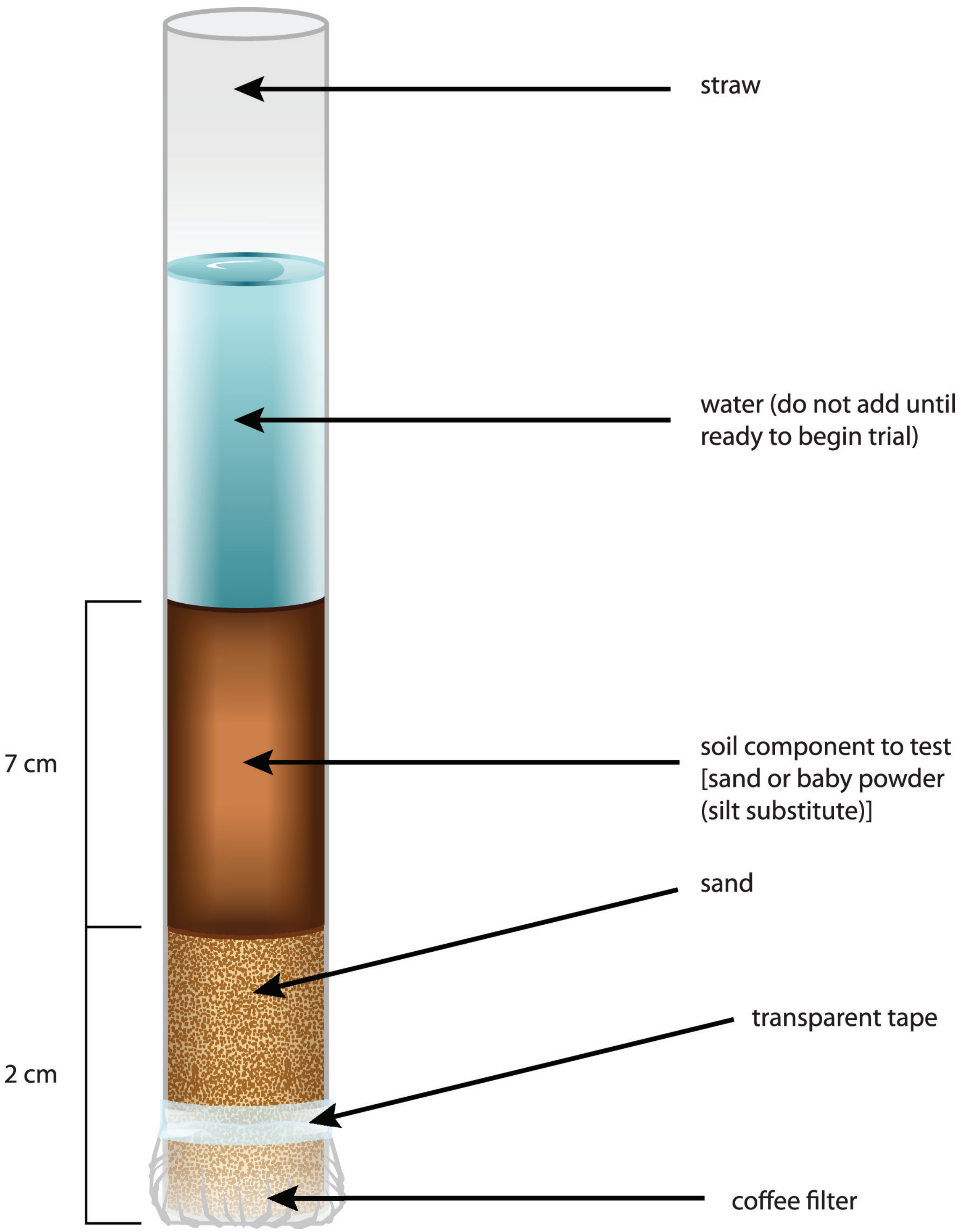
7. Add your measurements to the class data chart.

MASTER 2.2

COLUMN SETUP

NAME

DATE



MASTER 2.3

MAKING SENSE OF THE DATA

NAME

DATE

WORK WITH YOUR TEAMMATES TO ANSWER THE FOLLOWING QUESTIONS.

1. How does the size of sand grains compare with the size of baby powder particles? What is your evidence?

2. Which substance allowed water to move through more quickly?

3. Based on your data from your experiment using sand and baby powder, write 1–2 sentences about particle size and the movement of water through the column.

4. The data from the column containing clay show that it took longer for the water to move through the column. If the statement you wrote for question 3 is correct, how does the size of a particle of clay compare with a particle of sand or baby powder?

5. Which substance retained the most water in the straw? Which substance retained the least?

6. Write a sentence that summarizes the relationship between water retention and particle size.

7. At the beginning of the experiment, your column of sand, baby powder, or clay (in the demonstration) was 7 cm in height. What differences did you see in the height at the end of the experiment?

8. What accounts for the differences in height at the end of the experiment?

MASTER 2.4

PARTICLE SIZE, SURFACE AREA, AND WATER MOVEMENT

NAME

DATE

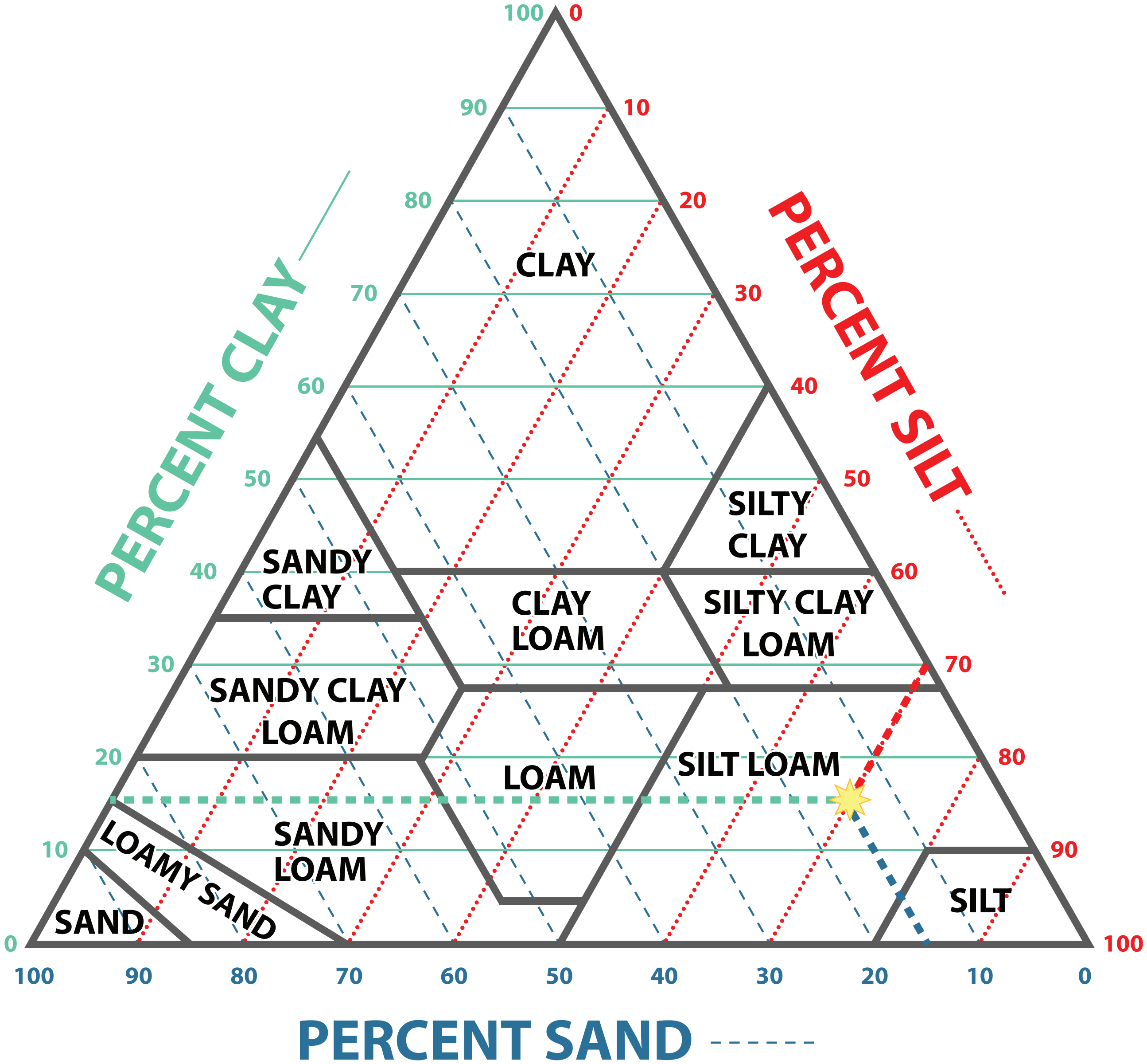
PARTICLE SIZE	SURFACE AREA (same total volume)	WATER MOVEMENT SPEED	WATER RENTENTION
↑	________	________	________
↓	________	________	________

MASTER 2.5

THE SOIL TRIANGLE

NAME

DATE



MASTER 2.6
SOIL PARTICLE SIZE

NAME

DATE

SOIL COMPONENT	PARTICLE DIAMETER
Rock	Greater than 75.0 mm
Gravel	2.0 to 75.0 mm
Sand	0.05 mm to 2.0 mm
Silt	0.002 to 0.05 mm
Clay	Less than 0.002 mm

LESSON 3
EXPLAIN

PLANT-SOIL INTERACTIONS

AT A GLANCE

OVERVIEW

Students begin the lesson by agreeing or disagreeing with several statements about plant roots. They use a hand lens to examine roots of young seedlings and are given a chance to revise their responses. The diffusion process used by roots to absorb nutrients is modeled. Students then move on to investigating soil horizons and the formation of soil. To conclude the lesson, students investigate the Great Dust Bowl as an example of the disruption of topsoil layers and how agricultural practices changed because of lessons learned.

MAJOR CONCEPTS

- Plants remove water and nutrients from the soil through the plant's root system.
- Some nutrients move into root cells from the soil by diffusion and others by an energy-requiring process (active transport).
- Plants transport water from the roots to the rest of the plant using the xylem.
- Plants transport food from the leaves to the rest of the plant using the phloem.
- Soil horizons are layers in the soil that vary in their composition.
- Soil is formed from the breakdown of parent material and the addition of organic materials, nutrients, and minerals.
- The loss of the topsoil layer can have consequences on agriculture, the economy, and human health.

OBJECTIVES

After completing this lesson, students will be able to

- explain the roles of diffusion and active transport in moving nutrients from the soil to the plant;
- describe the formation of soil and soil horizons; and
- describe the events in the Great Dust Bowl, how they relate to soil horizons, and how those events affected agricultural practices.

TEACHER BACKGROUND

Consult the following sections in Teacher Background: **7.0 PLANT-SOIL INTERACTIONS, 8.0 THE PLANT VASCULAR SYSTEM, 11.0 THE DUST BOWL**

IN ADVANCE

PHOTOCOPIES

ACTIVITY	MASTER	NUMBER OF COPIES
1	Master 3.1, What Do You Know about Roots?	1 per student and 1 to project
	Master 3.2, Moving Water and Nutrients into Roots	1 per student
	Master 3.3, Experiments with Roots	1 to project
2	Master 3.4, The Plant Vascular System	1 to project
3	Master 3.5, Soil Horizons	1 to project
	Master 3.6, Where Does Soil Come From?	1 per student
	Master 3.7, Soil Formation	1 per student
4	Master 3.8, Disrupting the Soil Horizons: The Dust Bowl	1 per student
	Master 3.9, Farming Practices	1 per team of 2-3 students
	Master 3.10, Dust Study	1 to project

MATERIALS

ACTIVITY	MATERIALS
1 **SEEDLING PREPARATION** (5 TO 6 DAYS IN ADVANCE) **DIFFUSION DEMONSTRATION** (MOVING WATER AND NUTRIENTS INTO ROOTS)	**FOR EACH TEAM OF 4 STUDENTS:** • 1 drinking glass • 1 hand lens • 6 pinto bean (or other type) seeds • 1 cup of water • 1 paper towel **FOR EACH TEAM OF 4 STUDENTS:** • 1 paper or Styrofoam cup • 1 large container • 1 bottle of food coloring • Water (enough to fill the large container) • 1 sharp pencil
2	**FOR THE CLASS DEMONSTRATION:** • 1 paper or Styrofoam cup • 2 pieces of celery stalk • 1 bottle of food coloring (blue works well)
3	Pens or pencils in different colors
4	None

PREPARATION

ACTIVITY 1: FROM SOIL TO ROOTS

SEEDLING PREPARATION. In *Step 5,* students are asked to observe the root systems of young seedlings. For this activity, any type of seeds may be used so long as the roots have grown about 1 or 2 cm. Pinto bean seeds are easy to obtain and work well. To germinate the seeds, place several seeds in a row along one side of a paper towel as shown in *Figure 3.1a.* Carefully roll up the paper towel from bottom to top. Place the rolled paper towel into a glass of water so that the seeds are at the top and out of the water glass *(Figure 3.1b)*. Water will wick up through the paper towel and keep the seeds moist. Prepare enough seedlings so that each team of 4 students will have a seed to observe. Assume that just 1/2 of the seeds you prepare will germinate. Set the glasses of seeds in a location where they will not be disturbed. The seeds will need approximately 5 to 6 days for the roots to grow enough for observation. During the germination period, be careful to replace any water that is lost through evaporation.

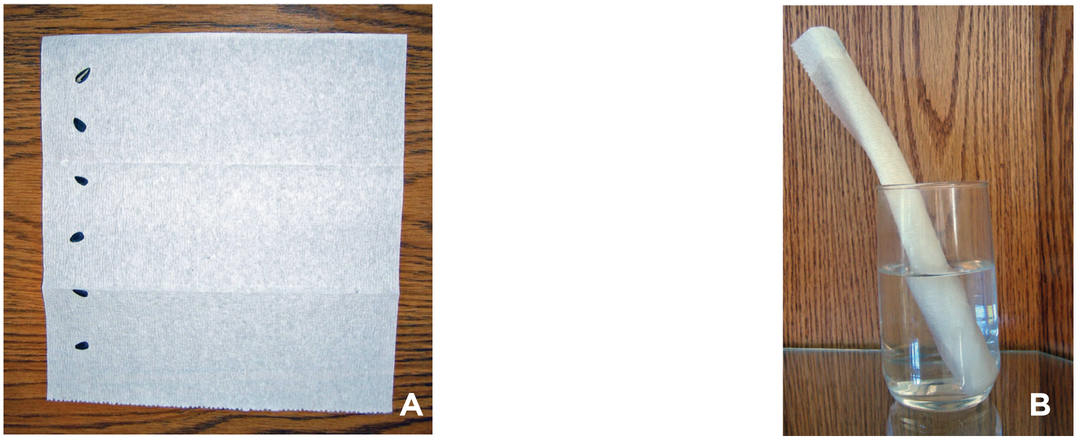


FIGURE 3.1 A. SEEDS ARE ROLLED UP IN A PAPER TOWEL. B. SEEDS ARE PLACED INTO A GLASS OF WATER.

ACTIVITY 2: FROM ROOTS TO THE PLANT

CELERY DEMONSTRATION. Use a sharp knife to cut celery stalks into pieces approximately 5 cm (2 inches) long. Make sure that the cut surfaces are flat and will allow the celery to rest upright when placed into the paper cups. Approximately 2–3 hours before class begins, put one piece of celery into a cup containing the food coloring. Wrap the other piece of celery in plastic wrap until needed.

FIGURE 3.2. XYLEM DEMONSTRATION USING CELERY

PROCEDURE

ACTIVITY 1: FROM SOIL TO ROOTS

Students learn about plant roots and their role in obtaining water and nutrients from the soil for plants to use.

1. REMIND STUDENTS THAT IN THE PREVIOUS LESSON THEY LEARNED THAT THERE ARE AIR SPACES IN SOIL. THESE AIR SPACES CAN BE FILLED WITH WATER CONTAINING DISSOLVED NUTRIENTS. ASK, "HOW DOES THE PLANT OBTAIN NUTRIENTS FROM THE WATER THAT IS IN THE SOIL?"

Students' responses will vary. If necessary, guide the discussion to mention the plant's root system.

2. DISPLAY A COPY OF *MASTER 3.1, WHAT DO YOU KNOW ABOUT ROOTS?* USE A PIECE OF PAPER TO COVER ALL BUT THE FIRST STATEMENT. READ THE FIRST STATEMENT AND ASK THE STUDENTS TO INDICATE BY A SHOW OF HANDS WHETHER THEY AGREE OR DISAGREE WITH THE STATEMENT.

This discussion is designed to help you assess the students' prior knowledge of the topic. If necessary, review for the class the essential features of diffusion and active transport.

DIFFUSION

- Molecules move randomly due to their kinetic energy.
- This movement causes molecules to intermingle.
- The net movement of molecules is from an area of higher concentration to one of lower concentration.
- The net movement of molecules stops when the concentration of the molecules is the same everywhere.
- The movement of the molecules comes from their kinetic energy and does not need additional energy (unlike active transport).

ACTIVE TRANSPORT

- Active transport is a process used by cells to move molecules from an area of lower concentration to one of higher concentration.
- It requires energy.
- If your students already have been introduced to the energy molecule ATP, you may mention it as the source of energy for active transport.

3. CONTINUE REVEALING THE REST OF THE STATEMENTS, ONE AT A TIME, AND ASKING STUDENTS WHETHER THEY AGREE OR DISAGREE WITH THE STATEMENTS.

After students vote on each statement, ask for 1 or 2 volunteers to explain why they voted as they did. At this time, do not correct wrong answers. The students will come back to these statements later in the lesson. Answers are found and revealed to students in *Step 15.*

4. EXPLAIN THAT THEY WILL NOW INVESTIGATE THE MECHANISM BY WHICH ROOTS OBTAIN NUTRIENTS FROM THE SOIL. DIVIDE THE STUDENTS INTO TEAMS OF 4. PASS OUT TO EACH TEAM A YOUNG SEEDLING (TAKEN FROM THE PAPER TOWEL GERMINATION) AND A HAND LENS.

This activity refers to the way that most plants obtain their nutrients through the root system. Legumes that carry out nitrogen fixation in their roots are a special case and are not dealt with here.

5. INSTRUCT THE STUDENTS TO TAKE A MINUTE TO OBSERVE THE SEEDLING'S ROOT SYSTEM WITH THE HAND LENS AND WRITE DOWN THEIR OBSERVATIONS ON A PIECE OF PAPER.

The root hairs are white and very fine. Provide a dark background against which the root hairs are more easily visible.

6. AFTER THE STUDENTS HAVE RECORDED THEIR OBSERVATIONS, ASK VOLUNTEERS TO DESCRIBE WHAT THEY SAW.

Students will report seeing one large root emerging from the seed. They also will describe fine white hairs growing out from the root.

7. REMIND STUDENTS OF THE FIRST STATEMENT FROM *MASTER 3.1, WHAT DO YOU KNOW ABOUT ROOTS?* "PLANT ROOTS HAVE TINY HAIRS THAT ABSORB WATER." ASK, "WHY DO YOU THINK THAT PLANTS HAVE SO MANY ROOT HAIRS?"

Student responses will vary. Guide the discussion to bring out that more root hairs mean more surface area with which to contact water and nutrients in the soil. In *Lesson 2,* students learned about particle size and surface area. In this case, the small projections on the root are another example of the importance of increasing surface area.

8. ASK STUDENTS, "HOW DO NUTRIENTS IN THE SOIL WATER GET INTO THE ROOT HAIRS?"

Students' responses will vary. At this time, accept all answers.

9. EXPLAIN THAT STUDENTS WILL NOW INVESTIGATE THE PROCESS BY WHICH WATER ENTERS THE ROOT HAIRS. KEEP THE CLASS IN THEIR TEAMS. PASS OUT TO EACH TEAM 1 COPY OF *MASTER 3.2, MOVING WATER AND NUTRIENTS INTO ROOTS.*

10. ASK STUDENTS TO READ OVER THE PROCEDURE ON THE HANDOUT. EXPLAIN THAT THE CUP REPRESENTS THE ROOT HAIR, THE LARGER CONTAINER REPRESENTS THE WATER IN THE SOIL, AND THE FOOD COLORING REPRESENTS THE NUTRIENTS DISSOLVED IN THE WATER.

11. AFTER STUDENTS HAVE COMPLETED THEIR INVESTIGATIONS, RECONVENE THE CLASS AND ASK VOLUNTEERS TO EXPLAIN WHAT HAPPENED WHEN THE HOLES WERE POKED THROUGH THE CUP.

Students will report that the colored water slowly entered the cup.

12. ASK STUDENTS:

- **"WHY DID THE COLORED WATER ENTER THE CUP?"**

  Students' responses will vary. Guide the discussion to bring out the fact that although the concentration of water was the same on both sides of the cup, the concentration of the food coloring was higher outside the cup compared with inside the cup.

- **"WHAT IS THE PROCESS CALLED WHERE A SUBSTANCE MOVES FROM AN AREA OF HIGHER CONCENTRATION TO AN AREA OF LOWER CONCENTRATION?"**

  The process of diffusion was summarized in *Step 2.* Students should recall that diffusion involves a net movement of a substance from an area of higher concentration to one of lower concentration.

- **"WHERE DOES THE ENERGY COME FROM TO DRIVE THIS PROCESS?"**

  Students should recall from the discussion in *Step 2* that the kinetic energy of the molecules in solution drives the process.

