Feeding the World & Protecting the Environment

A HIGH SCHOOL ENVIRONMENTAL SCIENCE TEACHER SUPPLEMENTAL RESOURCE

NUTRIENTS FOR LIFE FOUNDATION

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NUTRIENTS FOR LIFE FOUNDATION

The Nutrients for Life Foundation is a global organization consisting of members and collaborative partners that develops and distributes science-based materials to improve plant nutrient literacy, soil health knowledge and promotes fertilizer's role in sustaining a growing population.

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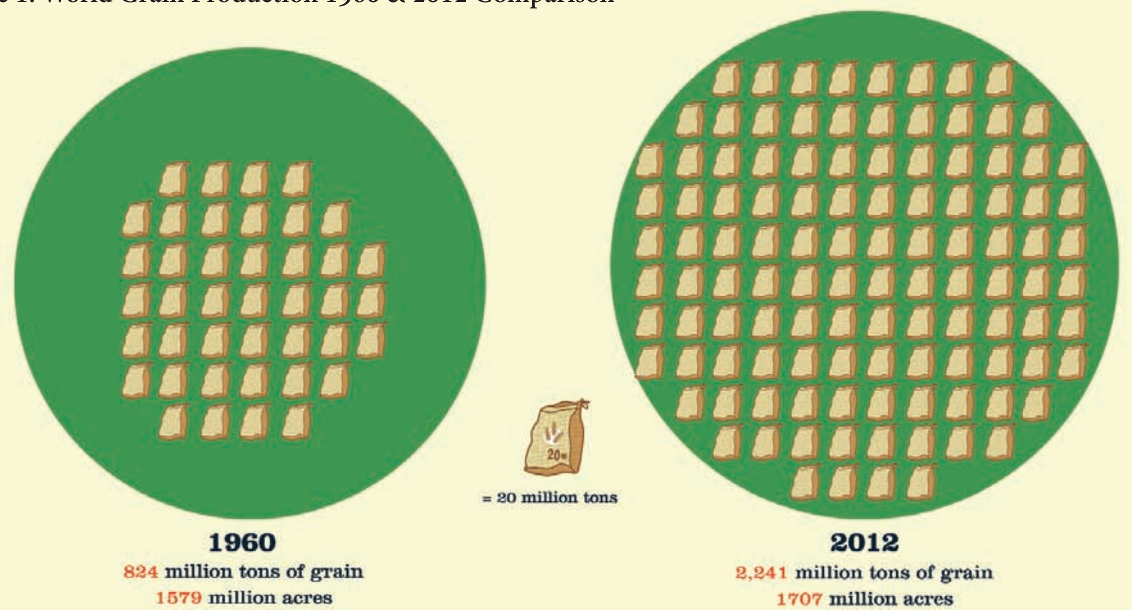
The explosive growth in agricultural productivity over the last 50 years is known as the "Green Revolution." The term was coined in 1968 by William S. Gaud, administrator of the U.S. Agency for International Development (USAID).

Nourishing Crops with Fertilizers

From 1960-2010, the population of Earth has more than doubled, yet the amount of land devoted to farming has remained almost the same. How is it possible to feed twice as many people from nearly the same amount of land? The answer is agricultural productivity. Impressive gains in agricultural productivity have kept world food production ahead of population growth. As an example, in 1960, world grain production totaled 824 million tons from 1,579 million acres. In 2012, it totaled 2,241 million tons from 1,707 million acres of land. If the extra 1,417 million tons of grain were grown at the same rate as in 1960, it would require an additional 2,587 million acres, which is 4.043 million square miles of land. In other words, agricultural productivity made it possible to save over four million square miles of land that can be left in a natural state or used for other purposes. This amount of land is nearly the entire land area of the United States and Mexico, including Alaska.

Table 1. World Grain Production 1960 & 2012 Comparison



Learn more about the Nobel Peace Prize winner in the book *The Man Who Fed the World* by Leon Hesser.

The same gains can be viewed on a smaller scale. In 1960, Iowa farmers averaged 62 bushels (bu.) of corn per acre on nearly 12.5 million acres. In 2013, the state average was 169 bu. per acre on more than 13 million acres, or nearly a three-fold increase in production per acre.

This explosive growth in agricultural productivity from 1950-2000 is known as the "**Green Revolution.**" The term was coined in 1968 by William S. Gaud, administrator of the United States Agency for International Development, (USAID), who said, "Developments in the field of agriculture contain the makings of a new revolution … I call it the Green Revolution."

The late Nobel Laureate Dr. Norman Borlaug (March 25, 1914–September 12, 2009) is considered "the Father of the Green Revolution." As a 30-year-old plant pathologist in 1944, Borlaug went to Mexico to solve a problem with rust, a fungal disease that perennially plagued the Mexican wheat crop. It took him 13 years to develop a strain of wheat that was resistant to rust, but a problem remained. Mexican wheat was tall and slender. When fertilizer was applied, the heads became heavy with grain and toppled over in the wind or rain. Realizing that he had to change the architecture of the wheat, Borlaug took dwarf varieties of Japanese wheat and crossed them with wheat that grows well in Mexico's hot, dry climate. Eventually he developed a short wheat variety that grew well in Mexico's climate, but didn't topple when the grain matured.

After his success in Mexico, Borlaug went to Pakistan and India where food production lagged behind population growth and American food aid was needed to avert famine. At first, derivatives of Mexico's dwarf wheat did not perform well because farmers were not using the right fertilizer, water management and weed control. Borlaug's persistence, learned from painstakingly crossbreeding plants, paid off as he guided both countries to self-sufficiency in wheat for the first time. He and his team of scientists also applied the same science and technology to rice and maize (corn). Borlaug said improved seeds were "the catalyst that ignited the Green Revolution," and mineral fertilizer is the "fuel" that powers it.

Before his death in 2009, Dr. Borlaug established the World Food Prize to be awarded each year to an individual(s) who made significant and measureable contributions to expanding the world food supply. The website, www.worldfoodprize.org, also contains more information about the Green Revolution.

Borlaug's work in developing countries mirrored what was happening in the developed world. Farmers were able to increase their yield by breeding better plant varieties, adopting better water management practices, and using **commercial fertilizer** more efficiently. Responsible fertilizer management practices ensure the appropriate type of nutrient is used at the right time; applied in the proper amount; and placed where the plant can most easily use it.

These practices play a large role in increasing crop production while minimizing nutrient losses to the environment. Today, the International Plant Nutrition Institute and the International Fertilizer Association estimate that fertilizer helps produce 50 percent more food than without it.

Plants depend on soil for mechanical support, water, air, and nutrients. They also depend on external factors such as light and temperature. These linked factors influence plant growth and nutrient uptake in numerous ways. As water and air occupy the pore spaces in the soil, factors that affect water influence soil and air. In turn, water affects the soil. Air, water, temperature and other environmental factors influence nutrient availability. Stress occurs if nutrient availability and plant growth are compromised. Plant growth also is affected by soil compaction, soil depth, and the presence or absence of many kinds of microbial organisms in the soil.

Essential Plant Nutrients

All plants require at least 17 essential elements to complete their life cycle. These include 14 mineral nutrients and 3 non-mineral elements: carbon (C), hydrogen (H), and oxygen (O). C, H and O make up about 96 percent of most plants, but the mineral elements are crucial to a plant's structure, growth and nutritional quality. The elements plants require in relatively large amounts are called macronutrients, while micronutrients are used in much smaller quantities.

Table 2. Essential Plant Nutrients

Element	Symbol	Classification	Chemical form taken into the plant
Hydrogen	H	Non-mineral nutrient	H_2O
Oxygen	O	Non-mineral nutrient	O_2 and CO_2
Carbon	C	Non-mineral 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+}

Nitrogen, phosphorus, and potassium are primary macronutrients, while calcium, sulfur, and magnesium are secondary macronutrients (Table 2). The rest of the essential elements are micronutrients, including boron, chlorine, and more. Plants absorb most of their essential elements from water in the soil. Usually the essential elements are taken up as positively or negatively charged ions.

Each plant nutrient has specific functions within the plant—some are relatively simple while others take part in complicated biochemical reactions (Table 2). All plant nutrients function together to support healthy growth. Each plant nutrient is available in different chemical forms and undergoes unique reactions after entering the soil. Regardless of their original source and their soil reactivity, the nutrients must be in a soluble and plant-available form before they can be taken up by plants. A nutrient deficiency results if a particular nutrient is not available in sufficient quantity to meet the needs of the growing plant (Table 3). Nutrient toxicity occurs when a nutrient is present in such excess that it harms the plant. Nutrients move through the ecosystem in cycles in which they are exchanged between animals, plants, the soil, and the air.

Table 3. Symptoms of Plant Deficiencies and Toxicities

Plant nutrient	Condition	Symptoms
Nitrogen	Deficiency	Light green to yellow leaves; stunted growth; 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	Nutrient deficiencies in magnesium and possibly calcium; wilting due to excess salt
Calcium	Deficiency	Poor fruit development; young leaves remain rolled and joined together; younger leaf tips show light green/whitish spots.
	Toxicity	Deficiencies in magnesium or potassium
Magnesium	Deficiency	Yellow or light green stripes between veins; 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
Boron	Deficiency	Deformed and discolored leaves; death of growing points
	Toxicity	Yellowed leaf tips, scorched appearance; premature leaf dropping
Chlorine	Deficiency	Wilting of upper leaves followed by chlorosis
	Toxicity	Leaf burn or drying of leaf tissues.
Copper	Deficiency	Young leaves uniformly pale yellow, or may wilt and wither without chlorosis.
	Toxicity	Reduced shoot vigor, poorly developed root systems, discolored roots, and leaf chlorosis (yellowing). They can be confused with symptoms of Fe deficiency.
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
Molybdenum	Deficiency	Overall chlorosis, mottled spotting
	Toxicity	Bright orange leaves
Nickel	Deficiency	"Mouse ear" is the expression used to describe a deficiency of Ni in pecan trees. The tip of the young leaves has dark spots and is rounded, similar to the ear of a mouse.
	Toxicity	Chlorosis due to reduced Fe adsorption, stunted growth of the root and shoot, and unusual spotting.
Zinc	Deficiency	Yellowing on young leaves; stunted growth; delayed maturity
	Toxicity	Possible iron deficiency

Essential Elements Review

Nourishing Crops with Fertilizers

Directions: **Fill in the Outline.**

I. Green Revolution

a. Description: ______________________________

b. Term coined in __________ by ____________________

II. ____________________: Father of the Green Revolution

a. Accomplishments

i. ______________________________

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ii. ______________________________

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iii. ______________________________

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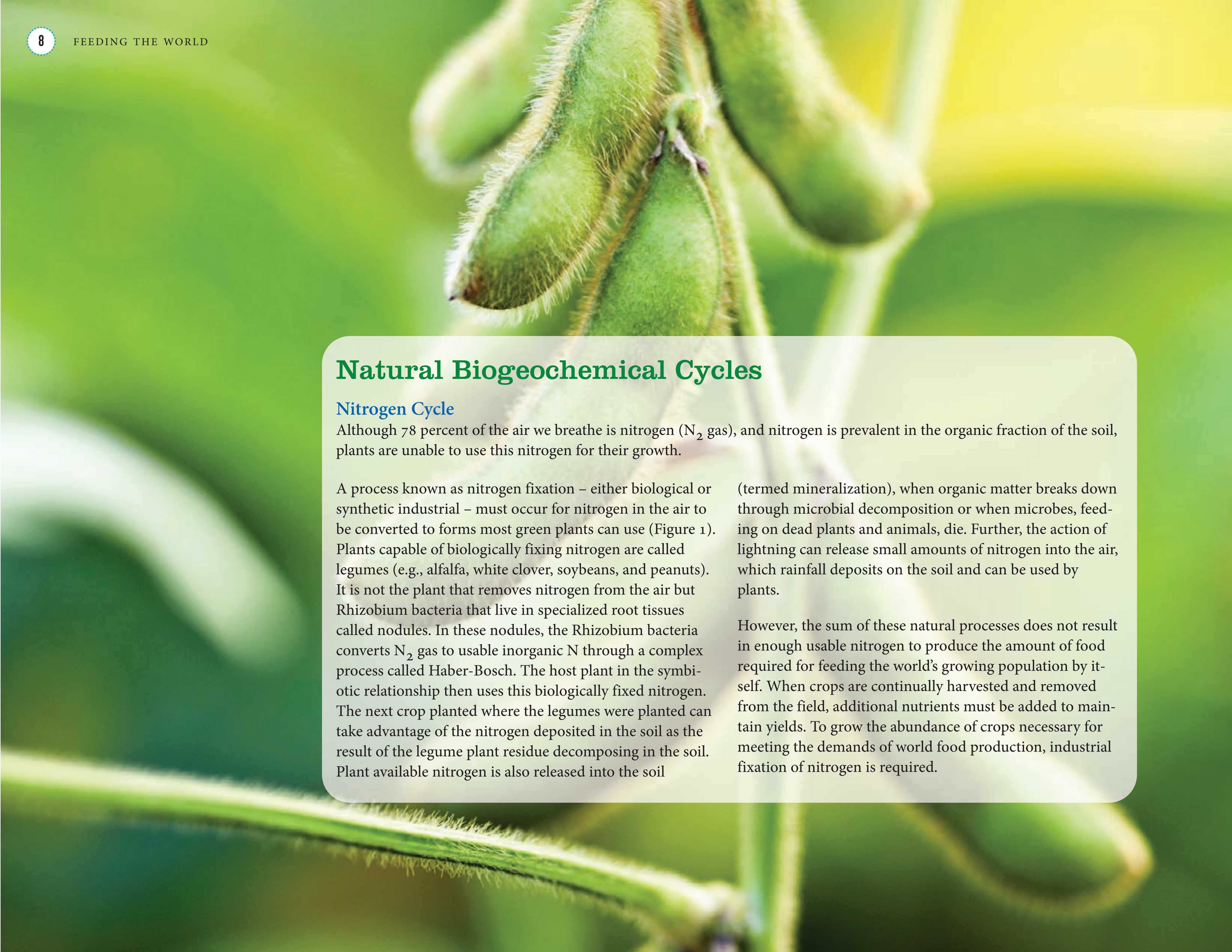