13. DISPLAY A COPY OF *MASTER 3.3, EXPERIMENTS WITH ROOTS*. COVER THE BOTTOM SECTION WITH A PIECE OF PAPER. REVEAL THE FIRST EXPERIMENT AND READ IT ALOUD. ASK THE STUDENTS WHAT THIS DATA TELLS THEM ABOUT HOW NUTRIENTS MOVE FROM THE SOIL INTO THE ROOTS.

Since the concentrations of some essential elements move from an area of low concentration to one of higher concentration, this suggests that energy was required for the movement and the process involved was active transport.

14. REVEAL THE SECOND EXPERIMENT, READ IT ALOUD, AND DISCUSS ITS MEANING.

Students should recognize that since the chemical halts ATP synthesis there would not be energy available to support active transport. Without active transport, those essential elements that depend on active transport to reach high concentrations will exhibit much lower concentrations in the root hairs as compared with the first experiment. Other essential elements that are transported by diffusion will be expected to have their concentrations unchanged.

15. CONCLUDE THE ACTIVITY BY DISPLAYING *MASTER 3.1, WHAT DO YOU KNOW ABOUT ROOTS?* ONCE AGAIN. AS BEFORE, ASK STUDENTS TO INDICATE BY A SHOW OF HANDS WHETHER THEY AGREE OR DISAGREE WITH EACH STATEMENT. ASK VOLUNTEERS TO EXPLAIN WHY THEY CHANGED THEIR MINDS ABOUT THEIR ANSWERS.

Students should be able to respond to the statements about roots as follows:

Answers to *Master 3.1, What Do You Know about Roots?*

1. PLANT ROOTS HAVE TINY HAIRS THAT ABSORB WATER. (TRUE)

Students were able to observe root hairs using the hand lens. A larger root system contacts and absorbs more water than a smaller one.

2. PLANTS ROOTS USE ENERGY TO PUMP WATER INTO THE PLANT. (FALSE)

As shown in the demonstration, water enters the root hairs by the passive process of diffusion. When root hairs contact the water, the water flows from a higher concentration in the soil toward a lower concentration in the root cells.

3. NUTRIENTS ENTER ROOT CELLS THROUGH THE PROCESS OF DIFFUSION. (TRUE)

Water enters the root system by diffusion and takes some dissolved nutrients with it.

4. NUTRIENTS ENTER ROOT CELLS THROUGH THE PROCESS OF ACTIVE TRANSPORT. (TRUE)

As shown by the experiments described in *Master 3.3, Experiments with Roots*, some nutrients are moved by active transport. Students should recognize that both diffusion and active transport have important roles in moving nutrients into plants from the soil.

5. PLANT ROOTS GROW UNTIL THEY FIND WATER. (FALSE)

Students may believe that roots can sense and grow toward water. This is a misconception. Roots can only grow where water is already present. As the surface of the soil dries out, roots near the surface may die while roots further down are in contact with water and can grow still deeper.

Before holding a class discussion, give each student 1 copy of *Master 3.1, What Do You Know about Roots?* Instruct students to write on their copies of *Master 3.1* why each statement is true or false. Students should include specific evidence from the lesson that supports their conclusions. Students can use their answers during the class discussion. You may also wish to collect students' papers to assess their understanding.

ACTIVITY 2: FROM ROOTS TO THE PLANT

This activity helps students think about how plants have specialized tissues for moving water and nutrients from the roots to all other parts of the plant.

1. EXPLAIN THAT GETTING NUTRIENTS INTO THE PLANT ROOTS IS AN IMPORTANT FIRST STEP. ASK STUDENTS, "HOW DOES WATER, AND THE NUTRIENTS IT CONTAINS, GET FROM THE ROOTS TO THE REST OF THE PLANT?"

Accept all reasonable answers at this time.

2. HOLD UP A PIECE OF CELERY AND A CUP CONTAINING FOOD COLORING. ASK STUDENTS TO PREDICT WHAT THE CELERY WILL LOOK LIKE AFTER IT HAS BEEN IN THE FOOD COLORING SOLUTION FOR A WHILE.

Do not correct misconceptions at this time. Students will come back to this in *Step 4*. If students are unfamiliar with the existence of a vascular system in plants, they may predict that the entire stalk of celery will be blue inside. If they know that plants have a vascular system, they would predict that there are specific places within the stalk that are blue (blue dots seen on the surface of the cut end).

3. DISPLAY A COPY OF *MASTER 3.4, THE PLANT VASCULAR SYSTEM*. BRIEFLY REVIEW THE INFORMATION ON THE MASTER SO THAT STUDENTS UNDERSTAND THAT PLANTS HAVE SPECIALIZED MECHANISMS FOR MOVING WATER AND NUTRIENTS.

4. RECONVENE THE CLASS AND HOLD UP THE PIECE OF CELERY THAT HAS BEEN IN THE FOOD COLORING. ASK VOLUNTEERS TO USE WHAT THEY HAVE LEARNED ABOUT THE PLANT VASCULAR SYSTEM TO EXPLAIN WHY THEIR EARLIER PREDICTIONS WERE OR WERE NOT ACCURATE.

Students should see that the food coloring was transported up the celery stalk and was visible as a series of colored dots along the top of the stalk. Some students may have seen this demonstration before and remember what the result is, but have not thought about what it means about the existence of a specialized mechanism for transporting water and nutrients.

Reinforce that the movement of water took place through the plant's xylem system, which explains why the food coloring was present in discrete places in the celery.

5. CONCLUDE THE ACTIVITY BY REMINDING STUDENTS THAT PHOTOSYNTHESIS PRODUCES SUGARS IN THE LEAVES. ASK THEM HOW THE SUGARS, NEEDED FOR ENERGY, REACH THE LOWER PARTS OF THE PLANT.

Students should recall from *Master 3.4, The Plant Vascular System* that phloem tissue is used to transport sugars downward from the leaves. You can point out that in the case of the celery stalk, the xylem and phloem tissues lie next to each other in structures called vascular bundles.

OPTIONAL HOMEWORK ASSIGNMENT

Ask students to write a short paper that describes how the plant vascular system is similar and dissimilar to the human circulatory system. Students' descriptions should include the following:

SIMILARITIES

- Both systems use a series of tube-like structures to transport material throughout the organism.
- Both systems use diffusion to move nutrients and oxygen gas (O_2) into cells.
- Plants have separate systems for moving water up the plant (xylem) and for moving food down the plant (phloem). Humans have a separate system for moving oxygenated blood (arterial system) and non-oxygenated blood (venous system).

DISSIMILARITIES

- The human circulatory system uses the heart to pump blood, while the plant vascular system lacks such an organ.
- Blood in the circulatory system contains cells, while the sap in the plant vascular system does not contain cells.
- Capillaries join the arterial and venous systems, but there are no similar structures in the plant vascular system.

ACTIVITY 3: SOIL FORMATION AND HORIZONS

This activity introduces students to soil formation. The way in which soil is formed results in layers, called soil horizons.

1. DISPLAY A COPY OF *MASTER 3.5, SOIL HORIZONS.* ASK STUDENTS TO MAKE OBSERVATIONS ABOUT THE SOIL THEY SEE IN THE PICTURES.

The main observation that students should make is that there appear to be layers in the soil that differ by color and thickness.

2. EXPLAIN THAT SOIL INCLUDES LAYERS AND THAT THE LAYERS ARE CALLED SOIL HORIZONS. GIVE EACH STUDENT A COPY OF *MASTER 3.6, WHERE DOES SOIL COME FROM?* ASK STUDENTS TO WORK IN TEAMS OF 2-3 TO MAKE AND RECORD OBSERVATIONS.

Give teams 2–3 minutes to write brief observations. In the next step, students will get additional information.

3. GIVE EACH STUDENT A COPY OF *MASTER 3.7, SOIL FORMATION.* INSTRUCT THEM TO USE THE INFORMATION ON THIS MASTER TO ADD INFORMATION AND DETAIL TO THE DESCRIPTIONS THEY WROTE ON MASTER 3.6.

Encourage students to talk with their team members as they work through this. It may be helpful if students use a different color pen or pencil to make their changes or additions. In this way, they can easily see how their initial observations compare with the new information they are adding. Students can also make notes on *Master 3.7* to cross-reference the steps on *Master 3.6.*

It may be helpful to point out to students that the cross-section of soil represented on *Master 3.6* is the same total thickness throughout. Soil is formed through the breakdown of bedrock and addition of organic materials. It is not formed only by the addition of material on top of bedrock.

4. CONCLUDE THE ACTIVITY BY REVIEWING THE INFORMATION ON *MASTERS 3.6* AND *3.7.* EXPLAIN TO STUDENTS THAT HORIZONS IN SOILS FROM DIFFERENT AREAS ARE LIKELY TO BE DIFFERENT—SOME THICKER OR THINNER.

This is also an opportunity to go back to what students have learned about soil in *Lesson 2.* In that lesson, students learned about soil texture and the dependency that plants have on getting water and nutrients from the soil. In this activity, students have learned about the soil horizons in which roots grow.

ACTIVITY 4: THE DUST BOWL

In this activity, students investigate the relationships between farming practices and protecting the topsoil.

1. REMIND STUDENTS THAT IN THE PREVIOUS ACTIVITY THEY LEARNED ABOUT THE FORMATION OF SOIL AND SOIL HORIZONS. EXPLAIN THAT ALTHOUGH IT TAKES MANY YEARS TO FORM FERTILE SOIL, IT CAN BE DESTROYED IN A RELATIVELY SHORT TIME.

2. ASK, "WHAT FACTORS DO YOU THINK CONTRIBUTE TO THE DISRUPTION OF THE SOIL HORIZONS?"

Student responses will vary. Some will mention natural factors such as weather (hot and dry) while others may mention human influenced factors such as farming practices.

3. EXPLAIN THAT STUDENTS ARE GOING TO INVESTIGATE A SEVERE EXAMPLE OF SOIL DESTRUCTION THAT OCCURRED IN THE GREAT PLAINS REGION OF THE UNITED STATES BACK IN THE 1930S.

4. ASK STUDENTS TO REFER BACK TO THEIR COPIES OF *MASTER 3.6, WHERE DOES SOIL COME FROM?* AND *MASTER 3.7, SOIL FORMATION*, AND ASK, "WHICH SOIL HORIZON IS THE MOST IMPORTANT TO PLANT HEALTH?"

Students should recall that the topsoil (layer A) contains minerals and organic materials that are important to plant health.

5. PASS OUT TO EACH STUDENT 1 COPY OF *MASTER 3.8, DISRUPTING THE SOIL HORIZONS: THE DUST BOWL.* INSTRUCT STUDENTS TO READ THE HANDOUT AND ON A SEPARATE PIECE OF PAPER DESCRIBE HOW THE DUST BOWL WAS RELATED TO:

WEATHER CONDITIONS • ECONOMIC CONDITIONS • FARMING PRACTICES

If appropriate, you can assign this for homework.

6. AFTER STUDENTS HAVE COMPLETED THEIR ASSIGNMENT, RECONVENE THE CLASS. ASK VOLUNTEERS TO REPORT HOW THE WEATHER, ECONOMY, AND FARMING PRACTICES CONTRIBUTED TO THE CREATION OF THE DUST BOWL.

Students should report the following:

WEATHER	ECONOMY	FARMING PRACTICES
• overestimation of the region's rainfall • an extended drought • high winds	• large influx of settlers who began farming • russian revolution and World War I causes crop prices to rise which led to more land being farmed • us government land grants to farmers • increased use of mechanized farming • overproduction of wheat • onset of the great depression	• increased use of mechanized farming • practice of "deep plowing" • leaving soil unprotected

7. EXPLAIN THAT THE MOST IMPORTANT GOVERNMENT RESPONSE TO THE DUST BOWL WAS TO ENCOURAGE FARMERS TO CHANGE THEIR FARMING PRACTICES. TO CONCLUDE THE ACTIVITY, TEAMS WILL LOOK MORE CLOSELY AT FARMING PRACTICES AND THEIR EFFECTS ON THE SOIL.

8. ARRANGE STUDENTS IN TEAMS OF 2–3. PASS OUT TO EACH TEAM 1 COPY OF *MASTER 3.9, FARMING PRACTICES.* INSTRUCT THE TEAMS TO READ THE SHORT DESCRIPTIONS OF FARMING PRACTICES AND TO FOLLOW THE DIRECTIONS ON THE HANDOUT.

Give teams about 10–15 minutes to discuss the farming practices and write down their conclusions.

9. ASK FOR VOLUNTEERS TO REPORT THEIR CONCLUSIONS ABOUT EACH FARMING PRACTICE.

Teams should report the following:

- Crop rotation addresses the problem of nutrient depletion. By rotating crops with different nutritional requirements, one crop can restore to the soil an essential element that was removed by the previous crop.
- Strip farming addresses the problem of soil erosion. The roots help hold the soil together. Positioning the cultivated strip perpendicular to the prevailing winds minimizes erosion from the bare strips.
- Contour farming addresses the problem of water runoff. The furrows made by the plow (perpendicular to the slope) serve as dams that slow water runoff during rainstorms.

10. EXPLAIN THAT RETURN OF RAIN TO THE GREAT PLAINS, THE END OF THE GREAT DEPRESSION, AND THE IMPLEMENTATION OF BETTER FARMING PRACTICES HELPED THE COUNTRY RECOVER FROM THE DUST BOWL. ASK, "DO YOU THINK THE US COULD EVER EXPERIENCE ANOTHER DUST BOWL? WHY OR WHY NOT?"

Student responses will vary. Some students may believe that the lessons learned from the 1930s will enable toady's farmers to avoid the mistakes of the past. Other students may be concerned that global warming may lead to another Dust Bowl.

11. PROJECT *MASTER 3.10, DUST STUDY*. ASK A VOLUNTEER TO READ THE STUDY ALOUD TO THE CLASS. ASK, DOES THIS DATA CAUSE YOU TO REVISE YOUR THINKING ABOUT A RETURN OF THE DUST BOWL?"

Some students may be surprised by these findings and think that another Dust Bowl is more likely than before.

12. EXPLAIN THAT SCIENTISTS BELIEVE THAT THIS INCREASE IN DUST EMISSIONS MAY BE DUE TO SEVERAL FACTORS INCLUDING INCREASED WINDSTORM FREQUENCY, DROUGHT CYCLES, AND CHANGES IN LAND USE PATTERNS. THIS MOVEMENT OF DUST CAN HAVE SIGNIFICANT EFFECTS ON BOTH THE AREA WHERE THE DUST IS REMOVED AND THE AREA WHERE IT IS DEPOSITED.

If students are interested, they could do additional research on the Internet to learn more about topsoil depletion in different areas of the world and how topsoil depletion in one area can have consequences in a very different part of the world. For example, scientists can track dust traveling from Africa across the Atlantic Ocean. Some studies are finding wide-ranging effects, including damage to the health of coral reefs in the Caribbean.

LESSON 3 ORGANIZER

ACTIVITY 1: FROM SOIL TO ROOTS WHAT THE TEACHER DOES	PROCEDURE REFERENCE
Remind students that they learned about air spaces in soil that can be filled with water containing dissolved nutrients. Ask, "How does the plant obtain nutrients from the water that is in the soil?"	Page 93 Step 1
Display a copy of *Master 3.1, What Do You Know about Roots?* Cover all but the first statement. Read the first statement and ask the students to indicate whether they agree or disagree with the statement.	Page 93 Step 2
Continue revealing statements, one at a time, and asking students whether they agree or disagree with the statements.	Page93 Step 3
Explain that they will now investigate the mechanism by which roots obtain nutrients from the soil. Divide the students into teams of 4. Give each team a young seedling and a hand lens.	Page 93 Step 4
Instruct the students to observe their seedling's root system with the hand lens and write down their observations on a piece of paper.	Page 93 Step 5
After the students have recorded their observations, ask volunteers to describe what they saw.	Page 94 Step 6
Remind students of the first statement (Plant roots have tiny hairs that absorb water.) from *Master 3.1, What Do You Know about Roots?* Ask, "Why do you think that plants have so many root hairs?"	Page 94 Step 7
Ask students, "How do nutrients in the soil water get into the root hairs?"	Page 94 Step 8
Explain to students that they will now investigate the process by which water enters the root hairs. Keep the class in their teams. Pass out to each team 1 copy of *Master 3.2, Moving Water and Nutrients into Roots.*	Page 94 Step 9
Ask students to read over the procedure. Explain that the cup represents the root hair, the larger container represents the water in the soil, and the food coloring represents the nutrients dissolved in the water.	Page 94 Step 10
After students have completed their investigations, reconvene the class and ask volunteers to explain what happened when the holes were poked through the cup.	Page 94 Step 11
Ask students: • "Why did the colored water enter the cup?" • "What is the process called where a substance moves from an area of higher concentration to an area of lower concentration?" • "Where does the energy come from to drive this process?"	Page94 Step 12
Display *Master 3.3, Experiments with Roots.* Cover the bottom so only *Experiment 1* is revealed. Read that experiment aloud. Ask the students what these data tell them about how nutrients move from the soil into the roots.	Page 94 Step 13
Reveal the second experiment, read it aloud, and discuss its meaning.	Page 95 Step 14
Conclude the activity by displaying *Master 3.1, What Do You Know about Roots?* once again. As before, ask students to indicate whether they agree or disagree with each statement. Ask volunteers to explain why they changed their minds about their answers.	Page 95 Step 15

ACTIVITY 2: FROM ROOTS TO THE PLANT WHAT THE TEACHER DOES	PROCEDURE REFERENCE
Explain that getting nutrients into the plant roots is an important first step. Ask students, "How does water, and the nutrients it contains, get from the roots to the rest of the plant?"	Page 96 Step 1
Hold up a piece of celery (the one that has not been in food coloring) and ask students to predict what the celery will look like after it has been in the food coloring solution for a while.	Page 96 Step 2
Display a copy of *Master 3.4, The Plant Vascular System*. Briefly review the information on the master so that students understand that plants have specialized mechanisms for moving water and nutrients.	Page 96 Step 3
Hold up the piece of celery that has been in the food coloring. Ask volunteers to use what they have learned about the plant vascular system to explain why their earlier predictions were or were not accurate.	Page 96 Step 4
Conclude the activity by reminding students that photosynthesis produces sugars in the leaves. Ask them how the sugars, needed for energy, reach the lower parts of the plant.	Page 96 Step 5

ACTIVITY 3: SOIL FORMATION AND HORIZONS WHAT THE TEACHER DOES	PROCEDURE REFERENCE
Display *Master 3.5, Soil Horizons*. Ask students to make observations about the soil they see in the pictures.	Page 97 Step 1
Explain that soil has layers and that the layers are called soil horizons. Give each student a copy of *Master 3.6, Where Does Soil Come From?* Ask students to work in teams of 2–3 to make and record observations.	Page 97 Step 2
Give each student a copy of *Master 3.7. Soil Formation*. Instruct them to use the information on this master to add information and detail to the descriptions they wrote on Master 3.6.	Page 97 Step 3
Conclude the activity by reviewing the information on *Masters 3.6* and *3.7.* Explain to students that horizons in soils from different areas are likely to be different—some thicker or thinner.	Page 97 Step 4

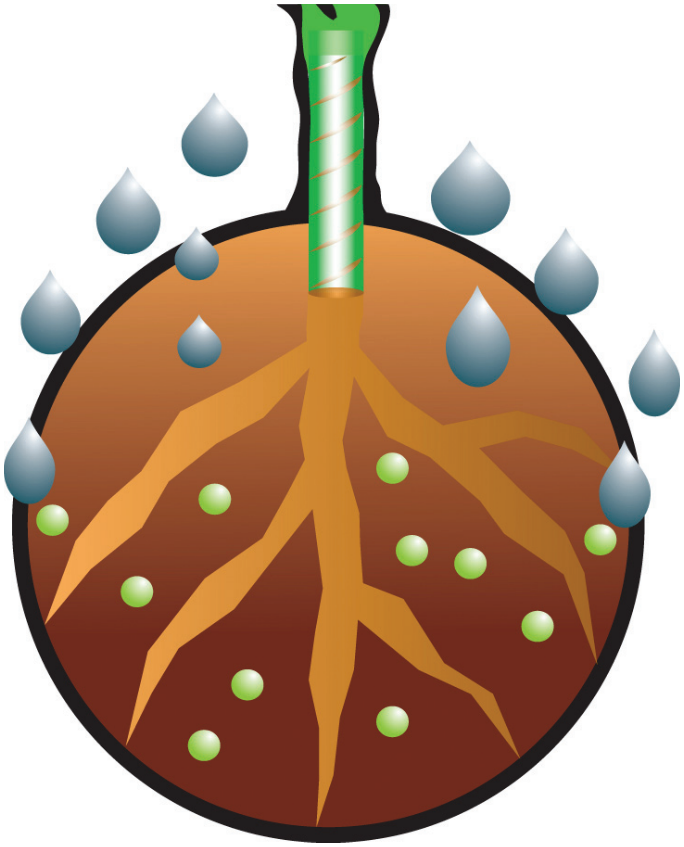
LESSON 3 ORGANIZER CONTINUED

ACTIVITY 4: THE DUST BOWL WHAT THE TEACHER DOES	PROCEDURE REFERENCE
Remind students of the soil horizons. Explain that they take many years to form but can be destroyed in much less time.	Page 97 Step 1
Ask, "What factors do you think contribute to the disruption of the soil horizons?"	Page 97 Step 2
Explain to students that they are going to investigate a severe example of soil disruption that occurred in the Great Plains region of the United States back in the 1930s.	Page 97 Step 3
Ask students to refer back to their copies of *Master 3.6, Where Does Soil Come From?* and *Master 3.7, Soil Formation* and ask, "Which soil horizon is the most important to plant health?"	Page 97 Step 4
Pass out to each student 1 copy of *Master 3.8, Disrupting the Soil Horizons: The Dust Bowl.* Instruct students to read the handout and on a separate piece of paper describe how the Dust Bowl was related to • weather conditions, • economic conditions, and • farming practices.	Page 98 Step 5
Ask volunteers to report their descriptions based on the information on *Master 3.8.*	Page 98 Step 6
Explain that the most important government response to the Dust Bowl was to encourage farmers to change their farming practices. To conclude the activity, teams will look more closely at farming practices and their effects on the soil.	Page 98 Step 7
Arrange the students back into their teams. Pass out to each team 1 copy of *Master 3.9, Farming Practices.* Instruct the teams to read the short descriptions of farming practices and to follow the directions on the handout.	Page 98 Step 8
Ask volunteers to report their conclusions about each farming practice.	Page 98 Step 9
Explain that return of rain to the Great Plains, the end of the Great Depression, and the implementation of better farming practices helped the country recover from the Dust Bowl. Ask, "Do you think the US could ever experience another Dust Bowl? Why or why not?"	Page 98 Step 10
Project *Master 3.10, Dust Study.* Ask a volunteer to read the study aloud to the class. Ask, "Do these data cause you to revise your thinking about a return of the Dust Bowl?"	Page 99 Step 11
Explain that scientists believe that this increase in dust emissions may be due to several factors including increased windstorm frequency, drought cycles, and changes in land-use patterns.	Page 99 Step 12

MASTER 3.1

WHAT DO YOU KNOW ABOUT ROOTS?

NAME	
DATE	



1. Plant roots have tiny hairs that absorb water.
2. Plant roots use energy to pump water into the plant.
3. Nutrients enter root cells through the process of Diffusion.
4. Nutrients enter root cells through the process of Active Transport.
5. Plant roots grow until they find water.

MASTER 3.2

MOVING WATER AND NUTRIENTS INTO ROOTS

NAME
DATE

PROCEDURE

STEP 1	Fill the cup about 1/2 full of water.
STEP 2	Place the cup of water into the center of the larger container.
STEP 3	Fill the larger container with water until its level is the same as that in the cup.
STEP 4	Add several drops of food coloring to the water in the larger container and gently mix the water until the color is evenly distributed through the water. Do not add food coloring to the water in the cup!
STEP 5	Using a sharp pencil, poke 2 holes in the cup, opposite each other.
STEP 6	Watch the water in the cup for 5 minutes and record your observations in the following space.

OBSERVATIONS

MASTER 3.3
EXPERIMENTS WITH ROOTS

NAME

DATE

EXPERIMENT 1

Scientists measured the concentrations of various essential elements in the soil and inside the root hairs. They found that some essential elements had concentrations up to 100 times greater inside the root hairs as compared with the soil.

What process can move a substance against its concentration gradient?

EXPERIMENT 2

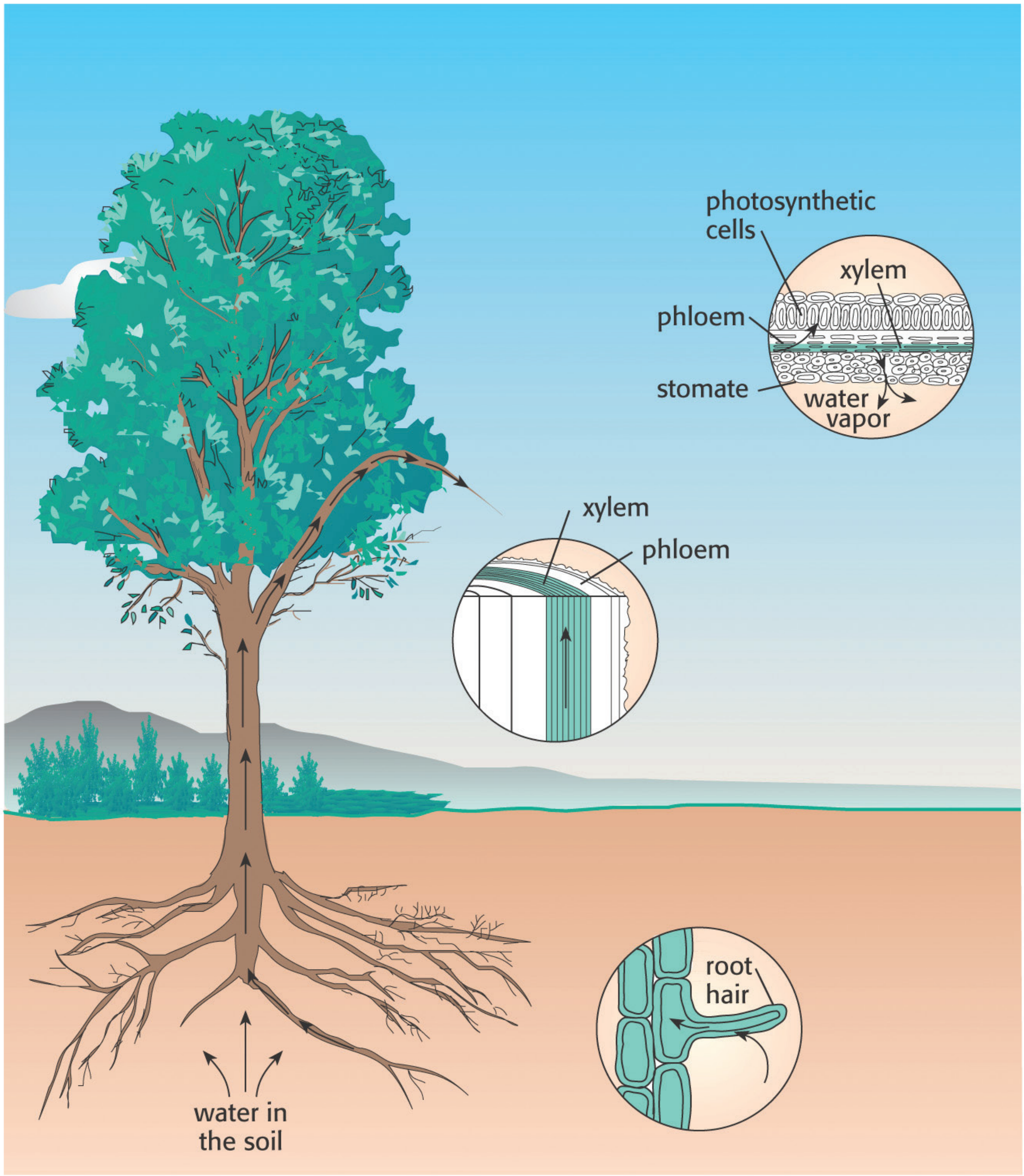
The data from Experiment 1 caused the scientists to suspect that active transport was responsible for concentrating some essential elements in the root hairs. They next exposed the living roots to a chemical that stops the synthesis of ATP. Once again, they measured concentrations of essential elements in the soil and inside the root hairs.

What do you think they observed?

MASTER 3.4
THE PLANT VASCULAR SYSTEM

NAME

DATE



1. **XYLEM** transports water **up** from the roots.
2. **PHLOEM** transports sugars produced in the leaves during photosynthesis **down** the plant.

MASTER 3.5
SOIL HORIZONS

NAME

DATE

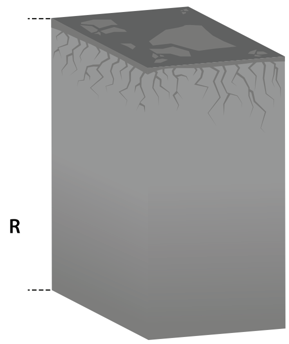
MASTER 3.6

WHERE DOES SOIL COME FROM?

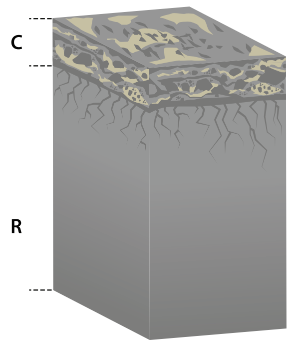
NAME

DATE

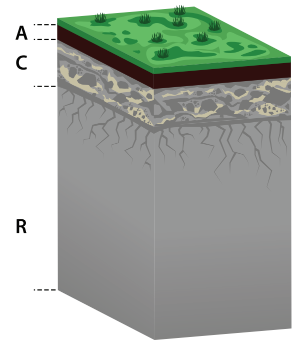
1 0 years



2 ~10 years



3 ~100 years

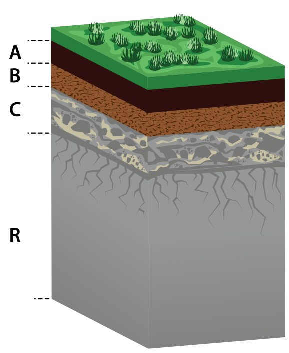


1

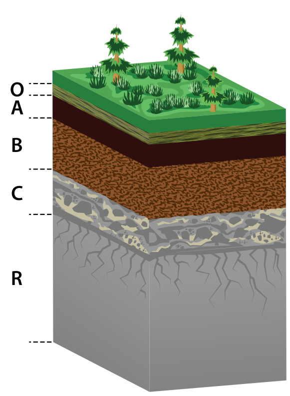
2

3

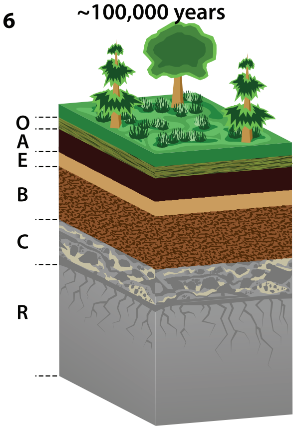
4 ~1,000 years



5 ~10,000 years



6 ~100,000 years



4

5

6

MASTER 3.7

SOIL FORMATION

NAME

DATE

Why are there layers in soil? Why doesn't soil look the same throughout its depth? The answers to these questions relate to how soil forms. Soil layers are called soil horizons. Soil formation actually starts with the parent material. When the parent material is rock, it may also be called bedrock. In this example we assume soil forms from rock, but parent material can also be loose sediment deposited by a river. Over time, the top layers of the parent material (R) start to break down into smaller pieces called regolith. This layer of smaller rocks and gravel form the C layer. Very few plant roots penetrate into this layer; very little organic material is found in this layer.

As time continues, plants start to grow on the surface. The growth and then death of these plants start to add organic matter to the forming soil. This organic matter mixes with minerals to form the A layer. The A layer is usually the darkest layer of soil because of the organic matter it contains. The A layers also contain a great deal of organisms, particularly microorganisms, that can help break down dead plant and animal remains to release their minerals into the soil. The A layer is often referred to as topsoil.

As more time passes, the A horizon may continue to thicken as more organic material and minerals mix. A layer of organic material (O layer) may form above the A layer. The O horizon is made up of leaf litter and humus (decomposed organic matter with fewer minerals than in the A horizon). As the A and O horizons continue to form, the C layer continues to move downward.

The next layer to form is the B horizon—also called the subsoil. This layer often has a coarser structure and is more varied in color than other layers. The B horizon contains clay and mineral deposits (including iron oxides, aluminum oxides, and calcium carbonate). These minerals leach out of materials in the layers above into the water. The water then drips into the B horizon.

The E horizon forms between the A and B horizons. The leaching of minerals, including more highly colored minerals like iron, out of the A horizon materials into the water, and into the B horizon is particularly intense at the bottom of A horizon. The B layer can become darker and the bottom of the A horizon lighter, this light colored, highly leached horizon is the E layer. The E horizon is made up mostly of sand and silt and contains less organic matter than the A horizon.

The six main factors that interplay to form soil are:

- the type of parent material (bedrock or sediments),
- environmental conditions,
- terrain,
- living organisms,
- time, and
- human activities.

MASTER 3.7
SOIL FORMATION

NAME
DATE

Because these factors differ across the world and develop at different times, the characteristics of soil can be different in different places. Any given soil may have all, none, or a few of these horizons.

PARENT MATERIAL: The parent rock or sediment is important for ultimately determining whether the soil is sandy, loamy, or high in clay. The nature of the parent material also influences the length of time it takes to form soil. It can take hundreds of years just to form one centimeter of soil if the parent material is very hard. If it is not as hard, soils can form more quickly.

ENVIRONMENTAL CONDITIONS: Temperature and amount of water (rainfall) are important influences on the formation of soil. Higher temperatures increase the rate at which the parent material breaks down. This also increases the rate at which nutrients are released into the soil. The freezing and thawing of water can also help break down the parent materials. Greater amounts of water carry nutrients deeper into the soil. Soils tend to be deeper in hotter, wetter environments (such as the tropics) and shallower in colder environments (such as the Arctic).

TERRAIN: The soil on steep slopes is generally shallower than in the valleys below or on the plains. The soil that does develop on hills or mountains often is carried downhill into the land below.

LIVING ORGANISMS: Living plants and microorganisms that decompose dead vegetation can release acids that act to break down the rock on which the soil is forming. The decaying plant (and animal) remains contribute nutrients to the soil. Animals like earthworms make channels through the soil that can help roots grow and water and nutrients move. Other organisms, especially microbial decomposers, play important roles in the recycling of organic matter and the release of nutrients into the soil.

TIME: Soils can be millions of years old in some areas of the world. In other areas, soils may be much younger. Geologic events, such as earthquakes, may disrupt the environment and cause soil formation to begin anew in the affected area.

HUMAN INFLUENCES: Farmers have cultivated and tended their soils for centuries, and farmed soils differ in many respects to those that have not been disturbed. Agricultural practices such as plowing and fertilizer use can change the topsoil (A horizon). In other areas, human practices have led to soil erosion that changes the soil horizons.

MASTER 3.8

DISRUPTING THE SOIL HORIZONS: THE DUST BOWL

NAME

DATE

THE DUST BOWL

During the late 1800s, an unusual amount of rain fell on the Great Plains. This led farmers and agricultural experts to overestimate how much rainfall the region could expect. This unusually wet period caused more people to settle in the area and begin farming. Starting at the beginning of the twentieth century, a large wave of European settlers came to the Great Plains to farm. As demand for wheat increased, farmers sought to increase their profits by cultivating more and more land. The United States government encouraged more farming in the Great Plains. Homesteaders in western Nebraska were granted 640 acres of land to farm. Farmers elsewhere in the Great Plains were granted 320 acres.

The Russian Revolution and World War I caused crop prices to rise. Farmers began to use mechanized farming to plow fields and harvest crops over an ever-expanding area. For example, in eastern New Mexico and northwestern Texas, the area of farmland doubled between 1900 and 1920. It tripled again between 1925 and 1930. Agricultural experts recommended that farmers use drought-resistant strains of wheat and practice so-called “deep plowing.” As the name suggests, in deep plowing the land is plowed to a greater depth than usual. It is designed to help the roots of grain crops use moisture in the topsoil more efficiently.

In the 1920s and early 1930s, most farmers plowed their fields right after the previous harvest. Deep plowing removed the native grasses that grew in the fields before the farmers began farming. This left the soil unprotected for months until the next planting. When the weather was wet, this method of farming worked well. However, in 1930 an extended drought began that caused crops to fail. The dry soil was plowed into fine particles that were easily blown away by the near-constant wind.

High winds carried massive amounts of topsoil eastward. Throughout the 1930s, the area including the Texas and Oklahoma panhandles plus parts of New Mexico, Colorado, and Kansas experienced a series of huge dust storms. Some of these storms blew dust all the way to Chicago and eventually Cleveland, Buffalo, Boston, and New York City. During the winter of 1934–1935, snow fell in New England that was red because of the dust it contained.

Such large dust storms could be deadly. People who were caught outside during a severe dust storm ran the risk of being suffocated by breathing in large amounts of dust. However, most of the damage to human health was caused by living in the presence of dust for extended periods. The dust found its way into the homes, clothing, and lungs of the people living in the affected areas. Many people suffered from what became known as “dust pneumonia.” Dust that settled in the lungs caused inflammation and produced symptoms such as fever, chest pain, difficulty breathing, and coughing. Young children and the elderly were especially vulnerable to dust pneumonia. It has been estimated that hundreds of people died from it.

Starting in 1930, the country began its decade-long economic struggle known as the Great Depression. This near economic collapse combined with the overproduction of wheat and severe drought hit farmers in the Great Plains like a perfect storm. Prices for wheat crashed. Many farmers could not pay their bills and had their mortgages foreclosed by the banks. Many people became homeless and left the area to look for work. Many farms were abandoned and the barren land was subject to erosion by high winds.

MASTER 3.9
FARMING PRACTICES

NAME

DATE

FARMING PRACTICES

The cruel lesson of the Dust Bowl is that topsoil is a precious resource that must be protected. Some of the challenges associated with maintaining healthy soils include nutrient depletion, erosion, and water runoff. Different farming practices have been developed to address these challenges.

For each farming practice described below, write down which challenge(s) the practice is designed to address. Be sure to include an explanation of your reasoning.

CROP ROTATION

Long ago, farmers discovered that growing the same crop in the same field year after year led to unhealthy plants and decreased crop growth. To address this problem, farmers use crop rotation. They plant crops with different nutrient requirements one after the other in the same field. The aim is to strike a balance so that not all of the crops are depleting any given nutrient in the soil.

STRIP FARMING

This practice involves dividing the field into parallel, long, narrow strips. The strips are organized so that they are perpendicular to the prevailing winds. Every other strip is planted with seed while the strips in between are left unplanted.

CONTOUR FARMING

Contour farming involves plowing a field along its elevation lines. This means that the ruts formed by the plow run perpendicular to the slopes. The furrows form level curves around the field. This keeps rain from running rapidly downhill, causing erosion.

MASTER 3.10

DUST STUDY

NAME

DATE

ARE SOIL HORIZONS STILL IN DANGER?

The amount of dust blown across the landscape has increased over the last 17 years in large swaths of the West, according to a study led by the University of Colorado, Boulder.

For the new study, the research team set out to determine if they could use calcium deposition as a proxy for dust measurements. Calcium can make its way into the atmosphere—before falling back to Earth along with precipitation—through a number of avenues, including coal-fired power plants, forest fires, ocean spray, and, key to this study, wind erosion of soils.

The amount of calcium dissolved in precipitation has long been measured by the National Atmospheric Deposition Program (NADP), which began recording the chemicals dissolved in precipitation in the late 1970s to better understand the phenomenon of acid rain.

Brahney and her colleagues reviewed calcium deposition data from 175 NADP sites across the United States between 1994 and 2010, and they found that calcium deposition had increased at 116 of them. The sites with the greatest increases were clustered in the Northwest, the Midwest, and the Intermountain West, with Colorado, Wyoming, and Utah seeing especially large increases.

Other areas of the world are more affected by dust movement than is the US. For example, satellite images have tracked large amounts of dust moving all the way from Africa to South America.

REFERENCES

Brahney, J, Ballantyne, A P., Sievers, C., and Neff,, J. C. (2013). Increasing Ca2+ deposition in the western US: The role of mineral aerosols. Aeolian Research, 10, 77–87.

Amount of dust blown across the West is increasing, says CU-Boulder study. (June 10, 2013). Retrieved from http://www.colorado.edu/news/releases/2013/06/10/amount-dust-blown-across-west-increasing-says-cu-boulder-study

LESSON 4

ELABORATE

PLANT NUTRIENT DEFICIENCIES

AT A GLANCE

OVERVIEW

Students discuss the definition of "fertilizer" and relate it to plant nutrition and the need to restore nutrient balance in the soil when farming. They discuss how people and plants can suffer from nutrient deficiencies. Students assume the roles of plant doctors and diagnose nutrient deficiencies in corn plants.

MAJOR CONCEPTS

- Plants, like people, require essential elements to be present in certain quantities in order to be healthy.
- Plants extract nutrients from the soil. In the case of crops, large portions of these nutrients are removed from the ecosystem when crops are harvested.
- Plants with nutrient deficiencies show specific symptoms.
- Fertilizers provide essential nutrients for plants.
- The soil is a "nutrient bank" that can hold a limited amount of nutrients. Fertilizers put more "money" in the bank by restoring nutrient balance to an agricultural soil.

OBJECTIVES

After completing this lesson, students will be able to

- recognize that plants, like people, require essential nutrients to be present in the right amounts in order to be healthy,
- use reference materials to diagnose plant nutrient deficiencies,
- define fertilizer as a type of "food" for plants, and
- appreciate that fertilizers are used to replenish nutrients in agricultural soils.

TEACHER BACKGROUND

Consult the following sections in Teacher Background: ***9.0 NUTRIENT DEFICIENCIES OF PLANTS, 10.0 NOURISHING PLANTS WITH FERTILIZERS***

IN ADVANCE

PHOTOCOPIES

ACTIVITY	MASTER	NUMBER OF COPIES
1	No Masters	--
2	Master 4.1, “Humanity Against Hunger” (print activity only)	1 to project (print activity only)
	Masters 4.2a–c, Corn Case Studies (print activity only)	1 per team of 2–3 students (print activity only)
	Master 4.3, Plant Doctor Evaluation Form (print activity; optional for web activity)	1 per team of 2–3 students (print activity; optional for web activity)
	Masters 4.4a–d, Plant Doctor Reference Manual (print activity only)	1 per team of 2–3 students (print activity only)
	Master 4.5, Crops, Soil, and Nutrients	1 per student and 1 to project
OPTIONAL EXTENSION	Master 4.6, Investigating Calcium Deficiencies	1 per student and 1 to project
	Master 4.7, Additional Experimental Results	1 to project
	Master 4.8, Calcium and Plant Growth	1 per student
	Master 4.9, EDTA Effects on Pea Plants (optional)	1 to project (optional)

MATERIALS

ACTIVITY	MATERIALS
1	No materials
2	Different-colored pens or pencils
OPTIONAL EXTENSION	**FOR THE TEACHER** Ethylenediaminetetraacetic acid, disodium salt, dehydrate (EDTA), Water, Sodium hydroxide (1 N), pH meter or pH test strips **FOR EACH TEAM OF 3 STUDENTS** 6 paper or plastic cups*, Dissecting needle (or other tool for poking holes in bottom of cups), Potting soil, Tap water, EDTA solution (5 mM and 25 mM; after seeds have germinated), 6 pea seeds, Permanent marker pen, Ruler (after seeds have germinated), Stick or skewer (optional; may be helpful after plants have germinated to hold them upright)

*The size of the cup is not critical. Small paper cups (3-oz. bathroom size) are suitable for this activity. The size is adequate for growing the peas for the short duration of the investigation and requires less space and soil than larger cups.