Natural Biogeochemical Cycles

Nitrogen Cycle

Although 78 percent of the air we breathe is nitrogen (N_2 gas), and nitrogen is prevalent in the organic fraction of the soil, plants are unable to use this nitrogen for their growth.

A process known as nitrogen fixation – either biological or synthetic industrial – must occur for nitrogen in the air to be converted to forms most green plants can use (Figure 1). Plants capable of biologically fixing nitrogen are called legumes (e.g., alfalfa, white clover, soybeans, and peanuts). It is not the plant that removes nitrogen from the air but Rhizobium bacteria that live in specialized root tissues called nodules. In these nodules, the Rhizobium bacteria converts N_2 gas to usable inorganic N through a complex process called Haber-Bosch. The host plant in the symbiotic relationship then uses this biologically fixed nitrogen. The next crop planted where the legumes were planted can take advantage of the nitrogen deposited in the soil as the result of the legume plant residue decomposing in the soil. Plant available nitrogen is also released into the soil (termed mineralization), when organic matter breaks down through microbial decomposition or when microbes, feeding on dead plants and animals, die. Further, the action of lightning can release small amounts of nitrogen into the air, which rainfall deposits on the soil and can be used by plants.

However, the sum of these natural processes does not result in enough usable nitrogen to produce the amount of food required for feeding the world's growing population by itself. When crops are continually harvested and removed from the field, additional nutrients must be added to maintain yields. To grow the abundance of crops necessary for meeting the demands of world food production, industrial fixation of nitrogen is required.

In 1918, scientists Fritz Haber (1868-1934) and Carl Bosch (1874-1940) were awarded the Nobel Prize for developing nitrogen fertilizer by synthesizing ammonia (NH_3) from nitrogen (N_2) gas and hydrogen. While this process has been modified several times, today the Haber-Bosch process remains the method through which almost all 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. The Haber-Bosch process has increased the amount of plant-available nitrogen by 60 percent to 70 percent. Ammonia is an important fertilizer and can also be used as a feedstock for other nitrogenous fertilizers. Ammonia, in its natural state, is a gas, but is a liquid at low temperature. The majority of ammonia fertilizer comes in the form of salts, solutions, or anhydrously. It 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. For its use as a fertilizer, urea is typically found in a solid form, either as granules or prills.

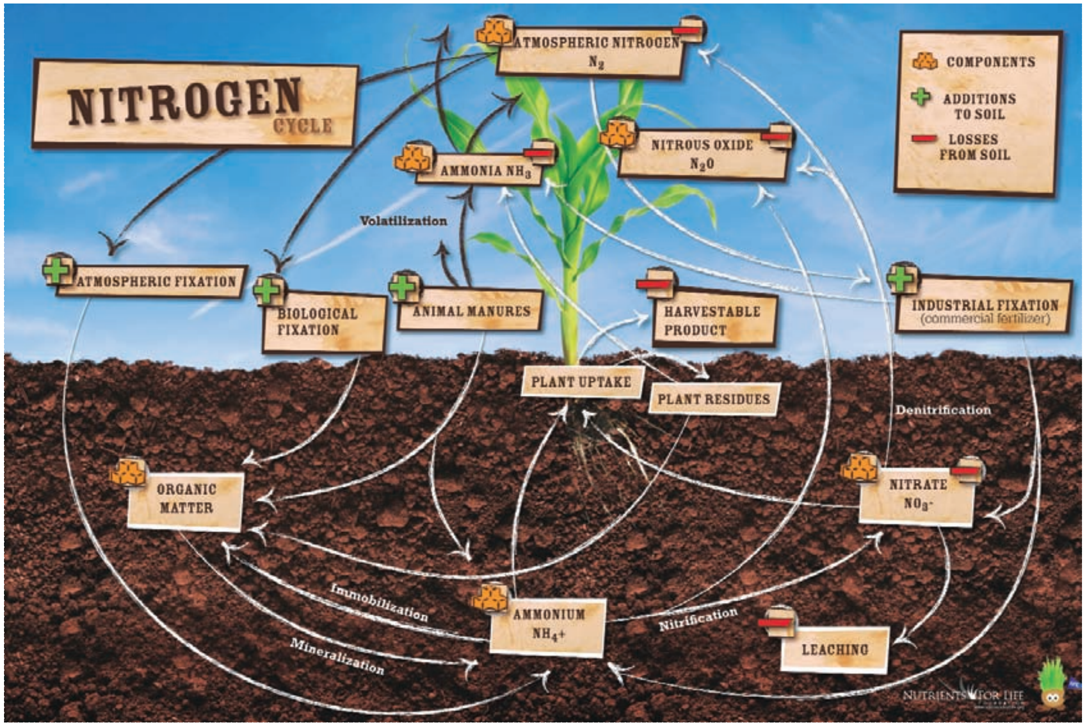


Figure 1. The Nitrogen Cycle

Unlike carbon, oxygen, and nitrogen, the phosphorus cycle is a sedimentary cycle, meaning biological fixation with microorganisms does not occur, nor is the atmosphere a reservoir for phosphorous (Figure 2). Plants take up phosphorus almost entirely through the soil. Plant material undergoing decomposition releases phosphorus in a plant-available form and weathering of rocks with phosphate minerals can also provide phosphorus.

Phosphorus Cycle

Phosphorus 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, which is the cell's energy molecule. It also plays vital roles in capturing light during photosynthesis to help fight external stress and prevent disease.

Sulfur Cycle

Although sulfur is a common element found in soil, it is also a mobile nutrient and can move quickly down through the soil to the subsoil. As a result, sulfur deficiencies are not uncommon in soil tests. Interestingly in the past, industrial "smokestack" emissions contributed sulfur to nearby soil. Through increased regulations on emissions, sulfur via "smokestacks" has been reduced.

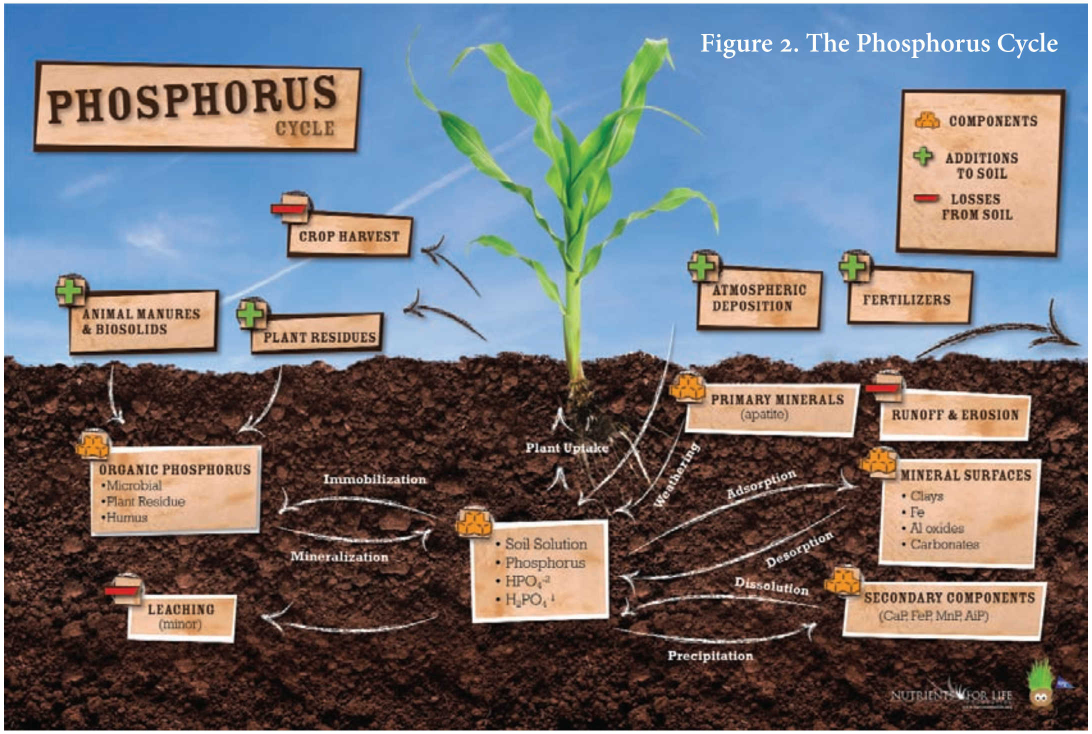


Figure 2. The Phosphorus Cycle

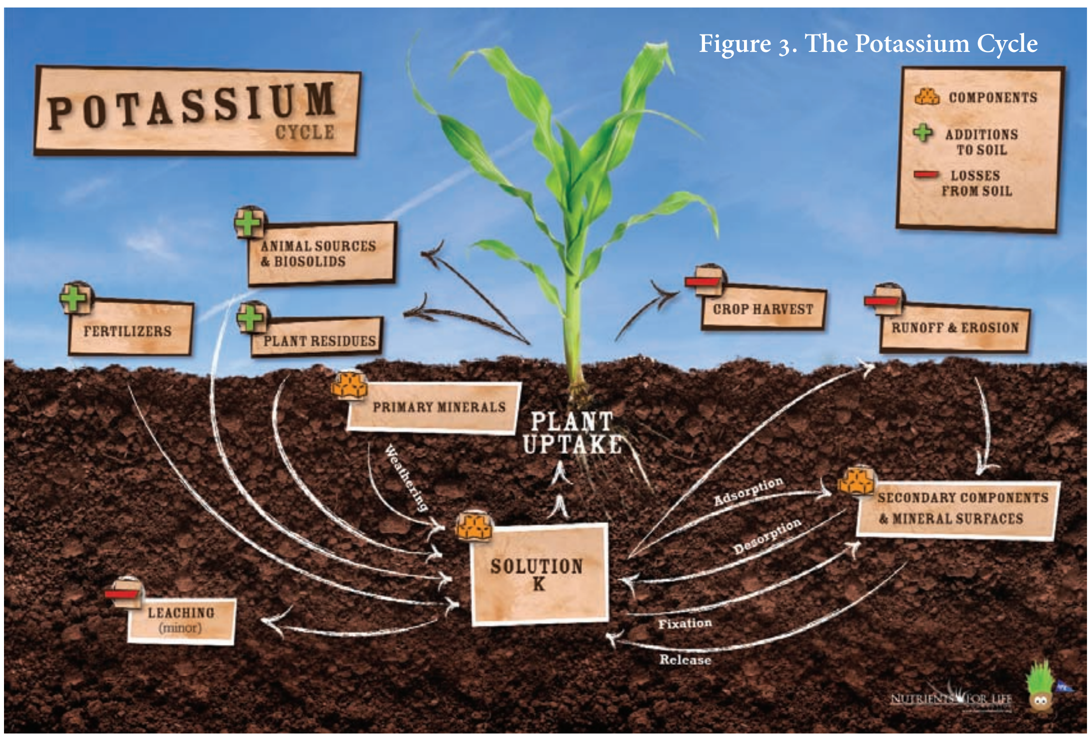


Figure 3. The Potassium Cycle

One of the first elements described by scientists, sulfur is essential to cell life. Sulfur is a component of amino acids methionine and cysteine, which are used in the synthesis of proteins in all living things. Enzymes associated with photosynthesis and chlorophyll synthesis also need sulfur.

The world's most important supply of sulfur is a bi-product from petroleum refining and from "sour" natural gas containing significant amounts of hydrogen sulfide (H_2S). Sulfur can also be obtained by mining sulfur-containing ores. Large deposits are associated with salt domes found along the Gulf of Mexico.