PREPARATION.

ACTIVITY 1: WHEN A PLANT NEEDS "FOOD"

No preparations are needed.

ACTIVITY 2: HUMANITY AGAINST HUNGER

Decide whether you will use the web-based or print-based version of this activity.

If using the web-based activity,

- reserve computers for students to use and
- preview the activity so that you are familiar with the content on and navigation of the website.

If using the print-based version of this activity,

- use scissors to cut *Master 4.2a–c, Corn Case Studies* along the dotted lines separating Primary Information from Secondary Information in each case study.

TEACHER NOTE

The images used as part of *Activity 2* are difficult to interpret in black & white. If making color photocopies for teams is prohibitive, you can post 1 or 2 copies of the color photocopies around the room for teams to view when they need them or you can project color images from the original masters.

EXTENSION ACTIVITY

There are several ways of carrying out this optional extension activity. The procedure calls for students to plant pea seeds and then do the hands-on investigation. This will take class time over a couple of weeks. Another option is for you to plant the pea seeds and then, when the plants are a few days old, have the students take over to do the experimental treatment of the plants. Both of these options present good hands-on experiences for students and emphasize several practices of science. If class time is limited, you could have students analyze the photographs of the pea plants on *Master 4.9, EDTA Effects on Pea Plants,* rather than conducting the activity in a hands-on manner.

This activity uses ethylenediaminetetraacetic acid (EDTA) to mimic a calcium deficiency for plant growth. EDTA chelates divalent cations such as Ca++ thereby making calcium unavailable to the growing plants.

EDTA can be purchased from a scientific supply company. You should purchase ethylenediaminetetraacetic acid, disodium salt, dehydrate ($C_{10}H_{14}N_2Na_2O_8 \cdot 2H_2O$) that has a molecular weight of 372.24. Because this chemical is used in molecular biology experiments, you may already have it in your supplies.

If you have 10 teams of students, 1 L each of 25 and 5 mM EDTA solution should be adequate. If you have more or fewer teams, you can adjust accordingly.

PREPARE 1 L OF AT 25 MM EDTA SOLUTION AS FOLLOWS:

- Add approximately 800 mL of tap water to a large beaker.
- Add 1 N NaOH solution to raise the pH of the water to 8.
- Slowly add 9.3 g of EDTA to the water in increments, waiting until it dissolves before adding more.
- If the EDTA does not go into solution, check the pH and add more NaOH if necessary (pH needs to be basic).
- After all of the EDTA is in solution, check the pH again. The pH does not need to be exact but should be between 7 and 8.
- Add water so that the final volume of solution is 1,000 mL (1 L).

PREPARE 1 L OF 5 MM EDTA SOLUTION AS FOLLOWS:

- Pour 200 mL of 25 mm EDTA solution (prepared above) into a separate graduated cylinder.
- Add water to a final volume of 1 L (1,000 mL).

MASTER 4.6, INVESTIGATING CALCIUM DEFICIENCIES, calls for student teams to begin the activity by planting pea seeds. To conserve class time, you could plant seeds ahead of time (about 5–7 days before beginning EDTA treatment). The seedlings should be approximately 5–7 cm tall when students begin the EDTA treatment. You can continue with the rest of the module's lessons while this investigation progresses (an additional 5–7 days should be adequate to see the effects of EDTA). Remember to plant more seeds than needed to account for any that do not germinate, and also to allow teams to select plants for treatment and control that are approximately the same size.

PROCEDURE

ACTIVITY 1: WHEN A PLANT NEEDS "FOOD"

1. BEGIN THE ACTIVITY BY ASKING STUDENTS HOW PLANTS GET THE NUTRIENTS THEY NEED FOR GROWTH.

If necessary, remind students that in the previous lessons they explored how plants obtained nutrients from the soil through the roots and transported them through the xylem tissue to the rest of the plant. Students may also mention photosynthesis. If necessary, remind students that in the case of photosynthesis, "food" refers both to the essential element carbon, which accounts for about half the weight of the plant, and to the light energy that is trapped and used to power plant metabolism. There are two important points that need to come out of this discussion. First, as discussed in Lesson 1, plants require essential elements (building blocks) that are not supplied by photosynthesis. Second, students should recall from Lessons 2 and 3 that essential elements are found in soil and absorbed by the plant through its root system.

2. REMIND STUDENTS THAT PLANTS AND PEOPLE ARE BOTH MADE OF CELLS AND THOSE CELLS NEED NUTRIENTS TO BE HEALTHY. ASK, "WHAT HAPPENS TO US IF WE DON'T GET ENOUGH OF AN ESSENTIAL NUTRIENT?"

Student responses will vary. Students will recognize that when we have a nutrient deficiency, we get sick.

3. CONTINUE THE DISCUSSION BY ASKING STUDENTS TO PREDICT WHAT MIGHT HAPPEN TO PLANTS IF THEY DO NOT GET THE NUTRIENTS THEY NEED. ASK STUDENTS TO WORK INDEPENDENTLY TO WRITE THEIR IDEAS IN THEIR NOTEBOOK OR ON PAPER. AFTER STUDENTS HAVE WRITTEN THEIR OWN IDEAS, ASK THEM TO SHARE THEIR IDEAS WITH THE CLASS. RECORD ANSWERS ON THE BOARD OR CHART PAPER.

Keep this discussion moving and short. Accept all reasonable answers. Use probing questions to assess whether students think the plant's response would be the same for all missing nutrients or whether there might be differences. Students will be investigating this question in the next activity and can revisit this list later.

ACTIVITY 2: HUMANITY AGAINST HUNGER WEB VERSION

TEACHER NOTE

Critical thinking is important to this activity. Not all of the information provided to students is helpful in identifying nutrient deficiencies. For example, the presence or absence of weeds in the fields is not a useful piece of information.

The Web version of this activity can be accessed at **https://www.nutrientsforlife.org/games/humanity/**. One part of this activity, "Your Assignment for Humanity Against Hunger," has an audio narration. If headphones are available, students can work at their own pace. In the event that neither headphones nor speakers are available for student computers, consider projecting the activity and showing the beginning of this part of the activity.

The web version allows students to type their initial observations into an online page that is identical to *Master 4.3.* However, the web program will not save this information. If you would like students to complete *Master 4.3* as an assignment to turn in for a grade, you will need to provide them with a hardcopy of *Master 4.3* and ask that they record their answers on it while conducting the simulation.

If the students' computers are linked to a printer, then they can print an Award of Merit at the conclusion of the activity, which indicates that they completed all of the required steps correctly.

1. FOR THIS ACTIVITY, DIVIDE THE CLASS INTO GROUPS OF 3 STUDENTS. EACH GROUP WILL EVALUATE 3 CASE STUDIES.

If sufficient computers are available, allow each student to work alone.

2. INSTRUCT THE STUDENTS TO ACCESS THE "HUMANITY AGAINST HUNGER" ACTIVITY AT HTTPS://WWW.NUTRIENTSFORLIFE.ORG/GAMES/HUMANITY/.

3. **AT THE HOME PAGE, INSTRUCT THE STUDENTS TO BEGIN BY CLICKING ON "THE FOOD CRISIS IN AFRICA." ASK VOLUNTEERS TO READ PARTS OF THE ARTICLE.**

   This section serves as an introduction to agricultural issues in Africa and sets the stage for the next part of the activity during which students will investigate how nutrient deficiencies affect plant growth.

4. **PAUSE FOR A MOMENT AFTER READING FOR A BRAINSTORMING SESSION WITH THE STUDENTS. ASK, "CAN YOU THINK OF WAYS TO HELP SOLVE AFRICA'S FOOD SHORTAGE PROBLEM?"**

5. **INSTRUCT STUDENTS TO RETURN TO THE HOME PAGE AND SELECT "YOUR ASSIGNMENT FOR HUMANITY AGAINST HUNGER." AT THIS POINT, THE STUDENTS WILL COMPLETE THE WEB ACTIVITY ON THEIR OWN, FOLLOWING THE DIRECTIONS GIVEN ON THE WEBSITE.**

   If you wish, project the first part of "Your Assignment for Humanity Against Hunger" up through the point where the narration gives instructions about what students will do during the activity.

6. **WHEN STUDENTS HAVE COMPLETED THE ASSIGNMENT, ENSURE THAT THEY PRINT OUT THEIR EVALUATION REPORTS TO TURN IN TO YOU.**

7. **AFTER THE ASSIGNMENT PORTION OF THE ACTIVITY IS COMPLETED, ENCOURAGE STUDENTS TO EXPLORE THE "ADDITIONAL RESOURCES/LINKS" SECTION.**

ACTIVITY 2: HUMANITY AGAINST HUNGER PRINT VERSION

This activity enables students to investigate how deficiencies in key nutrients result in observable changes in plant health.

1. **PROJECT *MASTER 4.1, HUMANITY AGAINST HUNGER* AND ASK FOR A VOLUNTEER TO READ IT ALOUD.**

2. **EXPLAIN THAT STUDENTS ARE GOING TO REVIEW INFORMATION SENT IN BY LOCAL FARMERS WHO SUSPECT THAT THEIR CROPS SUFFER FROM A NUTRIENT DEFICIENCY. STUDENTS WILL WORK TO DIAGNOSE THE SPECIFIC NUTRIENT DEFICIENCY AFFECTING EACH CROP PLANT. STUDENTS WILL REFER TO PHOTOGRAPHS AND BRIEF DESCRIPTIONS OF FOUR DIFFERENT NUTRIENT DEFICIENCIES TO HELP THEM MAKE THEIR DIAGNOSES.**

3. **ARRANGE THE CLASS INTO TEAMS OF 2–3 STUDENTS. PASS OUT TO EACH TEAM 1 COPY OF PRIMARY INFORMATION FOR EACH CASE STUDY THAT THEY ARE TO EVALUATE. ASK STUDENTS TO READ PRIMARY INFORMATION FOR THEIR CASE STUDIES.**

   Each team receives the top portion of each page of *Master 4.2a–c, Corn Case Studies*. Each student in the team will be responsible for 1 of the case studies.

4. **PASS OUT TO EACH TEAM 1 COPY OF *MASTER 4.3, PLANT DOCTOR EVALUATION FORM*. INSTRUCT STUDENTS TO WRITE DOWN IN THE APPROPRIATE SPACE WHAT THEY CONSIDER THE IMPORTANT INFORMATION RELATED TO THEIR CASE STUDY.**

   Encourage students to discuss the information with their teammates and to work together to construct their answers.

5. **PASS OUT TO EACH TEAM 1 COPY OF *MASTER 4.4A–D, PLANT DOCTOR REFERENCE MANUAL*. INSTRUCT STUDENTS TO MAKE A PRELIMINARY DIAGNOSIS FOR THEIR CASE STUDIES BY USING THE INFORMATION CONTAINED IN THE REFERENCE MANUAL. HAVE STUDENTS ENTER THEIR INITIAL DIAGNOSES IN THE APPROPRIATE SPACES ON THEIR EVALUATION FORMS.**

   Remember, each student in the team is responsible for 1 of the 3 case studies. Students should list symptoms of the nutrient deficiency that matches the important information of their particular case study.

6. **ASK IF TEAMS ARE CERTAIN OF THEIR DIAGNOSES.**

   Some students may indicate that they have correctly diagnosed their case studies. Ask them what additional information would help them confirm or refute their diagnoses.

7. **EXPLAIN TO THE CLASS THAT SOME ADDITIONAL INFORMATION ABOUT THEIR CASE STUDIES HAS BECOME KNOWN. GIVE EACH TEAM THE BOTTOM PORTION OF EACH PAGE OF *MASTER 4.2A–C, CORN CASE STUDIES*, WHICH CONTAINS SECONDARY INFORMATION.**

8. **ASK TEAMS TO READ THE SECONDARY INFORMATION FOR THEIR CASE STUDIES AND USE THIS INFORMATION TO REEVALUATE THEIR DIAGNOSES. THEY SHOULD INDICATE ON THE EVALUATION FORM WHETHER THEY WANT TO CONFIRM THEIR INITIAL DIAGNOSES.**

9. **IF TEAMS HAVE CHANGED THE DIAGNOSIS, THEY SHOULD ENTER THE NEW DIAGNOSIS TOGETHER WITH THE REASON FOR THE CHANGE IN THE APPROPRIATE SPACES ON THE EVALUATION FORM.**

   Ask students to use a different-color pen or pencil when they make changes or additions to their diagnosis or explanation. By doing this, both you and the students will be able to monitor changes in their thinking as they get more information.

10. **RECONVENE THE CLASS AND DISCUSS EACH CASE STUDY IN TURN, ASKING TEAMS HOW THEY ARRIVED AT THEIR DIAGNOSES.**

    Write the teams' diagnoses on the board or chart paper.

    Answers to the case studies:

    CORN CASE STUDY 1

FROM PRIMARY INFORMATION	
IMPORTANT SYMPTOMS	Stunted growth, yellow leaves, sandy soil
INITIAL DIAGNOSIS	These symptoms are consistent with either nitrogen or potassium deficiency. The yellowed leaves seem to have the V-shaped pattern associated with nitrogen deficiency.
MATCHING SYMPTOMS	Stunted growth, yellow leaves, sandy soil
AFTER READING SECONDARY INFORMATION	
IS YOUR INITIAL DIAGNOSIS CONFIRMED?	Answers will vary.
IF NOT, WHAT IS YOUR NEW DIAGNOSIS?	Answers will vary.
IF NOT, WHAT CAUSED YOU TO CHANGE YOUR DIAGNOSIS?	The second photograph shows a leaf with the V-shaped pattern of yellowing that is consistent with nitrogen deficiency. The fact that the fields have been exposed to heavy rains further supports the nitrogen-deficiency diagnosis.

CORN CASE STUDY 2

FROM PRIMARY INFORMATION	
IMPORTANT SYMPTOMS	Stunted growth, yellow leaves, sandy soil
INITIAL DIAGNOSIS	These symptoms are consistent with either nitrogen or potassium deficiency.
MATCHING SYMPTOMS	Stunted growth, yellow leaves, sandy soil
AFTER READING SECONDARY INFORMATION	
IS YOUR INITIAL DIAGNOSIS CONFIRMED?	Answers will vary.
IF NOT, WHAT IS YOUR NEW DIAGNOSIS?	Answers will vary.
IF NOT, WHAT CAUSED YOU TO CHANGE YOUR DIAGNOSIS?	The second photograph shows a yellowed leaf with dried edges that are consistent with potassium deficiency. The fact that the plants have weak stems further supports the potassium-deficiency diagnosis.

CORN CASE STUDY 3

FROM PRIMARY INFORMATION	
IMPORTANT SYMPTOMS	Stunted growth, compacted (dense) soil; purple color on some leaves
INITIAL DIAGNOSIS	The symptoms are consistent with phosphorus deficiency.
MATCHING SYMPTOMS	Stunted growth, compacted (dense) soil; purple color on some leaves
AFTER READING SECONDARY INFORMATION	
IS YOUR INITIAL DIAGNOSIS CONFIRMED?	Answers will vary.
IF NOT, WHAT IS YOUR NEW DIAGNOSIS?	Answers will vary.
IF NOT, WHAT CAUSED YOU TO CHANGE YOUR DIAGNOSIS?	Plants mature later than normal. The second photograph of a leaf shows distinct purple coloration, which is characteristic of phosphorus deficiency.

11. PROJECT *MASTER 4.5, CROPS, SOIL, AND NUTRIENTS*, AND PASS OUT 1 COPY TO EACH STUDENT. BEGIN BY ASKING VOLUNTEERS TO READ ALOUD THE INFORMATION AT THE TOP OF THE PAGE.

12. ALLOW TIME FOR STUDENTS TO WORK IN THEIR TEAMS OF 3 TO ANALYZE THE GRAPH AND ANSWER THE QUESTIONS ON THE HANDOUT.

Encourage students to discuss their ideas with their team members.

Depending on your students, it may be helpful to look at the graph on *Master 4.5* with the whole class before they begin answering the questions in their teams. The y-axis on the graph indicates the change in amount of a nutrient; it does not indicate the total amount of the nutrient in the soil. Zero on the graph indicates the starting amount of nutrients in the soil before crops have grown. This does not mean that the soil did not contain any nutrients. The direction from zero indicates whether there is more of a given nutrient in the soil after the crop has grown or whether there is less. For each nutrient and each crop represented on this graph, the level of nutrients in the soil is lower after the crops grow as indicated by bars that go down from the starting level.

13. HOLD A BRIEF CLASS DISCUSSION TO REVIEW ANSWERS TO THE QUESTIONS ON MASTER 4.5 AND TO CHECK THEIR UNDERSTANDING.

For this activity, the crop yields were based on an average yield for each crop grown in this country. However, yields will vary depending on a variety of factors including soil quality, water availability, and temperature, among others.

Some students may have difficulty envisioning what a bushel is. If they are interested, you can tell them that a bushel of corn is approximately 56 pounds. A bushel of either soybeans or wheat is approximately 60 pounds.

Sample responses to questions on *Master 4.5, Crops, Soil, and Nutrients:*

1. WHAT HAPPENED TO THE LEVEL OF NUTRIENTS IN THE SOIL AFTER GROWING THE CROPS?

In each case, nutrients were removed from the soil after the crops grew. The amount of each nutrient removed from the soil depended on the particular crop.

2. HOW WOULD THE LEVELS OF EACH MAJOR NUTRIENT BE CHANGED IF THE FARMER GREW 100 ACRES OF THE CROP? 1,000 ACRES OF THE CROP?

The goal of this question is to help students think about scale. They simply need to multiply the amount of each nutrient by 100 or 1,000 to answer these questions. If you wish, students could convert kilograms to pounds if they do not have a good idea of the amount. (One kilogram = 2.2 pounds.)

3. WHAT MIGHT HAPPEN TO THE CROPS IF THE FARMERS PLANT THEIR CROPS IN THIS SOIL AGAIN IN FUTURE YEARS?

In the scenario, the farmers started with nutrient-rich soil, which was depleted of nutrients when the crops grew. When they planted crops in the soil the next year, it is possible that the soil would not have enough of the nutrients remaining to meet the plants' needs. Even if the soil contained sufficient amounts of each nutrient the second year, over time, it is likely that the soil would become depleted and the plants would show signs of nutrient deficiencies.

4. WHAT ACTIONS MIGHT THE FARMERS NEED TO TAKE IF THEY WANT TO CONTINUE GETTING GOOD HARVESTS FROM THEIR CROPS IN THE FUTURE?

Students are likely to mention adding fertilizer to the soil to replace the nutrients that have been removed from the soil. Some students may specify commercial or organic fertilizers. Explain that they will explore the advantages and disadvantages of these fertilizers in the next lesson.

TEACHER NOTE

The data for the graph on *Master 4.5* were obtained using the Nutrient Crop Tool on the USDA website **(http://plants.usda.gov/npk/main)**. On this site, you can investigate nutrient needs for a wide variety of plants and you can adjust for number of acres and crop yield.

EXTENSION ACTIVITY: INVESTIGATING CALCIUM DEFICIENCY (OPTIONAL)

1. **PROJECT *MASTER 1.3, ESSENTIAL ELEMENTS FOR PLANTS* AND POINT OUT THAT CALCIUM IS CONSIDERED AN ESSENTIAL NUTRIENT FOR PLANTS. ASK STUDENTS TO PREDICT (IN GENERAL TERMS) WHAT THEY THINK MIGHT HAPPEN IF A PLANT DOES NOT HAVE ITS NEED FOR CALCIUM MET.**

   Based on what they learned in *Activity 2*, students should suggest that there would be some physical manifestation of calcium deficiency that could be observed as a change in color, size, or overall health of the plant.

2. **EXPLAIN TO STUDENTS THAT THEY ARE GOING TO INVESTIGATE HOW CALCIUM DEFICIENCIES AFFECT PLANT GROWTH. THEY ARE GOING TO USE A CHEMICAL CALLED EDTA (ETHYLENEDIAMINETETRAACETIC ACID) TO CREATE A CALCIUM-DEFICIENT ENVIRONMENT FOR PLANTS EXPERIMENTALLY. INFORM STUDENTS THAT EDTA IS A CALCIUM CHELATOR—IN SIMPLE TERMS, EDTA BINDS THE CALCIUM IN A WAY THAT MAKES IT UNAVAILABLE TO THE PLANT.**

3. **WRITE ON THE BOARD THE QUESTION, "WHAT EFFECTS DOES CALCIUM DEFICIENCY HAVE ON THE GROWTH OF PEA PLANTS?" INFORM STUDENTS THAT THEY WILL ANSWER THIS QUESTION EXPERIMENTALLY.**

   Having this question visible where students can refer to it will help keep the testable question in students' minds and help focus their attention.