Potassium Cycle

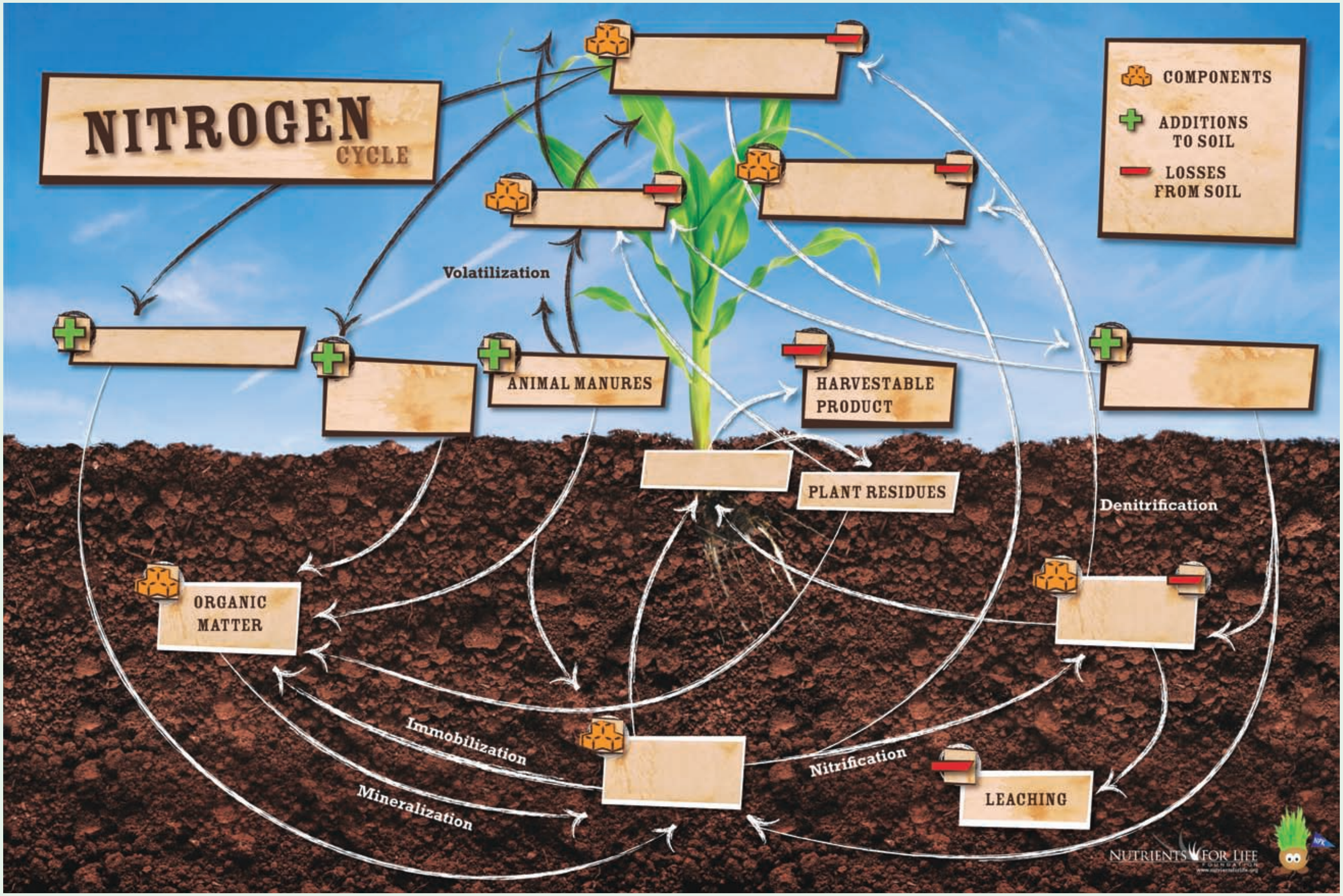
Potassium (K) is one of the three macronutrients, along with nitrogen (N) and phosphorus (P), and is essential to several physiological processes of every living cell (Figure 3). Potassium activates enzymes that are catalysts for chemical reactions involved with plant growth. It acts as a regulator for both water balance in plants and the rate of photosynthesis. Potassium can be released from organic matter (decaying plants) in soils, but in modern cropping systems, most potassium comes from commercial fertilizers. Commercially produced potassium is mined from sedimentary salt beds left behind following the evaporation of ancient seas and lakes. Alternatively, some sulfate of potash is harvested from the Great Salt Lake in Utah. Nearly all potassium fertilizer is in the form of potassium chloride (KCl).

NAME

PERIOD

Nitrogen Cycle Organizer

Directions: Fill in the blanks with the appropriate answer.