4. **GIVE EACH STUDENT 1 COPY OF *MASTER 4.6, INVESTIGATING CALCIUM DEFICIENCIES*. ALSO, PROJECT THE FIRST PAGE OF THE MASTER. REVIEW THE STEPS IN THE PROCEDURE WITH STUDENTS AND GUIDE A DISCUSSION USING QUESTIONS SUCH AS THE FOLLOWING TO MAKE SURE THEY UNDERSTAND THE EXPERIMENTAL DESIGN.**

- **WHY WOULD WE PLANT SOME PEAS THAT WOULD BE WATERED USING TAP WATER RATHER THAN WATER CONTAINING EDTA?**

  The plants watered with tap water serve as a control.

- **WHY WOULD WE WAIT UNTIL THE PEAS ARE ABOUT 5-7 CM TALL BEFORE STARTING THE TREATMENT WITH THE EDTA SOLUTION?**

  If you began watering with EDTA at the beginning of the experiment, you would be investigating what effect calcium has on germination, which could be different than the effects on growth and appearance.

- **WHAT TYPES OF EVIDENCE WILL WE BE COLLECTING?**

  Students will be collecting both empirical data (height of plants) and observational data (color, overall appearance of plants).

- **WHY WOULD WE NEED TO KEEP THIS EXPERIMENT GOING OVER SEVERAL DAYS?**

  The effects will not be seen immediately. Growth of plants occurs slowly over time, so any effect on growth will most likely take some time to become apparent.

5. **ASK STUDENTS TO WORK IN TEAMS OF 3 FOR THIS ACTIVITY. ALLOW TIME FOR TEAMS TO PLANT THE PEA SEEDS THAT WILL BEGIN THE EXPERIMENT.**

6. **TEAMS WILL NEED TO MAKE SURE THAT THE CUPS HOLDING THE SEEDS ARE WATERED PERIODICALLY SO THEY DO NOT DRY OUT. IT WILL TAKE APPROXIMATELY 5-7 DAYS AFTER PLANTING UNTIL THE SEEDLINGS ARE 5-7 CM TALL AND READY FOR THE EXPERIMENTAL TREATMENTS TO BEGIN.**

7. ONCE THE TREATMENTS BEGIN, TEAMS SHOULD SEE RESULTS IN ABOUT 1 WEEK.

If the pea plants start getting tall and falling over, you may want to use a skewer or stick to keep each plant upright and not falling down and getting tangled with other plants.

If appropriate, encourage students to take photographs of the plants as an additional way to record data.

8. AT THE CONCLUSION OF THE EXPERIMENT, ASK STUDENTS TO RECORD FINAL OBSERVATIONS ON THEIR DATA CHART. NEXT, ASK STUDENTS TO RECORD THEIR INFORMATION ON A CLASS CHART SIMILAR TO THE FOLLOWING. PROVIDE A PLACE WHERE STUDENTS CAN RECORD OBSERVATIONS TO SHARE WITH THE CLASS.

5 mM EDTA		25 mM EDTA		TAP WATER	
STARTING HEIGHT (CM)	FINAL HEIGHT (CM)	STARTING HEIGHT (CM)	FINAL HEIGHT (CM)	STARTING HEIGHT (CM)	FINAL HEIGHT (CM)

9. AFTER ALL TEAMS HAVE ADDED THEIR DATA TO THE CLASS DATA CHART, INSTRUCT THEM TO CALCULATE AVERAGE VALUES FOR EACH COLUMN.

10. CONDUCT A CLASS DISCUSSION THAT SUMMARIZES THE EFFECTS OF CALCIUM DEPLETION THAT WERE OBSERVED AS PART OF THE INVESTIGATION.

The data that they collected about plant height will likely reveal that plants watered with EDTA did not grow as tall as plants watered with tap water and that the plants watered with 25 mM EDTA were more severely affected than plants watered with 5 mM EDTA. In addition, students should have observations about the leaves or other parts of the plants that they can share.

The following photographs and data show results of some of the experiments conducted during development of this curriculum. They can be used as representative data.

FIRST EXPERIMENT:

BEFORE TREATMENT

AFTER TREATMENT

The second experiment seen below included treatment with 5 mM EDTA and liquid fertilizer (Miracle Gro mixed according to package directions). The fertilizer treatment is not included in the current procedure.

SECOND EXPERIMENT:

BEFORE TREATMENT

AFTER TREATMENT

The following data provide another way to look at the effects of EDTA, and liquid fertilizer in this experiment, on the growth of pea plants. If students collect data from their own experiments, they can compare this data with their own. Alternatively, you can share this data with them during a class discussion.

EFFECT OF EDTA AND FERTILIZER ON PEA GROWTH

	TREATMENT			
	TAP WATER	5 mM EDTA	25 mM EDTA	LIQUID FERTILIZER (MIRACLE GRO)
HEIGHT (CM)	25.4	27.9	15.2	30.5
	35.6	25.4	16.5	40.6
	24.1	22.9	17.8	30.5
	24.1	17.8	20.3	30.5
AVERAGE	**27.4**	**23.5**	**17.5**	**33.0**

11. PROJECT *MASTER 4.7, ADDITIONAL EXPERIMENTAL RESULTS*. EXPLAIN THAT THIS HANDOUT SHOWS PHOTOGRAPHS OF PLANTS THAT WERE WATERED WITH EITHER TAP WATER OR 25 MM EDTA. ASK STUDENTS TO MAKE OBSERVATIONS FROM THE PHOTOGRAPHS. RECORD OBSERVATIONS ON THE BOARD OR CHART PAPER.

Students will notice that both plants looked healthy and were bushy and green before the experiment started. At the conclusion of the experiment, students should observe that the control plant (tap water) remained healthy, green, and bushy. The plant treated with 25 mM EDTA seems to have many dead leaves near the base, fewer leaves, and the remaining leaves are less green and there may be some dead or dying areas around the edge of the leaves.

12. PASS OUT TO EACH STUDENT 1 COPY OF *MASTER 4.8, CALCIUM AND PLANT GROWTH*. EXPLAIN THAT THIS HANDOUT PROVIDES ADDITIONAL INFORMATION ABOUT THE ROLE OF CALCIUM IN PLANTS AND THE EFFECTS OF CALCIUM DEPLETION. ASK STUDENTS TO REMEMBER THEIR EXPERIMENTAL RESULTS AS THEY READ THIS NEW INFORMATION.

This reading provides a brief overview of some of the effects of calcium depletion. Many of the effects of calcium deficiency are observed on the most actively growing parts of the plant.

The plant shown in *Master 4.7* (after treatment with 25 mM EDTA) shows some of these traits. For example, you can see that there are many dead leaves around the base of the plant. These were new leaves that died before reaching maturity. In the older leaves, there were some spots and changes, but those took much longer to appear in the mature tissue compared with new tissues. Although not shown in the photographs, there were distinct changes in the root system of the EDTA-treated plant compared with the control plant. The roots were much less developed. In addition, when both plants were watered, the EDTA-treated plant did not take up as much water as the control plant.

OPTIONAL HOMEWORK ASSIGNMENT

Instruct students to work with a parent/guardian for this activity. They will obtain a soil sample from near where they live. They can use the phone book or the web to find an address for the local county cooperative extension office or state university that conducts soil testing. Students should send in their soil sample for analysis to assess its quality and to see if any essential nutrients are lacking. You can collect the soil analyses obtained by different students and see if there are any differences according to location.

Note that some states and universities will assess a fee for soil testing, which is typically no more than $10. Private organizations will charge more. Factoring in the time for the organization to conduct the test and prepare a report, this assignment is better used as a long-term project or science fair project.

LESSON 4 ORGANIZER

ACTIVITY 1: WHEN A PLANT NEEDS "FOOD" **WHAT THE TEACHER DOES**	**PROCEDURE REFERENCE**
Begin the activity by asking students how plants get the nutrients they need for growth.	Page 122 Step 1
Remind students that plants and people are both made of cells and those cells need nutrients to be healthy. Ask, "What happens to us if we don't get enough of an essential nutrient?"	Page 122 Step 2
Continue the discussion by asking students to predict what might happen to plants if they do not get the nutrients they need. Ask students to work independently first and then ask them to share their ideas with the class. Record answers on the board or chart paper.	Page 122 Step 3

ACTIVITY 2: HUMANITY AGAINST HUNGER (WEB VERSION) **WHAT THE TEACHER DOES**	**PROCEDURE REFERENCE**
For this activity, divide the class into groups of 3 students. Each group will evaluate 3 case studies.	Page 122 Step 1
Instruct the students to access the "Humanity Against Hunger" activity at **https://www.nutrientsforlife.org/games/humanity/**.	Page 122 Step 2
At the home page, instruct the students to begin by clicking on "The Food Crisis in Africa." Ask volunteers to read parts of the article.	Page123 Step 3
Ask students if they can think of ways to solve Africa's food shortage problem.	Page 123 Step 4
Instruct students to return to the home page and select "Your Assignment for Humanity Against Hunger." At this point, the students will complete the web activity on their own following the directions from the website.	Page 123 Step 5
When the students have completed the assignment, ensure that they print out their evaluation reports to turn in to you.	Page 123 Step 6
Encourage students to explore the "Additional Resources/Links" section.	Page 123 Step 7

LESSON 4 ORGANIZER CONTINUED

ACTIVITY 4: HUMANITY AGAINST HUNGER (PRINT VERSION) **WHAT THE TEACHER DOES**	**PROCEDURE REFERENCE**
Project *Master 4.1, Humanity Against Hunger* and ask a volunteer to read it aloud.	Page 123 Step 1
Explain that students are going to review information sent in by local farmers who suspect that their crops suffer from a nutrient deficiency. Students will work to diagnose the specific nutrient deficiency affecting each crop plant. Students will refer to photographs and brief descriptions of four different nutrient deficiencies to help them make their diagnoses.	Page 123 Step 2
Arrange the class into teams of 2–3 students. Pass out to each team 1 copy of Primary Information for each case study that they are to evaluate. Ask students to read Primary Information for their case studies.	Page 123 Step 3
Pass out to each team 1 copy of *Master 4.3, Plant Doctor Evaluation Form*. Instruct students to write down in the appropriate space what they consider the important information related to their case study.	Page 123 Step 4
Pass out to each team 1 copy of *Master 4.4a–d. Plant Doctor Reference Manual*. Instruct students to make a preliminary diagnosis for their case studies by using the information contained in the reference manual. Have students enter their initial diagnoses in the appropriate spaces on their evaluation forms.	Page 123 Step 5
Ask if teams are certain of their diagnoses.	Page 123 Step 6
Explain to the class that some additional information about their case studies has become known. Give each team the bottom portion of each page of *Master 4.2a–c, Corn Case Studies*, which contains Secondary Information.	Page 124 Step 7
Ask teams to read the Secondary Information and use this information to reevaluate their diagnoses. They should indicate on the evaluation form whether they want to confirm their initial diagnoses.	Page 124 Step 8
If teams have changed the diagnosis, they should enter the new diagnosis together with the reason for the change in the appropriate spaces on the evaluation form.	Page 124 Step 9
Reconvene the class and discuss each case study in turn, asking teams how they arrived at their diagnoses.	Page 124 Step 10
Project *Master 4.5, Crops, Soil, and Nutrients*, and pass out 1 copy to each student. Ask volunteers to read aloud the information at the top of the page.	Page 125 Step 11
Allow time for students to work in their teams of 3 to analyze the graph and answer the questions on the handout.	Page 126 Step 12
Hold a brief class discussion to review answers to the questions on Master 4.5 and to check students' understanding.	Page 126 Step 13

EXTENSION ACTIVITY (OPTIONAL) **WHAT THE TEACHER DOES**	**PROCEDURE REFERENCE**
Display *Master 1.3, Essential Plant Nutrients*, and point out that calcium is considered an essential nutrient for plants. Ask students to predict (in general terms) what might happen if a plant does not have its need for calcium met.	Page 127 Step 1
Explain to students that they are going to investigate how calcium deficiencies may affect plant growth. They are going to use a chemical called EDTA to create a calcium-deficient environment for plants experimentally. Inform students that EDTA binds the calcium in a way that makes it unavailable to the plant.	Page 127 Step 2
Write on the board the question, "What effects does calcium deficiency have on the growth of pea plants?" Inform students that they will answer this question experimentally.	Page 127 Step 3
Give each student 1 copy of *Master 4.6, Investigating Calcium Deficiencies*. Also, project page 1 of the master. Review the steps in the procedure with students and use questions such as the following to make sure they understand the experimental design. • Why would we plant some peas that would be watered using tap water rather than EDTA? • Why would we wait until the peas are about 5-7 cm tall before starting the treatment with EDTA? • What types of evidence will we be collecting? • Why would we need to keep this experiment going over several days?	Page 127 Step 4
Ask students to work in teams of 3 for this activity. Allow time for teams to plant the pea seeds that will begin the experiment.	Page 127 Step 5
Teams will need to make sure that the cups holding the seeds are watered periodically so they do not dry out. Once the treatments begin, teams should see results in about 1 week.	Pages 127 - 128 Steps 6-7
Ask students to record final observations on their data chart. Also, ask them to record information on a class chart. Provide a place where students can record observations to share with the class.	Page 128 Step 8
After all teams have added their data to the class data chart, instruct them to calculate averages for each column.	Page 128 Step 9
Through a class discussion, summarize the effects of calcium depletion that were revealed as part of their investigation.	Page 128 Step 10
Project *Master 4.7, Additional Experimental Results*. Explain that this master shows photographs of plants that were watered with either tap water or 25 mM EDTA. Ask students to make observations from the photographs. Record observations on the board or chart paper.	Page 129 Step 11
Pass out to each student 1 copy of *Master 4.8, Calcium and Plant Growth*. Explain that this handout provides additional information about the role of calcium in plants and the effects of calcium depletion. Ask students to remember their experimental results as they read.	Page 130 Step 12

MASTER 4.1
HUMANITY AGAINST HUNGER

NAME

DATE

You have been selected to join **HUMANITY AGAINST HUNGER,** an international effort dedicated to fighting hunger around the world. Globally, it is estimated that 842 million people—12 percent of the global population—were unable to meet their dietary energy requirements in 2011–13. Thus, around one in eight people in the world are likely to have suffered from chronic hunger, not having enough food for an active and healthy life. The vast majority of hungry people—827 million—live in developing regions.

Your first assignment is to travel to sub-Saharan Africa and help farmers from a small village. Africa remains the region with the highest prevalence of undernourishment, with more than one in five people estimated to be undernourished.

Although some areas of Africa have rich soil and support plant growth, other areas do not. Growing food for the increasing human population is an important challenge. African farmers have traditionally cleared land, grown and harvested their crops, and then moved on to clear more land for the next planting. After harvesting their crops, the farmers left the land alone so that it would eventually regain its fertility.

However, increasing population growth has limited this traditional farming practice which worked so well in the past. Today, farmers often grow crop after crop on the same land, thereby “mining,” or depleting, the soil of its nutrients. Most of them realize that they need to repair the soil, but often they lack the knowledge or the money needed to do so.

Your task is to help the local farmers diagnose nutrient deficiencies among their crops. Then you will make recommendations on how to restore nutrient balance to the soil and improve crop yields.

MASTER 4.2a

CORN CASE STUDY 1

NAME

DATE

PRIMARY INFORMATION

The farmer reports that his corn grows in sandy soil. The plants are stunted and have yellow leaves. They are free of pests, and the fields are free of weeds. The farmer provided the following photograph.

SECONDARY INFORMATION

The farmer sent this additional photograph of an affected leaf. He reports that his fields have been exposed to heavy rains and higher than normal temperatures.

MASTER 4.2b

CORN CASE STUDY 2

NAME

DATE

PRIMARY INFORMATION

The farmer reports that the plants are stunted. Her corn grows in sandy soil. Some weeds are present in the fields. She provided the following photograph, which shows some yellowing of leaves.

SECONDARY INFORMATION

The farmer sent this additional photograph of a leaf from an affected plant. She also reports that some of her plants have stems that are not strong enough to support the ears of corn.

MASTER 4.2c

CORN CASE STUDY 3

NAME

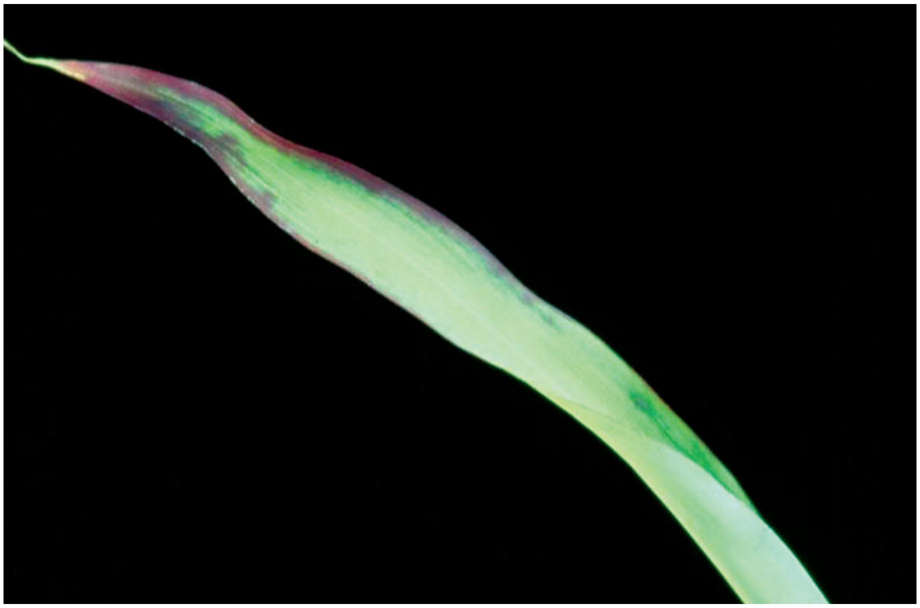
DATE

PRIMARY INFORMATION

The farmer reports that her plants are stunted. Her fields are composed of compacted (dense) soil and are free of weeds. She provided the following photograph of two affected plants.

SECONDARY INFORMATION

The farmer sent this additional photograph of a leaf from an affected plant. The discoloration seen near the tip of the leaf is purplish. She reports that her corn is maturing later than it should and that she is beginning to see some weeds growing in her fields.



MASTER 4.3
PLANT DOCTOR EVALUATION FORM

NAME	
DATE	
CASE STUDY NUMBER	

INSTRUCTIONS

STEP 1. Complete 1 evaluation form for each case study.

STEP 2. After reviewing Primary Information, record your responses in the following spaces:

IMPORTANT SYMPTOMS
INITIAL DIAGNOSIS
SYMPTOMS THAT MATCH THE NUTRIENT DEFICIENCY

STEP 3. After reviewing Secondary Information, record your responses in the following spaces.

IMPORTANT SYMPTOMS	
IS YOUR INITIAL DIAGNOSIS CONFIRMED?	**YES** OR **NO**
IF NOT, WHAT IS YOUR NEW DIAGNOSIS?	
IF NOT, WHAT CAUSED YOU TO CHANGE YOUR DIAGNOSIS?	

MASTER 4.4a
PLANT DOCTOR
REFERENCE MANUAL

NAME

DATE

INTRODUCTION

Like humans, plants need a proper diet to be healthy. Unlike humans, however, plants cannot move to find food. They can only take up nutrients available in the soil or, in the case of legumes, from the atmosphere. Different species of wild plants are adapted to different levels of nutrients, and many thrive in low-nutrient soils. However, when growing most crop plants, if a nutrient is missing, or present in a lesser amount than is needed, then the crop plant cannot reach its maximum growth potential. The consequences of nutrient deficiencies can be moderate or severe, depending on the extent of the deficiency. The symptoms displayed vary depending on the type of plant and which nutrient is lacking. Sometimes, a nutrient deficiency causes the plant to become more susceptible to disease, similar to a person who has a weak immune system. A plant doctor (called an agronomist) determines which nutrient is deficient and recommends using a fertilizer that contains enough of the nutrient to restore the plant to good health. This manual describes the symptoms associated with nitrogen, phosphorus, potassium, and zinc deficiencies for corn plants. Photographs are supplied to help diagnose the deficiencies.

NUTRIENT DEFICIENCIES OF CORN

NITROGEN DEFICIENCY

The major symptom of this problem is a general yellowing of the plant. The yellowing begins at the leaf tip and gradually works its way down to the base of the leaf. Older leaves show a V-shaped yellowing of the inner leaves, with the leaf edges remaining green in a V pattern. The plants may appear stunted and spindly. Symptoms of nitrogen deficiency are most noticeable in plants growing in lower, poorly drained parts of the field. Nitrogen deficiency also can result after heavy rains remove nitrogen from sandy soils. Nitrogen is an important building block used by plants for many aspects of growth. Restoring nitrogen to the soil will improve crop yields.

A NORMAL LEAF IS ON THE RIGHT. LEAVES FROM INCREASINGLY NITROGEN-DEFICIENT PLANTS ARE ON THE LEFT.

MASTER 4.4b
PLANT DOCTOR
REFERENCE MANUAL

NAME

DATE

NUTRIENT DEFICIENCIES OF CORN

PHOSPHORUS DEFICIENCY

Plants that lack phosphorus show stunted growth and mature later than healthy plants. Late-maturing crop plants are more susceptible to frost, harvest damage, disease infection, and summer drought. The leaves and stems often show purpling or reddening.

Phosphorus deficiency can result when soil phosphorus levels have declined due to nutrient removal. It can also occur in cool conditions that reduce diffusion to the root. As a result, many farmers apply some phosphorus with the seed to support early growth when the soil is cool. Restoring phosphorus to the soil allows crop plants to mature properly and be better protected from disease, drought, and frost.

THESE PHOSPHORUS-DEFICIENT CORN PLANTS SHOW THE CHARACTERISTIC DARKENING OF THE LEAVES.

MASTER 4.4c

PLANT DOCTOR
REFERENCE MANUAL

NAME

DATE

NUTRIENT DEFICIENCIES OF CORN

POTASSIUM DEFICIENCY

Plants that lack potassium show stunted growth and mature later than normal plants. Potassium deficiency results in yellowing and drying of the leaf edges, especially on older leaves. The death of cells in the leaves may be visible as a dark discoloration. The stems of potassium-deficient plants are weak and often break below the ears.

Potassium deficiencies happen most often in soils that are sandy, wet, or compacted (dense) or when potassium has been removed through repeated cropping and natural levels are low. Restoring potassium to the soil will help the plants better absorb water and prevent wilting and dry leaves.

THE OLDER LEAVES OF POTASSIUM-DEFICIENT CORN PLANTS YELLOW AND DIE AROUND THE EDGES (LEFT), WHILE AREAS OF CELL DEATH ON LEAVES MAY APPEAR AS DARK SPOTS (RIGHT).

MASTER 4.4d

PLANT DOCTOR
REFERENCE MANUAL

NAME

DATE

NUTRIENT DEFICIENCIES OF CORN

ZINC DEFICIENCY

Plants lacking zinc show pale- to whitish-colored bands located between the veins of the leaves. The plants may be stunted. Zinc deficiency is associated with soils that are alkaline and contain little organic material.

LEAVES FROM ZINC-DEFICIENT PLANTS SHOW PALE STRIPES ON THEIR LEAVES.

MASTER 4.5
CROPS, SOIL, AND NUTRIENTS

NAME

DATE

Agriculture is a major industry in the United States. Approximately 20 percent (408 million acres) of our land area is used for crop production. The top field crops grown in the US are corn, soybeans, and wheat.

CORN

- The US is the largest producer of corn in the world.
- In 2011, the US produced over 12 billion bushels of corn.
- The US produces 32 percent of the world's corn crop.
- Corn grown for grain accounts for almost one quarter of the harvested crop acres in the US.
- On average, a farmer can harvest approximately 150 bushels of corn (for grain) on 1 acre of land.

SOYBEANS

- Soybeans rank second behind corn as a major crop in the US.
- The US accounts for 50 percent of the work's soybean production.
- In 2011, US farmers harvested 3.06 billion bushels of soybeans from 73.6 million acres of cropland.
- On average, a farmer can harvest approximately 46 bushels of soybeans (for grain) on 1 acre of land.

WHEAT

- Wheat ranks third as a major field crop in the US.
- The US produces over 2.2 billion bushels of wheat a year.
- The US produces approximately 10 percent of the world's wheat.
- On average, a farmer can harvest approximately 50 bushels of wheat (for grain) on 1 acre of land.

In previous lessons, you learned that plants get many of their nutrients from the soil. Earlier in this lesson, you observed how plants are affected if they do not get the nutrients they need. Consider the following scenario. Three farmers each have very good, nutrient-rich soil. One farmer plants corn, one plants soybeans, and one plants wheat. Each farmer's harvest matches the average in the US for each crop (150 bushels/acre for corn, 46 bushels per acre for soybeans, and 50 bushels per acre).

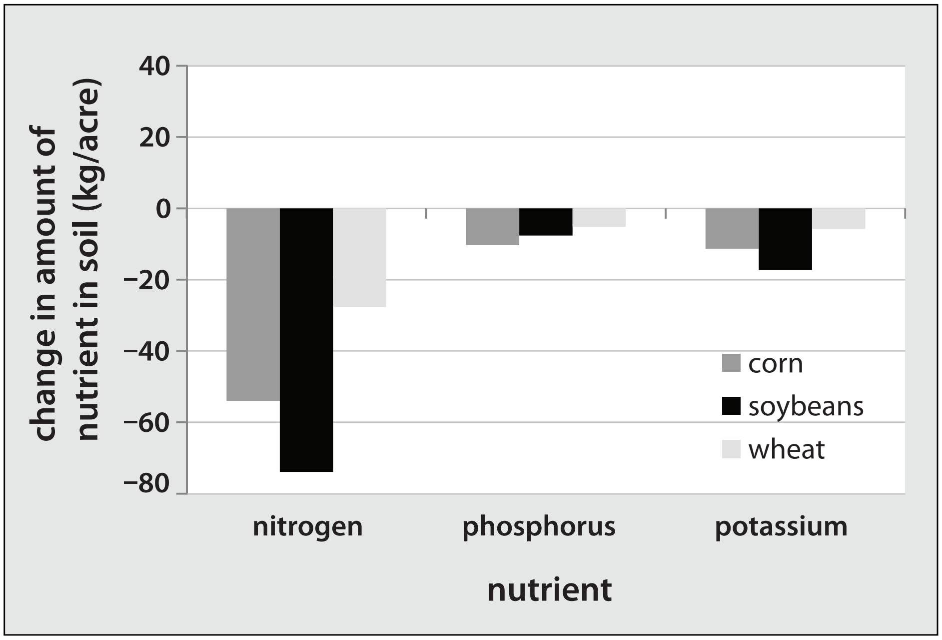
US Environmental Protection Agency. (2013). Major Crops Grown in the United States. http://www.epa.gov/oecaagct/ag101/cropmajor.html

MASTER 4.5
CROPS, SOIL, AND NUTRIENTS

NAME

DATE

How does growing those crops affect the soil? Look at the following graph that shows how nutrient levels are changed in just one acre of land after growing the crops.



Zero indicates the starting amount of the nutrient in one acre of soil (**before** the crops were grown).

The y-axis measures the change in amount of nutrient in the soil.

A positive number means that there is **more** of the nutrient in the soil after the crop has grown.

A negative number means that there is **less** of the nutrient in the soil after the crop has grown.

ANSWER THE FOLLOWING QUESTIONS:

What happened to the level of nutrients in the soil after growing the crops?

How would the levels of each major nutrient be changed if the farmer grew 100 acres of the crop? 1,000 acres of the crop?

What might happen to the crops if the farmers plant their crops in this soil again in future years?

What actions might the farmers need to take if they want to continue getting good harvests from their crops in the future?

MASTER 4.6

INVESTIGATING CALCIUM DEFICIENCIES

NAME

DATE

MATERIALS FOR EACH TEAM

- 6 paper or plastic cups
- Potting soil
- Tap water
- 6 pea seeds
- Permanent marker pen
- Ruler (after seeds have germinated)
- Stick or skewer (after plants have germinated to hold them upright)

PROCEDURE

1. Identify your team's cups with your initials or other identifying mark.
2. Poke small holes (2-3) in the bottom of each cup.
3. Fill each cup approximately 3/4 full with potting soil.
4. Moisten the potting soil with water. If the level of the potting soil goes down, add more so that the cup is approximately 3/4 full.
5. Place 1 pea seed on top of the potting soil.
6. Cover the seeds with additional potting soil and water thoroughly.
7. Record the date that the seeds were planted in the chart below.
8. Set cups in the designated place. Make sure they are watered regularly and that they do not dry out.
9. In your data chart, record observations, including when you first see signs of germination.
10. When the plants are approximately 5-7 cm tall, choose the three seedling plants that are closest to the same height. (This should be approximately 5-7 days after planting.) You will use these for your experiment.
11. Label each cup with the treatment that you will give
    - **Tap water**
    - **5 mM EDTA**
    - **25 mM EDTA**
12. Begin watering each plant according to its treatment. Record the date and the height of each plant in your data table when you begin the treatments.
13. Continue watering the plants regularly and do not let them dry out or over water. Observe the plants regularly. Record any observations in your data table. Make sure to measure the height of the plants in addition to visual observations.
14. Continue the experiment until your teacher asks you to collect final data. Record final data in your chart.
15. Add your data to the class chart.

MASTER 4.6

DATA CHART

NAME
DATE

DATE	ACTION TAKEN OR OBSERVATIONS

*IF YOU NEED ADDITIONAL SPACE FOR YOUR DATA CHART, YOU CAN DRAW A CHART ON PLAIN OR LINED PAPER.

MASTER 4.7

ADDITIONAL EXPERIMENTAL RESULTS

NAME

DATE

BEFORE EXPERIMENTAL TREATMENT

WATER

AFTER EXPERIMENTAL TREATMENT

25 mM EDTA

MASTER 4.8
CALCIUM AND PLANT GROWTH

NAME

DATE

You probably know some of the reasons why calcium is important in the human body. Calcium helps form and maintain healthy teeth and bones. You may be less familiar with some other roles for this important element. Calcium also plays a role in the clotting of blood, the sending and receiving of nerve signals, muscle contraction and relaxation, and regulating the release of certain hormones and other chemicals in the body.

In plants, calcium is a constituent of cell walls and is involved in the new growth of leaves and root tips. It provides elasticity and expansion of cell walls, which prevent the growing points from becoming rigid and brittle. As scientists continue to study the role of calcium in plants, they find that calcium is important in many plant functions ranging from nutrient uptake to coordinating changes in the cells that help the plant react to the impact of environmental changes and stresses.

Calcium deficiencies in plants generally appear in areas of new growth, such as leaves, stems, buds, and roots. Young leaves may be deformed. Areas around the edge of the leaf may die or the entire leaf may die. In older leaves, dead (necrotic) spots may develop.

In plants like tomatoes and peppers, calcium deficiency causes a disorder called blossom-end rot. In such cases, a black leathery spot appears on the blossom end of the fruit. The fruit then stops developing and eventually falls off. In peanuts, low calcium levels cause a condition that prevents nuts from developing.

Calcium deficiencies also affect roots. Roots may be short, stubby, and misshapen. In severe cases, root tips may die.

MASTER 4.9

EDTA EFFECTS ON PEA PLANTS

NAME

DATE

BEFORE TREATMENT

AFTER TREATMENT

LESSON 5

EXPLAIN-ELABORATE

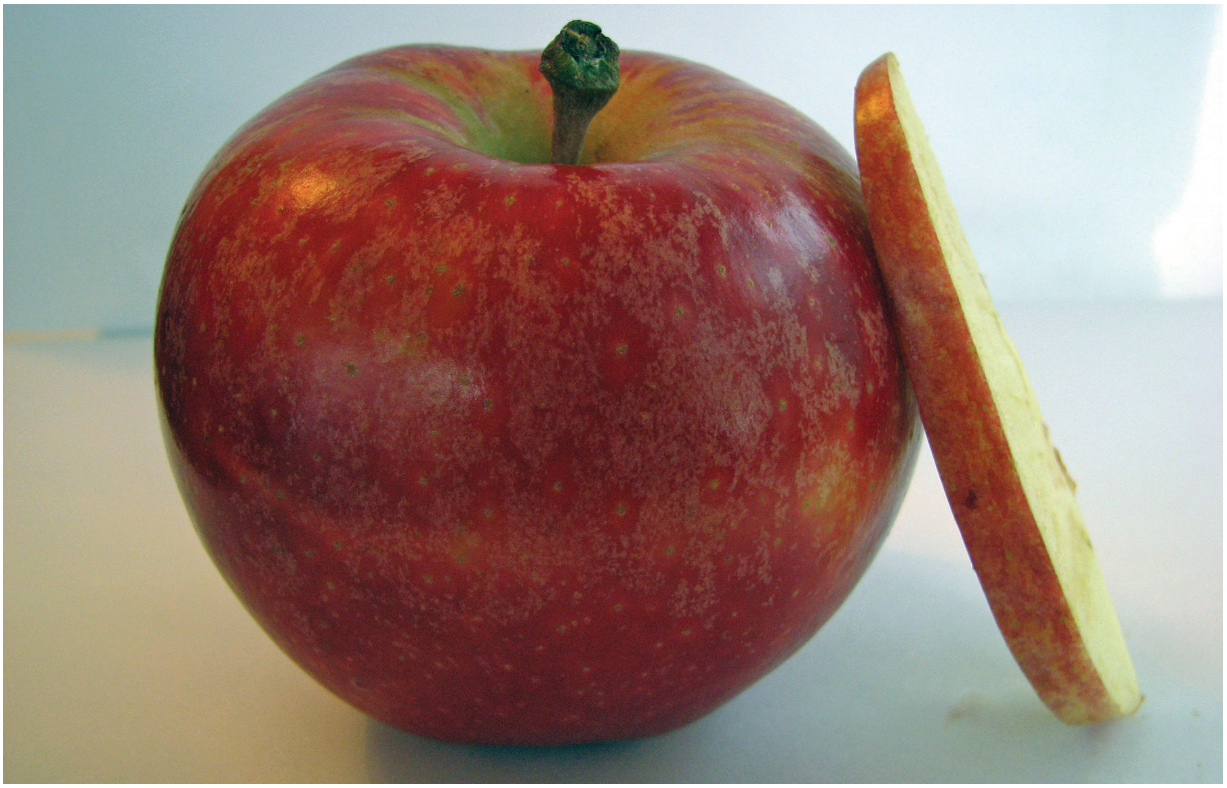
FERTILIZERS

AND THE ENVIRONMENT

NOURISHING THE PLANET

IN THE 21ST CENTURY

AT A GLANCE



OVERVIEW

An apple is used to model Earth. Students learn that just 1/32 of its surface is devoted to farmland. Students use estimates of population growth and land use to calculate how much additional farmland will be needed in the future. They discuss what sacrifices may be needed to feed a larger population. Nutrient pollution is defined, and students discuss ways of limiting it.

MAJOR CONCEPTS

- Only a small portion of Earth's surface is used to grow food.
- The world population is growing at a steady rate.
- Unless food productivity increases, more land will have to be farmed.
- Fertilizers help increase food productivity.
- Fertilizers can be commercial or organic.
- Excesses and deficiencies in nutrients can have negative impacts on water, soil, and air.

OBJECTIVES

After completing this lesson, students will be able to

- recognize that farmland is a finite resource,
- appreciate that the world's growing population demands an increase in food productivity,
- describe the role fertilizer plays in increasing food productivity,
- distinguish between organic and commercial fertilizers,
- describe how excess nutrients are harmful to the environment, and
- identify different sources of nutrient pollution.

TEACHER BACKGROUND

Consult the following sections in Teacher Background: **10.0 NOURISHING PLANTS WITH FERTILIZERS, 12.0 FERTILIZERS AND THE ENVIRONMENT, 13.0 TECHNOLOGY AND THE FUTURE OF AGRICULTURE**

IN ADVANCE

PHOTOCOPIES

ACTIVITY	MASTER	NUMBER OF COPIES
1	None	---
2	Master 5.1, Newspaper Articles	1 to project
	Master 5.2, Population and Land Use Graphs	1 per team of 3 students
	Master 5.3, Needs of the Future	1 per team of 3 students
*3	Master 5.4, Thinking about Fertilizers	1 per team of 3 students*
	Master 5.5, Pros and Cons of Different Fertilizers	1 per team of 3 students*
	Master 5.6, Nutrient Pollution	1 per team of 3 students*
	Master 5.7, Nutrient Pollution Discussion Questions	1 per team of 3 students*

*Half of the teams receive *Masters 5.4, Thinking about Fertilizers* and *5.5, Pros and Cons of Different Fertilizers*, and the other half receive *Masters 5.6, Nutrient Pollution* and *5.7, Nutrient Pollution Discussion Questions.*

MATERIALS

ACTIVITY	MATERIALS
1	**FOR THE TEACHER DEMONSTRATION** • 1 apple • 1 knife • 1 plate (paper) or cutting board
2	No materials except photocopies and masters to project
3	No materials except photocopies

PREPARATION

Prepare photocopies.

PROCEDURE

TEACHER NOTE

This activity uses an apple as a model of Earth. Students discuss the various ways people use land and make predictions about what percentage of Earth's land is needed to grow our food. After discussing the ways in which land is used *(Step 2)*, you may consider having the students create their own pie charts where they predict the percentages associated with different land uses, especially farming. Later, their predictions can be compared with the actual values revealed by the apple demonstration.

ACTIVITY 1: THE BIG APPLE

In this activity, students consider the challenges associated with the Earth's growing population and land use.

1. EXPLAIN TO THE CLASS THAT THIS ACTIVITY IS ABOUT HOW WE, AS A SOCIETY, USE LAND. THE AMOUNT OF LAND ON EARTH STAYS THE SAME AND AS THE WORLD'S POPULATION GETS LARGER, IT BECOMES EVEN MORE IMPORTANT THAT WE MAKE WISE DECISIONS ABOUT HOW IT IS USED.

2. EXPLAIN THAT LAND IS USED FOR MANY DIFFERENT REASONS. ASK, "WHAT ARE SOME OF THE MOST IMPORTANT USES FOR LAND?" WRITE STUDENTS' RESPONSES ON THE BOARD OR CHART PAPER.

Students' responses may include the following:

- farming
- homes
- industries or places where we work
- pastures or land for livestock
- parks, sports, and recreation
- mining
- wildlife habitat (mountain ranges, jungles, deserts, beaches, and tundra)

If students do not mention these kinds of uses, ask guiding questions to encourage them to think about how humans use land. A student may point out that some land, such as a desert, has no use. Of course, any land that is not being used by humans can be considered a habitat for wildlife, which can also lead to enjoyment by humans.

Student responses to this question give you an idea of how aware they are of the diverse demands placed on land resources.

3. CALL ATTENTION TO THE APPLE AND THE KNIFE. EXPLAIN THAT THE APPLE REPRESENTS EARTH. ASK, "HOW MUCH OF EARTH'S SURFACE DO YOU THINK IS DEVOTED TO FARMING?"

Students' responses will vary. Some may remember that about 70 percent of the surface is water.

4. USE THE KNIFE TO CUT THE APPLE INTO 4 EQUAL PARTS. SET 3 PARTS ASIDE AND HOLD UP THE REMAINING ONE QUARTER. EXPLAIN THAT THE SURFACE OF THE WORLD IS ABOUT 70 PERCENT WATER, SO THIS PIECE REPRESENTS THAT PART OF THE SURFACE THAT IS LAND.

Remind students that this relatively small amount of land must be put to many different uses.

5. USE THE KNIFE TO CUT THE ONE QUARTER PIECE OF APPLE IN HALF 3 MORE TIMES, EACH TIME DISCARDING 1/2. FINALLY, HOLD UP 1 OF THE SMALLEST PIECES AND EXPLAIN THAT IT REPRESENTS 1/32 OF THE SURFACE OF EARTH. THIS IS THE AMOUNT OF LAND USED FOR FARMING. POINT OUT THAT THE SKIN ON THIS SMALL PIECE OF APPLE REPRESENTS THE TINY LAYER OF TOPSOIL THAT WE DEPEND ON TO GROW FOOD.

6. EXPLAIN THAT BECAUSE WE PUT LAND TO SO MANY DIFFERENT USES, THE AMOUNT DEVOTED TO FARMING HAS HARDLY CHANGED DURING THE PAST 50 YEARS. SCIENTISTS ARE WORRIED ABOUT HOW WE WILL FEED THE WORLD'S GROWING POPULATION IN THE FUTURE.

Although additional land has been cleared for farming in many developing countries, it has largely been offset by a reduction of farmland in the developed countries.

ACTIVITY 2: USING LAND WISELY

In this activity, students use a world population projection to consider how much additional farmland will be needed to feed humans in the year 2050.

1. REMIND THE STUDENTS THAT IN *LESSON 4* THEY WERE CONCERNED WITH DIAGNOSING AND TREATING PLANT NUTRIENT DEFICIENCIES IN A SMALL AFRICAN VILLAGE. THE AIM WAS TO INCREASE FOOD PRODUCTION FOR THE LOCAL INHABITANTS. IN THIS ACTIVITY, THE FOCUS BROADENS TO CONSIDER HOW WE CAN FEED THE ENTIRE WORLD'S POPULATION.

2. DISPLAY *MASTER 5.1, NEWSPAPER ARTICLES* AND REVEAL ONLY THE TOP ARTICLE. ASK A STUDENT VOLUNTEER TO READ THE ARTICLE ALOUD.

3. EXPLAIN TO STUDENTS THAT THEY WILL CONTINUE IN THEIR ROLES AS AGRICULTURAL EXPERTS CONCERNED WITH INCREASING CROP YIELDS ON FARMS. ASK STUDENTS TO SUMMARIZE THE CONTENT OF THE ARTICLE.

Try to focus the discussion on the world. Most students in the United States do not have direct experience with severe hunger. Help them understand that in addition to human suffering, hunger can also lead to unstable governments, wars, and threats to national security—including that of the United States. It is in everyone's best interest to eliminate world hunger.

The article states that population growth contributes to the problem of world hunger. Do not dwell on population-control measures. The students are working as agricultural experts and need to focus on how to grow more and better food. The article also mentions availability of freshwater and increasing temperatures as challenges for growing more food. If students do not understand why increasing temperatures cause lower crop yields, explain that it takes more energy for plants (and people) to maintain themselves at higher temperatures. Using humans as an example, you can point out that marathon records are usually set at cooler temperatures.

4. NOW UNCOVER THE BOTTOM ARTICLE AND ASK A SECOND VOLUNTEER TO READ IT ALOUD. ASK STUDENTS TO SUMMARIZE THE ARTICLE.

Students should recognize that there are many factors that influence world hunger and that addressing the problem requires the skills of many different types of professionals including social scientists, climatologists, water management experts, and agricultural experts.

5. DIVIDE THE CLASS INTO TEAMS OF 3 STUDENTS. EXPLAIN THAT THEIR FIRST TASK IS TO INVESTIGATE HOW POPULATION GROWTH IS EXPECTED TO AFFECT FARMING IN THE FUTURE.

6. PASS OUT TO EACH TEAM A COPY OF *MASTER 5.2, POPULATION AND LAND USE GRAPHS* AND *MASTER 5.3, NEEDS OF THE FUTURE*. BRIEFLY REVIEW THE INFORMATION WITH STUDENTS.