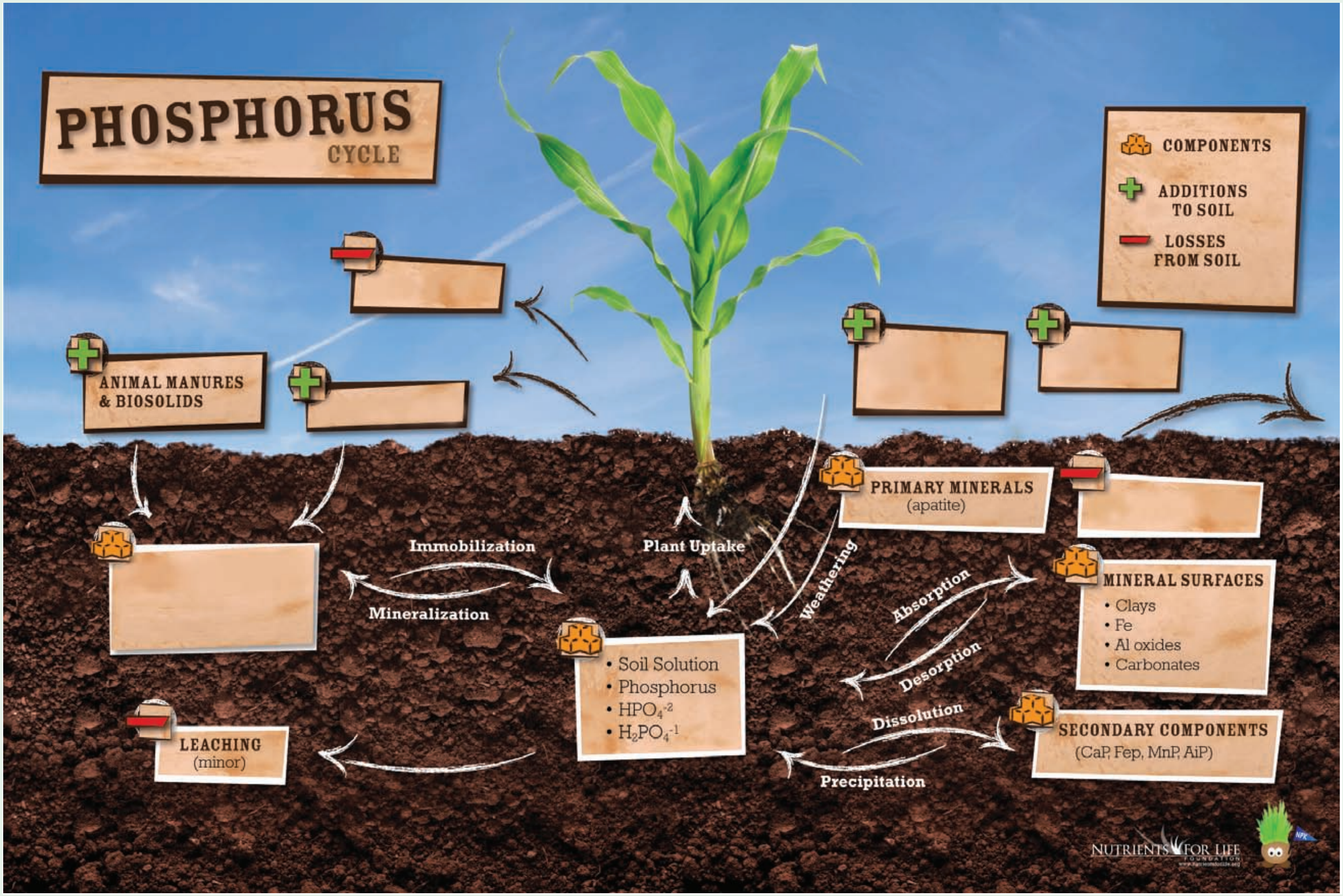


NAME

PERIOD

Phosphorus Cycle Organizer

Directions: Fill in the blanks with the appropriate answer.

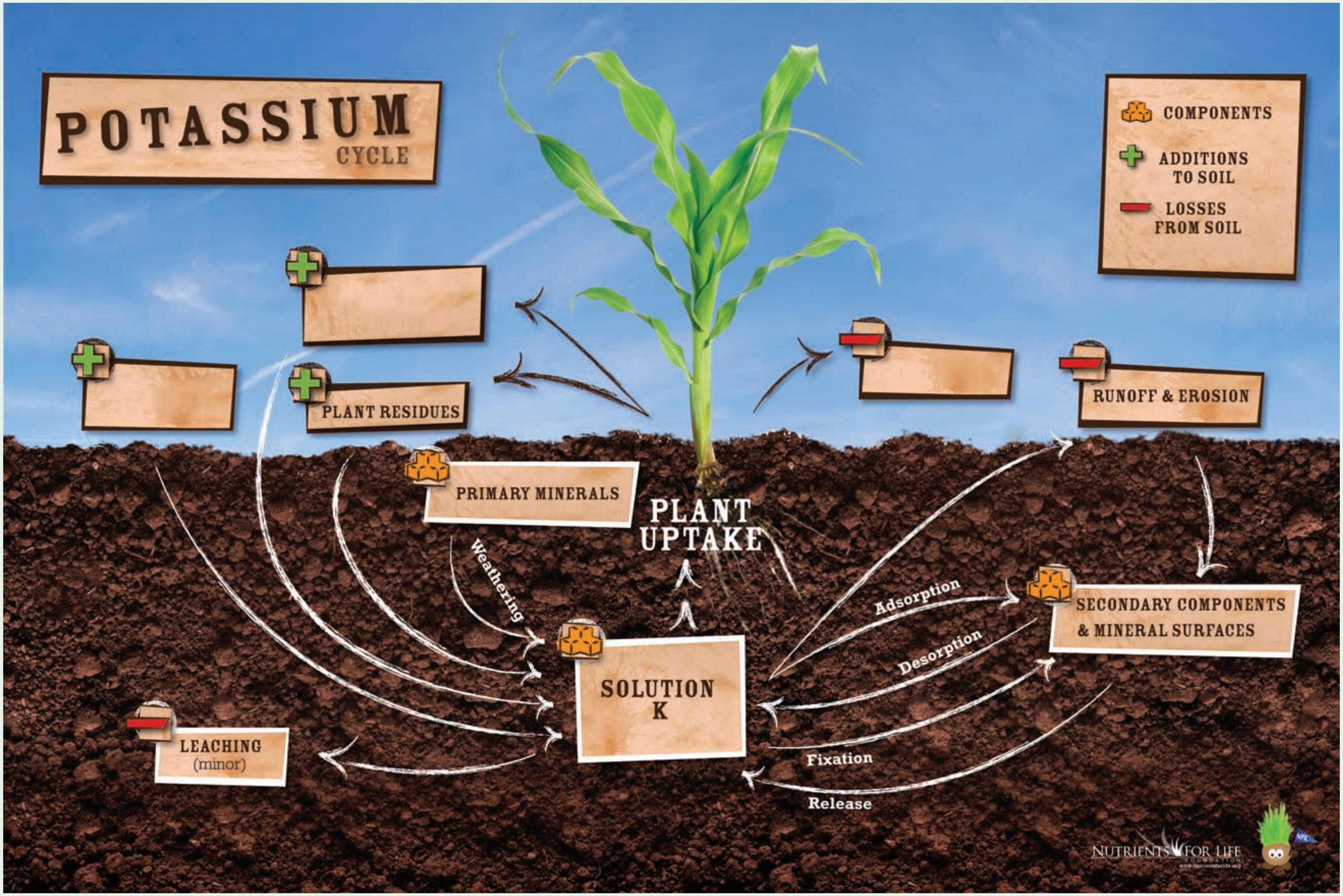


NAME

PERIOD

Potassium Cycle Organizer

Directions: Fill in the blanks with the appropriate answer.



Organic and Commercial Fertilizer

During the past 30 years, the United States has witnessed large growth in organic farming. The USDA's National Organic Program defines organic as "a labeling term that indicates that the food or other agricultural product has been produced through approved methods. These methods integrate cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity." Sewage sludge, irradiation, and genetic engineering may not be used. Most synthetic fertilizers are excluded as well.

USDA's National Organic Program (NOP) sets the rules for organic farmers, packers, processors and those who sell products labeled with the official "USDA Organic" seal (Figure 4). The NOP (www.ams.usda.gov/AMSv1.0/nop) is a marketing program and not a food safety or nutrition program.

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 are created from natural mineral deposits (phosphate and potash). Nitrogen fertilizer is manufactured from a number of sources. Most nitrogen fertilizer manufacturing involves ammonia (NH_3) in one way or another. Chemically, there is no difference between a nitrogen atom that comes from manufactured 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 to a plant. However, there are differences in the rate at which the nitrogen from these sources is made available to plants and the ratio of nitrogen to other elements, such as phosphorus.

A major distinction between organic and commercial fertilizers 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. Compost, which is often used by home gardeners, is a mixture of decayed organic material. Compost and manure 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 make it convenient for farmers to apply them at rates that ensure that growing plants' needs are met and environmental nutrient losses are minimized.

An advantage of plant-based organic fertilizers (e.g., compost) is that they increase the water holding capacity of soil by adding humus and carbon to the soil. They also feed beneficial microbes, making the soil easier to work. But organic fertilizers must decompose before the nutrients can be taken up by plants. This can be a disadvantage if a certain element, such as nitrogen, is needed immediately.