The population graph provides data about the world population from 1950 and projections for the population in the year 2100. The high, medium, and low estimates of the future world population are based on fertility rates (the number of children that people have). Instruct some teams to use the high estimate in their calculations, others the medium estimate, and the rest the low estimate.

The value of 12 percent of land devoted to farming refers to the world as a whole. Obviously, the corresponding figures for different countries vary considerably. This activity is designed to examine the problem of feeding the world and not to explore the situations within individual countries.

7. INSTRUCT TEAMS TO USE THE GRAPHS ON *MASTER 5.2, POPULATION AND LAND USE GRAPHS* TO PERFORM CALCULATIONS ON *MASTER 5.3, NEEDS OF THE FUTURE* ABOUT HOW MUCH FARMLAND WILL BE NEEDED IN THE YEAR 2050.

Give teams 10 minutes to perform their calculations. The numbers needed to perform the calculations can be estimated from the population graph.

Sample calculations for *Master 5.3, Needs of the Future*

PART A: HOW MUCH FARMLAND IS USED TO FEED EACH PERSON TODAY?

STEP 1. Use the World Population Growth graph on *Master 5.2, Population and Land Use Graphs* to estimate Earth's population right now: 7.1 billion people (in January 2014).

The 12 percent of land devoted to farming corresponds to 3.5 billion acres of farmland.

STEP 2. Divide the 3.5 billion acres of farmland by the population (from Step 1) to get the number of acres of farmland per person:

3.5 billion acres farmland ÷ 7.1 billion people = 0.5 acres per person

PART B: HOW MANY ACRES OF FARMLAND PER PERSON WILL BE AVAILABLE IN 2050?

STEP 1. Use the World Population Growth graph on *Master 5.2, Population and Land Use Graphs* to estimate Earth's population in the year 2050: 10.9 billion people (high), 9.6 billion people (medium), and 8.3 billion people (low)

STEP 2. Divide the 3.5 billion acres of farmland by the population (from Step 1) to get the number of acres of farmland per person:

3.5 billion acres farmland ÷ population estimate =

0.32 acres per person (high estimate)
0.36 acres per person (medium estimate)
0.42 acres per person (low estimate)

PART C: ASSUMING THAT CROP YIELDS STAY THE SAME, HOW MUCH ADDITIONAL LAND WILL BE NEEDED FOR FARMING IN 2050?

STEP 1. Calculate the estimated population increase factor from now to 2050:

population in 2050 (from Part B) ÷ population now (from Part A)

1.54 (high estimate)
1.35 (medium estimate)
1.16 (low estimate)

STEP 2. Multiply the 3.5 billion acres of farmland times the population increase factor (from Step 1):

3.5 billion acres farmland × population increase factor =

5.39 billion acres farmland needed in 2050 (high estimate)
4.73 billion acres farmland needed in 2050 (high estimate)
4.06 billion acres farmland needed in 2050 (high estimate)

STEP 3. To find out how much additional farmland will be needed in 2050, subtract the 3.5 billion acres (today's farmland) from the number of acres needed in 2050 (from Step 2):

5.39 billion acres needed in 2050 – 3.5 billion acres = **1.89 billion** extra acres of farmland needed (high estimate)

4.73 billion acres needed in 2050 – 3.5 billion acres = **1.23 billion** additional acres of farmland needed (medium estimate)

4.06 billion acres needed in 2050 – 3.5 billion acres = **0.56 billion** additional acres of farmland needed (low estimate)

8. ASK EACH TEAM TO REPORT THE RESULTS OF THEIR CALCULATIONS. WRITE THEIR ANSWERS ON THE BOARD OR CHART PAPER.

If any answers are out of the expected range, go through the calculation systematically, identify the mistake, and correct it. Obtain answers using the high, medium, and low population estimates.

9. ASK STUDENTS TO SUMMARIZE THE RESULTS.

If students do not point this out, emphasize that if crop yields stay the same between now and 2050, then perhaps an extra 1 billion acres of farmland will need to be set aside and cultivated.

10. ASK THE STUDENTS TO REMEMBER THE DIFFERENT USES OF LAND THAT THEY DESCRIBED IN STEP 2 OF *ACTIVITY 1, THE BIG APPLE.*

Point to the list of land uses that students created in *Activity 1.*

11. ASK, "IF A BILLION ACRES OF EXTRA FARMLAND ARE NEEDED TO FEED THE WORLD'S POPULATION, FROM WHERE SHOULD IT COME? WHAT ARE YOU WILLING TO SACRIFICE?"

Students likely will believe that people must have adequate land for the places where they live and work. They may suggest taking the land from parks or wildlife habitats. Some may suggest that if more people became vegetarians, the extra farmland could come from pastures where livestock graze.

These questions are not intended to settle the issue. Instead, they are intended to prompt a discussion that helps students see the scope of the problem and to consider some of the difficult decisions that may lie ahead.

This step gives you a sense of the students' awareness of the tradeoffs associated with the reallocation of limited resources.

12. EXPLAIN THAT IN THE NEXT ACTIVITY, THEY WILL CONSIDER HOW FARMING PRACTICES CAN INFLUENCE LAND USE AND CROP YIELDS.

ACTIVITY 3: FERTILIZERS AND THE FUTURE

In this activity, students identify advantages and disadvantages of using organic and commercial fertilizers. They also consider how to minimize nutrient pollution.

TEACHER NOTE
The readings about organic and commercial fertilizers are brief. The information is not meant to be comprehensive. Rather, it is designed to challenge students' critical-thinking skills and provide opportunities for them to construct explanations supported by evidence.

1. REMIND STUDENTS THAT IN *ACTIVITY 2, USING LAND WISELY,* THEY CALCULATED THAT APPROXIMATELY 1 BILLION EXTRA ACRES OF FARMLAND WOULD BE NEEDED TO FEED THE WORLD'S POPULATION IN 2050. ASK, "WHAT WERE TWO ASSUMPTIONS MADE IN REACHING THIS CONCLUSION?"

Students' answers will vary. Some may focus on assumptions associated with the rate of population growth. This is a good answer, but you should guide the discussion to remind students that their calculations assumed that the crop yields from farms would remain constant between now and 2050.

2. ASK, "WHAT WILL BE THE EFFECT OF INCREASING THE AMOUNT OF FOOD THAT AN ACRE OF FARMLAND CAN PRODUCE?"

Students should realize that if farmland becomes more productive, then fewer acres would be required to meet the world's food needs.

3. EXPLAIN THAT IN THEIR ROLES AS AGRICULTURAL EXPERTS, THEY ARE GOING TO MAKE RECOMMENDATIONS TO THE EARTH FOOD BANK ABOUT HOW TO FARM IN THE FUTURE. EXPLAIN TO STUDENTS THAT WHEN CONSIDERING THE PROPER USE OF FERTILIZER, THEY WANT TO INCREASE CROP YIELDS, WHILE AT THE SAME TIME MINIMIZING HARM TO THE ENVIRONMENT. PROPER APPLICATION OF FERTILIZER MEANS THE FOLLOWING:

- Fertilizer is added at the right time. Fertilizers should be applied during that part of the plant's life cycle when the nutrients are needed.
- Fertilizer is added at the right place. Fertilizers should be applied in a location where the nutrients can be taken up by the plant's root system.
- Fertilizer is added at the right rate. Fertilizers should be applied at the rate at which the plant can use the nutrients.

4. EXPLAIN THAT STUDENTS NEED TO LEARN MORE ABOUT FERTILIZERS AND THEIR EFFECTS ON THE ENVIRONMENT.

- Pass out to half of the teams a copy of *Master 5.4, Thinking about Fertilizers* and a copy of *Master 5.5, Pros and Cons of Different Fertilizers.*
- Pass out to the other teams a copy of *Master 5.6, Nutrient Pollution* and a copy of *Master 5.7, Nutrient Pollution Discussion Questions.*
- Instruct the teams to read the information found on the first handout (either *Master 5.4, Thinking about Fertilizers* or *Master 5.6, Nutrient Pollution)* and to discuss within their teams their understanding. Students should relate the ideas of "right time, right place, and right rate" when considering the use of fertilizers and their impacts on the environment.
- Students should use the second handout (either *Master 5.5, Pros and Cons of Different Fertilizers* or *Master 5.7, Nutrient Pollution Discussion Questions)* to record their conclusions.

Students reading about fertilizers should be able to identify 3 or 4 advantages and disadvantages of each type of fertilizer. Students reading about nutrient pollution should be able to describe how excess nutrients can produce algal blooms that use up oxygen in waterways, leading to suffocation of other plants and animals. They should be able to identify wastewater treatment facilities and industrial plants as point sources of nutrient pollution. They should identify urban development, septic systems, the burning of fossil fuels, and agricultural runoff as nonpoint sources of nutrient pollution. Student suggestions for limiting nonpoint sources of nutrient pollution will vary. There is no simple correct answer. Look for logical responses that students can defend using evidence. The idea is to get them thinking about the multiple sources of nutrient pollution and for them to realize that minimizing it will require a complex set of regulations, incentives, and government oversight.

5. AFTER THE TEAMS HAVE COMPLETED THEIR TASKS, ASK VOLUNTEERS TO READ THEIR CONCLUSIONS.

- Make a list of the advantages and disadvantages of each type of fertilizer on the board or on chart paper.
- Discuss answers to the questions about nutrient pollution.

6. ASK, "WHY DO YOU THINK THAT SOME FARMERS USE ORGANIC FERTILIZERS AND OTHERS USE COMMERCIAL FERTILIZERS?"

Student responses will vary. Try to bring out in the discussion that the farmers in the United States have more options than farmers in poorer countries who may have no choice but to use organic fertilizers that they produce for themselves. One consequence is that farmers in poorer countries often obtain lower crop yields as compared with farmers in the United States.

TEACHER NOTE
Try to avoid getting bogged down in debating whether or not food that is organically grown is safer or tastes better than food grown using commercial fertilizers. This is not the focus of the lesson. Scientific studies have not been able to find consistent taste, health, or safety differences between foods grown using the two types of fertilizers.

7. **CONCLUDE THE LESSON BY ASKING STUDENTS TO HOLD ON TO THEIR HANDOUTS. EXPLAIN THAT THEY WILL REFER TO THEM DURING THE NEXT LESSON WHEN THEY WILL BE MAKING RECOMMENDATIONS FOR FARMING IN THE FUTURE.**

LESSON 5 ORGANIZER

ACTIVITY 1: THE BIG APPLE WHAT THE TEACHER DOES	PROCEDURE REFERENCE
Explain that land is a precious resource and as the world's population increases, it is important that we use land wisely.	Page 154 Step 1
Explain that land has many uses. Ask, "What are some of the most important uses for land?" Write student responses on the board or chart paper.	Page 154 Step 2
Call attention to the apple and the knife. Explain that the apple represents Earth. Ask, "How much of Earth's surface do you think is devoted to farming?"	Page 154 Step 3
Cut the apple into 4 equal parts. Explain that 1 piece is about the amount of Earth that is land and not ocean.	Page 154 Step 4
Cut the 1/4 piece of apple in half 3 more times. Hold up 1 of the final pieces and explain that it represents 1/32 of Earth's surface. This is the amount of land used for farming.	Page 154 Step 5
Explain that the amount of land used for farming has changed little over the past 50 years. Tell students that scientists are worried about how we will feed the world's population in the future.	Page 155 Step 6

ACTIVITY 2: USING LAND WISELY WHAT THE TEACHER DOES	PROCEDURE REFERENCE
Remind students that in the previous lesson they were concerned with food production in a small village. In this lesson, they will consider how to feed the entire world's population.	Page 155 Step 1
Project *Master 5.1, Newspaper Articles* and reveal the top article. Ask a volunteer to read the article aloud.	Page 155 Step 2
Explain to students that they will continue to work as agricultural experts. Ask them to summarize the article.	Page 155 Step 3
Reveal the bottom article and ask a volunteer to read it aloud. Ask students to summarize the article.	Page 155 Step 4
Divide the class into teams of 3 students. Explain that their first task is to investigate how population growth is expected to affect farming in the future.	Page 155 Step 5
Give each team 1 copy of *Master 5.2, Population and Land Use Graphs* and 1 copy of *Master 5.3, Needs of the Future.* Briefly review the information with students.	Page 155 Step 6
Instruct teams to use the graphs on *Master 5.2, Population and Land Use Graphs* to help them perform a calculation on *Master 5.3, Needs of the Future* about how much farmland will be needed in the year 2050..	Page 156 Step 7
Ask teams to report their results. Write their answers on the board or chart paper.	Page 157 Step 8
Summarize the results. If crop yields remain the same, an additional 1 billion acres of farmland will be needed between now and 2050.	Page 157 Step 9
Ask students to recall the different uses of land. Ask • "If a billion acres of extra farmland are needed to feed people, where should it come from?" • "What are you willing to sacrifice?"	Page 157 Steps 10-11
Explain that they will next consider how farming practices can influence land use and crop yields.	Page 157 Step 12

<table>
<tr><th>ACTIVITY 3: FERTILIZERS AND THE FUTURE
WHAT THE TEACHER DOES</th><th>PROCEDURE REFERENCE</th></tr>
<tr><td>Remind students that a billion acres of additional farmland will be needed to feed the world in 2050. Ask:
“What 2 assumptions were made in reaching this conclusion?”
“What will be the effect of increasing the amount of food that an acre of farmland can produce?”</td><td>Pages 157 - 158
Steps 1-2</td></tr>
<tr><td>Summarize aspects of the proper application of fertilizer.
Add it at the right time, meaning during that part of the plant’s life cycle when the nutrients are needed.
Add it at the right place, meaning in a location where the nutrients can be taken up by the plant’s roots.
Add it at the right rate, meaning at a rate at which the plant can use it.</td><td>Page 158
Step 3</td></tr>
<tr><td>Explain that students need to learn more about fertilizers and their effects on the environment.
Give half the teams 1 copy of Master 5.4, Thinking about Fertilizers and 1 copy of Master 5.5, Pros and Cons of Different Fertilizers.
Give the other teams 1 copy of Master 5.6. Nutrient Pollution and 1 copy of Master 5.7, Nutrient Pollution Discussion Questions.
Instruct students to read the information on the first handout, discuss it, and record their conclusions on the second handout.</td><td>Page 158
Step 4</td></tr>
<tr><td>Ask volunteers to read their conclusions.
List advantages and disadvantages of each type of fertilizer on the board or chart paper.
Discuss answers to the questions about nutrient pollution.</td><td>Page 158
Step 5</td></tr>
<tr><td>Ask, “Why do you think that some farmers use organic fertilizers and others use commercial fertilizers?”</td><td>Page 158
Step 6</td></tr>
<tr><td>Instruct students to keep their handouts. They will refer to them in the final lesson..</td><td>Page 159
Step 7</td></tr>
</table>

MASTER 5.1

NEWSPAPER ARTICLES

NAME

DATE

THE DAILY HERALD

SPECIAL EDITION, DECEMBER 14

STUDY FORECASTS FUTURE FOOD SHORTAGE

A new study published in the Journal of World Agriculture raises concerns that in the future there will not be enough food for the world's growing population. The study was carried out by an international group of scientists with support from the Earth Food Bank. According to the study, the population of the world is increasing by about 80 million people each year.

To feed the growing population, crop yields will need to increase significantly. The researchers listed many factors that limit food production but singled out two for special consideration. First, the amount of freshwater available for farming is projected to limit food production. Second, higher temperatures around the world are already causing large losses in grain yields among the world's major producers. The study concluded by recommending that the Earth Food Bank sponsor a program dedicated to setting priorities and establishing policies that will enable all of the world's people to be fed.

THE DAILY HERALD

MORNING EDITION, MARCH 17

EARTH FOOD BANK TO HOLD MEETING ON FOOD PRODUCTION

In response to a recent international study on population and food production, the secretary general of the Earth Food Bank has announced that it will sponsor a series of two-week-long conferences next summer to address world hunger. Attendees at each conference will discuss a different aspect of the problem and make recommendations for meeting the world's food needs. According to the study, the four major aspects of the problem are

- reducing carbon emissions that contribute to increasing Earth's temperature,
- stabilizing population growth,
- making better use of our water resources, and
- increasing the crop yields on farms.

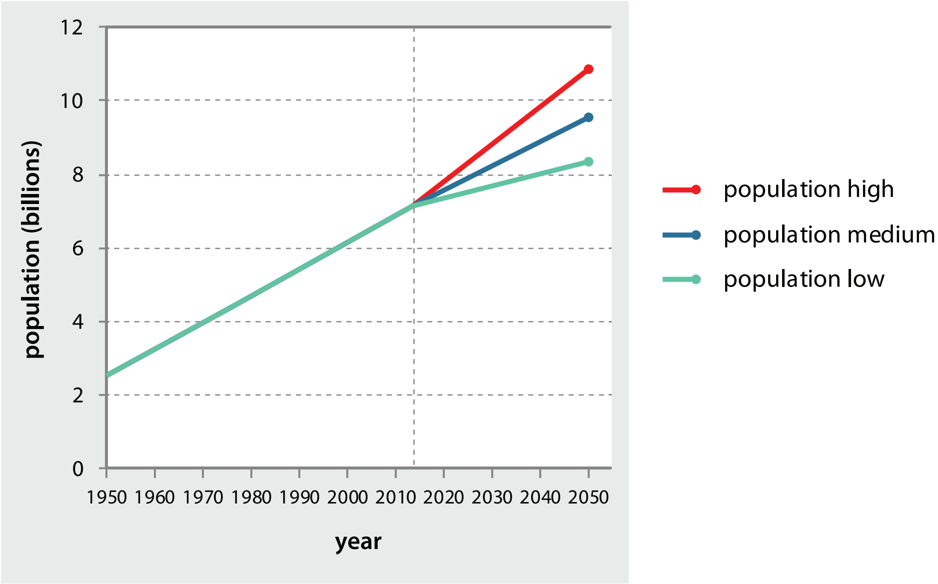
An international group of experts will attend each conference. The experts will submit a report to the secretary general that describes their recommendations. Scientists from Humanity Against Hunger will organize the conference on increasing crop yields. These scientists have experience applying modern agricultural practices in developing countries.

MASTER 5.2
POPULATION AND LAND USE GRAPHS

NAME

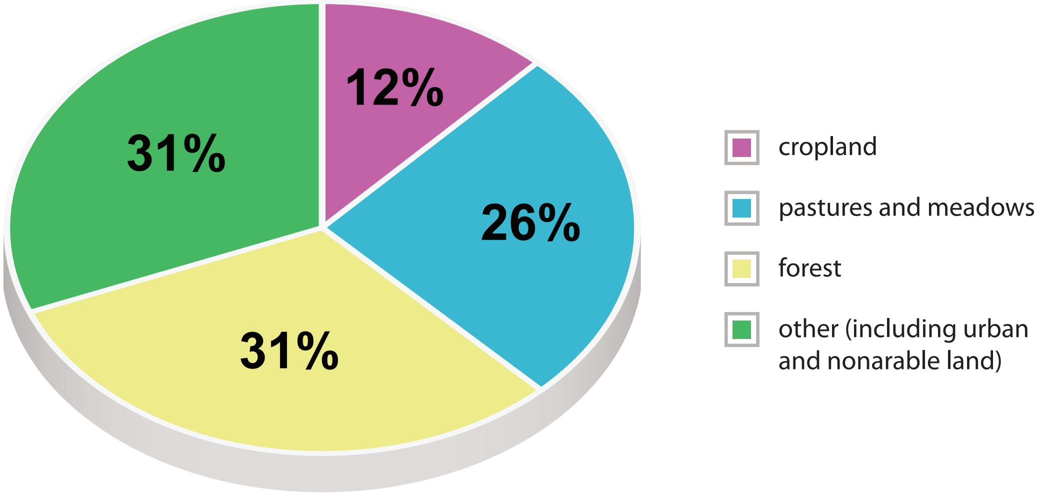
DATE

WORLD POPULATION GROWTH



Source: United Nations, Department of Economic and Social Affairs, Population Division (2013). World Population Prospects: The 2012 Revision, Volume I: Comprehensive Tables ST/ESA/SER.A/336. http://esa.un.org/unpd/wpp/index.htm

Global Land Use (billions of acres)



Source: Food and Agriculture Organization of the United Nations (2014). FAOSTAT. http://faostat3.fao.org/faostat-gateway/go/to/home/E

MASTER 5.3

NEEDS OF THE FUTURE

NAME
DATE

PART A: HOW MUCH FARMLAND IS USED TO FEED EACH PERSON TODAY?

STEP 1. Use the World Population Growth graph on *Master 5.2, Population and Land Use Graphs* to estimate Earth's population right now: ______ billion people.

STEP 2. The 11 percent of land devoted to farming corresponds to 3.5 billion acres of farmland.

STEP 3. Divide the 3.5 billion acres of farmland by the population (from Step 1) to get the number of acres of farmland per person:

3.5 BILLION ACRES FARMLAND ÷ ______ BILLION PEOPLE = ______ ACRES PER PERSON

PART B: HOW MANY ACRES OF FARMLAND PER PERSON WILL BE AVAILABLE IN 2050?

STEP 1. Use the World Population Growth graph on *Master 5.2, Population and Land Use Graphs* to estimate Earth's population in the year 2050: _____ billion people

STEP 2. Divide the 3.5 billion acres of farmland by the population (from Step 1) to get the number of acres of farmland per person:

3.5 BILLION ACRES FARMLAND ÷ ______ BILLION PEOPLE = ______ ACRES PER PERSON

PART C. ASSUMING THAT CROP YIELDS STAY THE SAME, HOW MUCH EXTRA LAND WILL BE NEEDED FOR FARMING IN 2050?

STEP 1. Calculate the estimated population increase factor from now to 2050:

POPULATION IN 2050 (FROM PART B) ÷ POPULATION NOW (FROM PART A) = ______

STEP 2. Multiply the 3.5 billion acres of farmland times the population increase factor (from Step 1):

3.5 BILLION ACRES FARMLAND × POPULATION INCREASE FACTOR = ______ BILLION ACRES FARMLAND NEEDED IN 2050

STEP 3. To find out how much extra farmland will be needed in 2050, subtract the 3.5 billion acres (today's farmland) from the number of acres needed in 2050 (from Step 2):

______ BILLION ACRES NEEDED IN 2050 – 3.5 BILLION ACRES = ______ BILLION EXTRA ACRES OF FARMLAND NEEDED

MASTER 5.4

THINKING ABOUT FERTILIZERS

NAME

DATE

Farmers may choose to use conventional farming practices or organic ones. In reality, the choices facing farmers are much more complex than using this or that production system. Many farmers use elements of both approaches. Additionally, a comparison of conventional farming and organic farming is not the same thing as a comparison of organic nutrient sources and inorganic nutrient sources. Organic farming tends to minimize or eliminate the use of synthetic inputs while maximizing the use of natural resources. The descriptions below refer to organic and commercial nutrient sources, not to organic and conventional farming.

ORGANIC FERTILIZERS usually contain little or no synthetic materials. They encourage the use of local natural resources. For example, animal manure (that would otherwise have to be disposed of) is often used to fertilize crop plants. Organic fertilizers usually contain some nutrients that dissolve in water, but most of the nutrients are released slowly as microbes in the soil break down the organic material into forms that the plant roots can absorb. Organic fertilizers contain relatively low and unpredictable amounts of nutrients as compared with commercial fertilizers. The lower amounts of nutrients in organic fertilizers mean that farmers may need to use larger amounts of organic fertilizers in order to meet the needs of the crops. The balance of nutrients in organic fertilizer is often not what the crops need. This can mean that in order to supply the needed amount of nitrogen, for example, the fertilizer may also supply too much of another nutrient such as phosphorus. On the other hand, the lower nutrient amounts in organic fertilizers may make it less likely that crop plants will be damaged through exposure to excessive amounts of nutrients. Although organic fertilizers can be less expensive than commercial fertilizers, the use of organic fertilizers may produce lower crop yields. More land may be required to grow plants used as fertilizer (green manure) or to raise the livestock that produce the animal manure.

COMMERCIAL FERTILIZERS are produced through industrial processes. Commercial fertilizer is natural in the sense that its components come from natural mineral deposits or, in the case of nitrogen, from the air. These fertilizers contain nutrients in forms that crop plants can use. The amounts of each nutrient contained in commercial fertilizers are known precisely. This means that farmers know the exact amounts of nutrients applied to plants. A bag of commercial fertilizer is labeled with three numbers that describe the amounts of nitrogen, phosphorus, and potassium that it contains. For example, a bag labeled 15-5-10 contains 15 percent nitrogen, 5 percent phosphorus, and 10 percent potassium. In general, commercial fertilizers allow the farmer more control over plant nutrition than organic fertilizers because the amounts of nutrients in commercial fertilizers are precisely known and they are released in a more predictable way. Overuse of commercial fertilizers is more likely to occur as compared to overuse of organic fertilizers. No matter what type of fertilizers farmers use, they need to follow best management practices in order to raise healthy crops while, at the same time, protecting the environment.

MASTER 5.5

PROS AND CONS OF DIFFERENT FERTILIZERS

NAME
DATE

ORGANIC FERTILIZERS	
ADVANTAGES	DISADVANTAGES

COMMERCIAL FERTILIZERS	
ADVANTAGES	DISADVANTAGES

MASTER 5.6

NUTRITION POLLUTION

NAME

DATE

When we think of environmental pollution, we think of chemicals from industry and car exhaust fouling our air and water. Although nutrients occur naturally, they, too, can be a source of pollution. You should recall that either too little or too much of a nutrient can harm a plant or animal. A similar situation exists with regard to our environment. Excessive amounts of nutrients in our waterways are bad for the environment because they can lead to explosive growth of aquatic organisms such as phytoplankton, algae and bacteria. This rapid growth reduces the amount of sunlight available to other plants and animals. Furthermore, the metabolism of these organisms uses up the available oxygen and can cause fish and other animals to suffocate.

NONPOINT source pollution refers to polluted runoff water. When water from any source such as rain or irrigation for crops washes over land, it picks up contaminants that may include nutrients. These contaminants find their way into waterways either directly or through storm drains. So-called point sources of pollution come from a specific source such as a factory or waste-treatment plant.

In urban areas, such point sources are often the main contributors to nutrient pollution. Urban areas also are affected by nonpoint source pollution. For example, the burning of fossil fuels by cars and industry releases nitrogen compounds into the air. These compounds fall to the surface with rain and contribute to nutrient pollution.

As suburban areas have grown, they have moved beyond the reach of city sewer systems. Homes in many areas use septic systems that release nutrients from wastewater into the ground. Farmers also contribute to the problem. Overuse of fertilizers sends excess nutrients into the environment. Today, the largest source of nutrient pollution from agriculture is nitrogen from animal wastes that leaks into surface waters.

Antipollution laws are helping reduce nutrient pollution from point sources such as factories. Nonpoint sources represent the largest pollution threat to our waters, but they are difficult to identify and control. Can you think of ways to limit nutrient pollution from nonpoint sources?

MASTER 5.7

NUTRIENT POLLUTION
DISCUSSION QUESTIONS

NAME	
DATE	

DISCUSSION QUESTIONS

1. Why are excessive amounts of nutrients bad for the environment?

2. What is the difference between a point source and a nonpoint source of nutrient pollution? List two examples of each type of source.

3. What are some ways to limit nutrient pollution from nonpoint sources?

LESSON 6
EVALUATE

NOURISHING THE PLANET
IN THE 21ST CENTURY

AT A GLANCE

OVERVIEW

In this concluding lesson, students continue in their roles as agricultural experts. First, they discuss what challenges must be met in order to feed the world's population in 2050. Students then analyze a list of 10 recommendations about farming and select the three that they feel are most important. A class discussion results in choosing a final top five recommendations. As a homework assignment, students explain why their choices were better than the three recommendations that received the fewest votes.

MAJOR CONCEPTS

- The world's growing population demands that more food be produced in the future.
- Unless crop yields continue to improve, a greater portion of the world's land will have to be devoted to farming.
- A variety of farming practices can contribute to increases in food productivity.
- Meeting the challenge of nourishing the planet in the 21st century is a concern for all nations.

OBJECTIVES

After completing this lesson, students will be able to

- appreciate how soil properties contribute to plant health,
- recognize that nutrient deficiencies limit crop productivity,
- understand the role of fertilizer in growing plants and in restoring nutrient balance to agricultural soils,
- relate crop productivity to the need for more farmland, and
- describe challenges associated with feeding the world's growing population.

TEACHER BACKGROUND
Consult all sections in Teacher Background.

IN ADVANCE

PHOTOCOPIES

ACTIVITY	MASTER	NUMBER OF COPIES
1	Master 6.1, Memo from the Secretary General	1 to project
	Master 6.2, Review of Lessons	1 per team of 3 students and 1 to project
	Master 6.3, Recommendations for Nourishing the Planet	1 per team of 3 students and 1 to project
	Master 6.4, Recommendations Worksheet	1 per team of 3 students

MATERIALS

ACTIVITY	MATERIALS
1	No materials except photocopies

PREPARATION

No preparations are needed except for making photocopies.

PROCEDURE

ACTIVITY 1: NOURISHING THE PLANET IN THE 21ST CENTURY

This final lesson is an opportunity for students to synthesis what they have learned in the previous lessons and for you to evaluate students' learning.

TEACHER NOTE
This lesson involves a scenario where students play the roles of agricultural experts helping make recommendations about farming on a global scale. Students are given a list of 10 agricultural recommendations and are asked to decide which are the most important. These recommendations are not meant to be comprehensive. They do not address many issues that are important to feeding the world's growing population. For example, topics such as water management, genetically modified food, and no-till farming are not mentioned. Remember that the intent of this lesson is not to engage in a thorough examination of all aspects of agriculture but rather to provide a reason for students to reflect on and use what they have learned throughout the course of this module.

1. INTRODUCE THE LESSON BY ASKING THE CLASS TO THINK ABOUT THE CHALLENGES ASSOCIATED WITH FEEDING AN EXTRA 2 BILLION OR EVEN 3 BILLION PEOPLE BY THE YEAR 2050.

Although the year 2050 will seem like forever to students, you may point out that most of them will be living during this time and will see firsthand how well, or not, societies have met this challenge.

TIP FROM THE FIELD TEST
Have students calculate how old they will be in the year 2050. This helps reinforce the idea that they can expect to be around to see how well the challenge of feeding the planet was met.

2. EXPLAIN THAT IN THIS LESSON, STUDENTS WILL CONTINUE IN THEIR ROLES AS AGRICULTURAL EXPERTS. PROJECT *MASTER 6.1, MEMO FROM THE SECRETARY GENERAL.* ASK A VOLUNTEER TO READ THE MEMO ALOUD.

3. PROJECT *MASTER 6.2, REVIEW OF LESSONS* AND PASS OUT A COPY OF THE HANDOUT TO EACH STUDENT. EXPLAIN THAT IF THEY ARE TO FUNCTION AS AGRICULTURAL EXPERTS, THEN THEY SHOULD TAKE A MOMENT TO REVIEW WHAT THEY HAVE LEARNED.

4. ASK STUDENTS TO THINK BACK TO THE FIRST LESSON AND DESCRIBE WHAT THEY LEARNED ABOUT PLANTS AND THEIR ESSENTIAL ELEMENTS.

If necessary, remind students what activities made up Lesson 1. Summarize their responses on the board or on a projected copy of *Master 6.2, Review of Lessons.* Instruct students to take notes on their copies of the handout. If not brought up by a student, guide the discussion to bring out the following:

- Plants require 17 essential nutrients to complete their life cycle.
- Plants and humans require similar sets of essential nutrients.
- Plants obtain their essential nutrients from air, water, and mostly the soil.

5. CONTINUE THE REVIEW FOR LESSONS 2 THROUGH 5, REMINDING THE STUDENTS OF THE ACTIVITIES THEY DID AND SUMMARIZING THEIR RESPONSES ON THE BOARD OR CHART PAPER.

If not brought up by a student, guide the discussion to bring out the following:

LESSON 2

- Soils vary in their compositions.
- Soils represent a "bank" of nutrients.
- Soils contain both organic and inorganic material.
- Soils contain differing amounts of air space.
- Soils differ in their abilities to hold and transmit water.

LESSON 3

- Plants remove water and nutrients from the soil through the plant's root system.
- Some nutrients move into root cells from the soil by diffusion and others by an energy-requiring process (active transport).
- The plant vascular system has some similarities to the human circulatory system.
- Plants transport water from the roots to the rest of the plant using the xylem.
- Plants transport food from the leaves to the rest of the plant using the phloem.
- Soil forms by the breakdown of bedrock (parent material) and the addition of organic material.
- The loss of topsoil can have serious consequences.

LESSON 4

- Plants, like people, require essential elements to be present in certain quantities in order to be healthy.
- Plants extract nutrients from the soil; people remove nutrients as crops.
- Plants with nutrient deficiencies show specific symptoms.
- Fertilizer is food for plants.
- The soil is a "nutrient bank" that can hold a limited amount of nutrients. Fertilizers put more "money" in the bank by restoring nutrient balance to agricultural soils.

LESSON 5

- Only a small portion of Earth's surface is used to grow food.
- The world's population is growing at a steady rate.
- Unless food productivity increases, more land will have to be farmed.
- Fertilizers help increase food productivity.
- Fertilizers can be commercial or organic.
- Excessive amounts of nutrients can pollute water, soil, and air.

6. ARRANGE THE CLASS INTO TEAMS OF 3 STUDENTS. PASS OUT TO EACH TEAM 1 COPY OF *MASTER 6.3, RECOMMENDATIONS FOR NOURISHING THE PLANET* AND 1 COPY OF *MASTER 6.4, RECOMMENDATIONS WORKSHEET.*

7. INSTRUCT THE TEAMS TO READ THE LIST OF 10 RECOMMENDATIONS ON *MASTER 6.3, RECOMMENDATIONS FOR NOURISHING THE PLANET,* DISCUSS THEM WITHIN THEIR TEAMS, AND DECIDE WHICH ARE THE 3 RECOMMENDATIONS MOST IMPORTANT TO HELPING FARMERS MEET THE CHALLENGE OF FEEDING THE WORLD'S GROWING POPULATION.

Students should write their selections in the appropriate spaces on *Master 6.4, Recommendations Worksheet.* Beneath each selected recommendation is a space where the student should explain why they believe that their choice is among the most important recommendations that should be made about farming in the future. Allow teams about 20 minutes to complete their tasks.

TEACHER NOTE

You will notice that all of the recommendations are reasonable. Each one is important for food production or environmental protection. The rationale is for students to consider how farmers can increase food production. Encourage them to refer to their notes on *Master 6.2, Review of Lessons,* review what they have learned from the module, use their critical-thinking skills to review the choices, and select those that they feel are most important for farmers to implement.

8. AFTER STUDENTS HAVE DECIDED ON THEIR THREE RECOMMENDATIONS AND WRITTEN THEIR EXPLANATIONS, DISPLAY *MASTER 6.3, RECOMMENDATIONS FOR NOURISHING THE PLANET*. READ THE FIRST RECOMMENDATION ALOUD AND ASK HOW MANY TEAMS INCLUDED IT AS ONE OF THEIR TOP 3 RECOMMENDATIONS. NEXT TO THE RECOMMENDATION, WRITE THE NUMBER OF TEAMS THAT SELECTED IT.

9. ASK FOR VOLUNTEERS TO EXPLAIN WHY THEY BELIEVE THAT RECOMMENDATION IS AMONG THE MOST IMPORTANT.

After the first student speaks, ask if anyone has additional reasons for choosing it. Allow students to provide all of their reasons before moving on to the next recommendation.

10. CONTINUE THIS PROCESS UNTIL ALL 10 RECOMMENDATIONS HAVE BEEN DISCUSSED.

Make sure you have tallied how many teams voted for each recommendation.

11. REMIND THE CLASS THAT THE SECRETARY GENERAL ASKED THEM TO SUBMIT A LIST OF THE TOP 5 RECOMMENDATIONS. EXAMINE THE VOTE TOTALS AND DECIDE WHICH 5 SHOULD BE SENT TO THE SECRETARY GENERAL.

If some recommendations have the same number of votes, discuss them further until a consensus is reached or break the tie by choosing a recommendation for which you would like an additional assessment opportunity.

OPTIONAL HOMEWORK ASSIGNMENT 1

ASK STUDENTS TO WRITE A LETTER TO THE SECRETARY GENERAL THAT DEFENDS THEIR RECOMMENDATIONS.

Students should refer to what they have learned during the module in making their arguments. Students' arguments should demonstrate an awareness of

- essential plant nutrients,
- the importance of fertile agricultural soils (not necessarily other soils),
- the mechanisms by which plants obtain and transport nutrients,
- the effects of nutrient deficiencies,
- the role of fertilizers in promoting crop growth,
- the impacts of fertilizers on the environment, and
- the relationship between crop yields and land use.

OPTIONAL HOMEWORK ASSIGNMENT 2

ASK STUDENTS TO RESEARCH AND WRITE A SHORT PAPER THAT DESCRIBES A STRATEGY FOR INCREASING WORLD FOOD PRODUCTION. THE STRATEGY SHOULD BE ONE THAT WAS NOT DISCUSSED DURING THE LESSON.

If students are having trouble focusing their research, suggest a topic such as genetically modified foods.

LESSON 6 ORGANIZER

ACTIVITY 1: NOURISHING THE PLANET IN THE 21ST CENTURY WHAT THE TEACHER DOES	PROCEDURE REFERENCE
Ask the students to consider the challenges associated with feeding an extra 2 billion or 3 billion people by the year 2050.	Page 174 Step 1
Explain that they will continue in their roles as agricultural experts. Project Master 6.1, Memo from the Secretary General. Ask a volunteer to read it aloud.	Page 174 Step 2
Project *Master 6.2, Review of Lessons* and give each student a copy of the master. Explain that they will review what they have learned in the previous lessons.	Page 174 Step 3
Ask students to think back to Lesson 1 and describe what they learned about plants and their essential elements. Summarize their responses on a projected copy of *Master 6.2, Review of Lessons.*	Page 174 Step 4
Discuss Lessons 2 through 5. Remind the students which activities were part of each lesson. Summarize their responses.	Page 175 Step 5
Arrange the class into teams of 3 students. Give each team 1 copy of *Master 6.3, Recommendations for Nourishing the Planet,* and 1 copy of *Master 6.4, Recommendations Worksheet.*	Page 175 Step 6
Instruct the teams to read the recommendations on *Master 6.3, Recommendations for Nourishing the Planet,* discuss them, and decide which 3 are most important. Instruct students to write their selections and reasons on *Master 6.4, Recommendations Worksheet.*	Page 175 Step 7
Project *Master 6.3, Recommendations for Nourishing the Planet.* Read the first recommendation and ask how many teams selected it. Write down the number of teams that selected it.	Page 176 Step 8
Ask volunteers to explain why they feel that recommendation is important.	Page 176 Step 9
Continue with this process until all 10 recommendations have been discussed.	Page 176 Step 10
Remind students that they must submit a list of their top 5 recommendations. Examine the vote totals and compile a list of the top 5 recommendations.	Page 176 Step 11

MASTER 6.1

MEMO FROM THE SECRETARY GENERAL

NAME

DATE

Earth Food Bank

MEMO

To: **Chairperson of the Earth Food Bank Executive Committee**

From: **Secretary General of the Earth Food Bank**

About: **Recommendations about Farming**

Regarding our initiative Nourishing the Planet in the 21st Century, I have received the preliminary report from the Committee on Increasing Crop Yields. I am preparing an executive summary that will be released worldwide to the press. This press release needs to include the recommendations that the committee feels are most important to help farmers feed our growing population. Although the final committee report will discuss these recommendations in detail, the press release needs to be short and to the point.

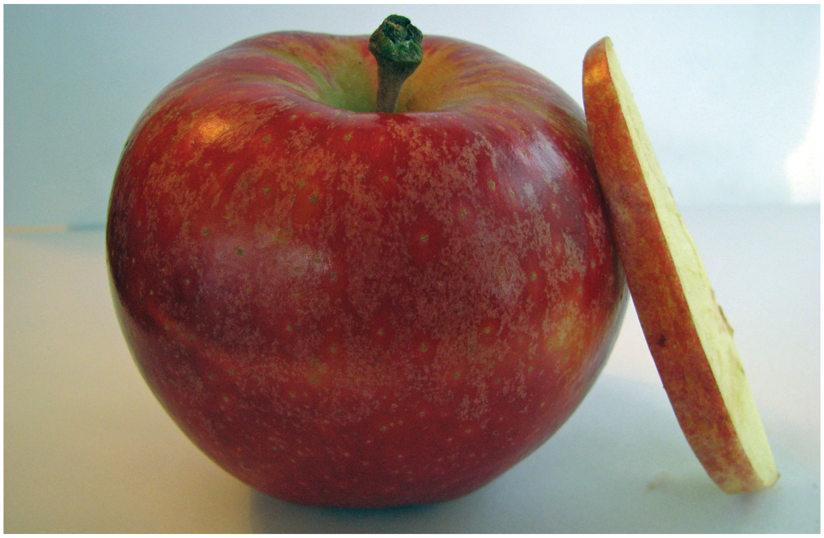
I have included with this memo a list of ten recommendations from the preliminary report. I would like the executive committee to review these recommendations and select what it considers the top five most important recommendations about farming. I will include these recommendations in my executive summary.

Thank you for your hard work and dedication to this important project.

MASTER 6.2
REVIEW OF LESSONS

NAME

DATE



1. ESSENTIAL ELEMENTS

2. PROPERTIES OF SOILS

3. MOVING NUTRIENTS THROUGH PLANTS

4. NUTRIENT DEFICIENCIES

5. LAND USE

MASTER 6.3

RECOMMENDATIONS FOR NOURISHING THE PLANET

NAME

DATE

Earth Food Bank

1. Farmers should use soils that allow plants to develop a healthy root system.
2. Whenever possible, farmers should use organic fertilizers.
3. Farmers should only grow crops in soils that have enough air space to allow water and oxygen gas to seep in and support plant growth.
4. Farmers should use commercial fertilizers to obtain the greatest crop yields.
5. Farmers should use methods that minimize nutrient losses to air and water.
6. Farmers should learn to diagnose plant nutrient deficiencies and use fertilizers to treat them.
7. Farmers should use methods that maintain the long-term fertility of the soil.
8. Only land currently being farmed should be used for agriculture.
9. Farmers should use proper amounts of fertilizers that supply essential nutrients that are missing from their soil.
10. Farmers should use the least amount of land necessary to feed the world's population.

MASTER 6.4

RECOMMENDATIONS WORKSHEET

NAME	
DATE	

PROCEDURE

STEP 1. Read *Master 6.3, Recommendations for Nourishing the Planet.*

STEP 2. Discuss the recommendations as a team and select the top 3 recommendations that your team feels are most important for farmers to meet the challenge of nourishing the world's population in the year 2050.

STEP 3. Write your team's selections in the following spaces. Include an explanation of why each of your choices is among the most important.

FIRST RECOMMENDATION	
EXPLANATION	

SECOND RECOMMENDATION	
EXPLANATION	

THIRD RECOMMENDATION	
EXPLANATION	

NOTES

NAME

DATE

NOTES

NAME	
DATE	

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