Manure-based organic sources are typically more volatile – or subject to movement – in the environment than commercial fertilizers (Table 4). If any nutrient – commercial or organic – is applied at a rate higher than plants can use it, the excess may run off the field or

Figure 4. USDA Organic Seal from NOP marketing program.

Table 4: Acreage Receiving Manure (by crop and species, 2006)
Acres applied (thousand), by source of manure

	Dairy cows	Beef cattle	Swine	Poultry	Other	All
Barley	54	36	4	4	2	100
Corn	5,612	1,617	1,161	472	224	9,086
Cotton	67	101	0	228	1	397
Oats	218	139	8	3	7	375
Peanuts	0	8	0	44	0	52
Sorghum	1	37	7	1	0	46
Soybeans	354	327	139	132	30	982
Wheat	107	250	26	12	6	401
All	**6,413**	**2,515**	**1,345**	**896**	**270**	**11,439**

Note: other sources include equine, sheep, and biosolids.

Source: ARMS Phase II surveys for the specific crops, 2003 through 2006, adjusted to age base using the June 2006 USDA/NASS Acreage report. James M. MacDonald, Marc O. Ribado, and Michael J. Livingston, et al., Manure Use for Fertilizer and for Energy: Report to Congress, USDA, ERS, AP037, Washington, DC, June 2009, http://www.ers.usda.gove/media/156155/ap037_I_.pdf.

disperse into the air and contribute to nutrient pollution. Additionally, compost is hard to produce in a large enough scale to meet the nutrient demands of larger farms. Most organic fertilizers used on farms are manure-based. However, transporting manure can often be prohibitive unless the animal waste is created adjacent to the cropland. Farms with animal waste must manage the manure responsibly. Manure must be collected, stored, and distributed to the cropland or pasture land. If manure is not properly managed, surface runoff can occur and inversely affect water quality. The nutrient content of the manure depends on its source, and the nutrient needs of the crops might not match those in the manure. Other factors preventing the wide use of manure fertilization include soil compaction from the manure application equipment and the relative cost and availability of commercial fertilizer.

Farmers who fertilize their crops have the choice of using either organic or commercial fertilizers, or a combination of the two types.

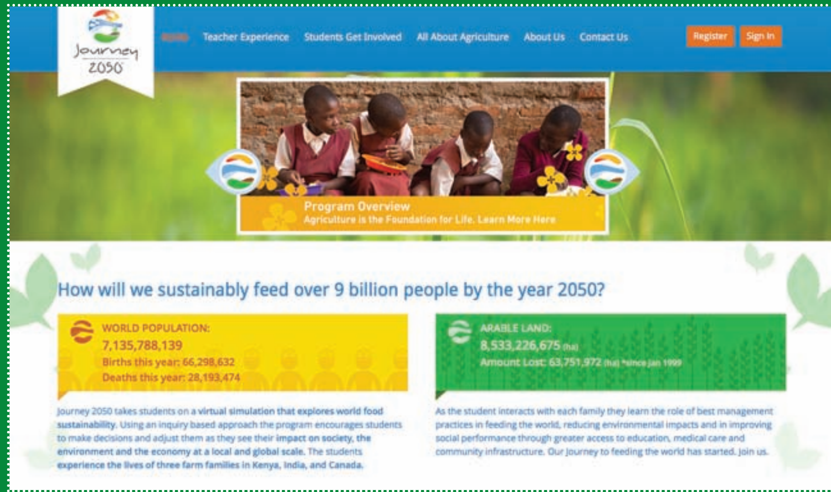
Roles in Sustainability

The most frequently used definition of sustainable development is from "Our Common Future," the 1987 report of the World Commission on Environment and Development (WCED). It states that sustainability is: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Sustainability requires the reconciliation of "three pillars" emphasizing environmental, social, and economic demands. What sustainability is, what its goals should be, and how these goals are to be achieved are sector- and industry-specific.

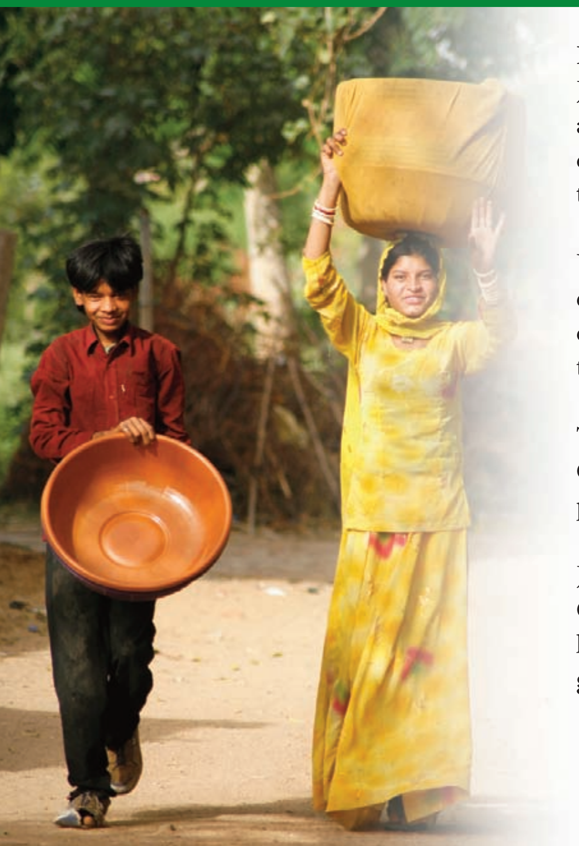
In the case of sustainable agriculture, the three pillars mean integrating three main goals: environmental health, economic profitability, and social and economic equity. Therefore, stewardship of both natural and human resources is of prime importance. Stewardship of human resources includes consideration of social responsibilities, such as the health and safety of workers, the economic needs of communities, and consumer health and safety both in the present and the future. Stewardship of land and natural resources involves maintaining or enhancing this vital resource base for the long term. The production and maintenance of an affordable, healthy food supply is critical to all of these goals.

Fertilizers' role in supporting worldwide food production is beyond question, but the role the fertilizer industry plays in preserving the natural environment is sometimes recognized less. The fertilizer industry is a strong leader in supporting and promoting agronomic research and outreach to farmers—to help them understand the latest technology and management practices available to protect the environment. Fertilizer use is a key component of sustainable agricultural intensification—a global effort to increase the productivity of existing land and water resources. This intensification of existing production patterns reduces pressure to bring sensitive land, forest, and water resources into agricultural production.

In addition to their support from fertilizer manufacturers and retailers, farmers receive environmental advice and technical information from USDA's Natural Resource Conservation Service (NRCS), Cooperative Extension System, certified crop advisers (CCA), and farm and commodity organizations.



Journey 2050



How will we sustainably feed 9 billion people by the year 2050?
Journey 2050 takes students on a virtual simulation that explores world food sustainability. Using an inquiry based approach the program encourages students to make decisions and adjust them as they see their impact on **society, the environment, and the economy** at a local and global scale.

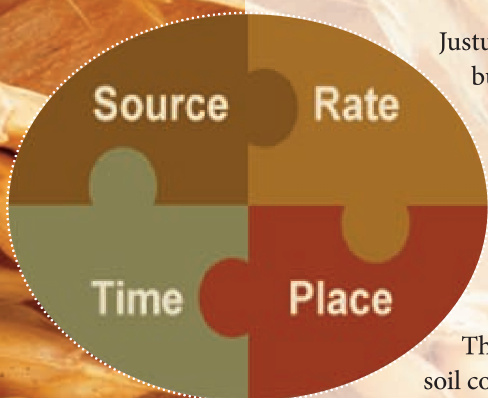
Using an iPad farming game, interactive videos, and hands-on activities students will experience agriculture like it's never been taught before. The program is being developed with teachers and sustainability experts to compliment curriculum and provide the critical thinking skills needed to address global food sustainability issues.

The students experience the lives of three farming families in **Kenya, India, and Canada.** As the students interact with each family they learn about best management practices and the impact that our present-day decisions will have on our future lives.

Journey 2050 is available as a field trip at the Agrium Western Event Centre in Calgary, Alberta, Canada plus an **online experience** for anyone in the world to play, learn, and explore agriculture sustainability. Students can access the Journey 2050 game through the Apple app store or www.journey2050.com.

4R Nutrient Stewardship

Applying the right source of plant nutrients at the right rate, the right time, and in the right place, is the core concept of 4R Nutrients Stewardship. All of these four "rights" are necessary for sustainable management of plant nutrition: management that sustainably increases the productivity of plants and crops. The 4R concept is simple, but the implementation is intensive and site specific.



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. Liebig stressed the value of replacing nutrients to maintain soil fertility. Liebig's Law of the Minimum states that the yield of a crop will be determined by the element present in the most limiting quantities (Figure 5). In other words, the excess of one nutrient cannot overcome the deficiency of another. All of the 17 essential elements must be present in balanced quantities sufficient to meet the requirements of the growing crop.

The best tool for determining the availability of plant nutrient supply is a soil test—a chemical analysis of soil composition. Several soil test methods are utilized to measure the availability of individual nutrients in collected soil samples. Different methods are often recommended for different regions because certain tests are more appropriate for some soil than others. As effective as soil testing can be in determining the right fertilizer rate, it is not always a reliable tool for estimating the availability of some of the more mobile nutrients, such as nitrogen and sulfur, in humid and high rainfall areas.

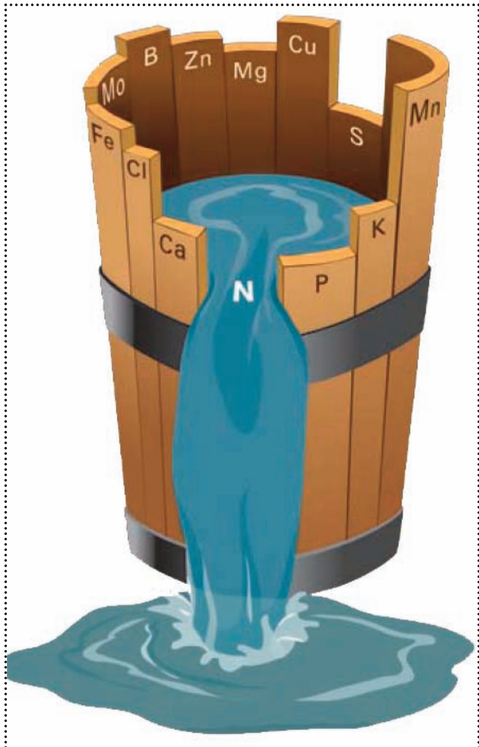


Figure 5. According to the law of the minimum, plant growth will be reduced if just one essential element is lacking.

Right Source

As you previously read, each plant nutrient has specific functions within the plant—some are relatively simple while others take part in extremely complicated biochemical reactions. All plant nutrients function together to support healthy plant growth. Once within the plant, the original source of the mineral nutrient is no longer important.

Selecting the right fertilizer source begins with determining which nutrients are actually required. Soil and plant analysis, plant tissue and sap tests, on-farm test plots, chlorophyll sensors, visual detection of deficiency symptoms, or soil tests can determine nutrients that are limiting. Each of these actions can provide useful information in making fertilizer application decisions. Merely guessing at the needed nutrients can precipitate numerous problems associated with under- or over-fertilization.

Each plant nutrient is available in different chemical forms and undergoes unique reactions after entering the soil. Regardless of their original source and their soil reactivity, the nutrients must be in a soluble and plant-available form before they can be taken up by plants.

Fertilizers are normally sold with a grade or guaranteed minimum analysis. The grade is presented as a series of numbers representing percent nutrient content by weight. The first number represents total nitrogen; the second, available phosphorus as P_2O_5 equivalent, and the third, soluble potassium as K_2O equivalent. For example, 100 kg of a 10-15-20 fertilizer contains 10 kg of nitrogen, 15 kg of P_2O_5, and 20 kg of K_2O. For fertilizers containing other nutrients, additional numbers can be added with the chemical symbol of the nutrient; for example, a 21-0-0-24S fertilizer contains 21 percent nitrogen and 24 percent sulfur.

Right Rate

Determining the nutrient use efficiency (NUE) of a crop production system is one way to evaluate effectiveness of fertilizer applications. It can be calculated many ways. One common method is to determine a crop's agronomic efficiency (AE). Agronomic efficiency is the amount of yield increase per unit of fertilizer applied. When the same units are used for yield increase and fertilizer rate, the expression becomes a unit-less ratio and is calculated as follows:

$AE= (Y-Y_0)/F$

1. Y is crop yield with fertilizer nutrient applied;
2. Y_0 is the crop yield with no application of the nutrient in question;
3. F is the amount of fertilizer nutrient applied.

The typical AE range is 10-25. This varies by type of crop. Wheat and barley are more likely to be at the lower end of the range. A high nitrogen feeder like corn could have an AE of 15-30 in a well-managed system.

As an example, without any nitrogen the yield for corn might be 2,800 lbs. of grain per acre, or 50 bu/ac. Adding a minimal 100 lbs. of nitrogen might increase yields to 5,600 lbs. of grain or 75 bu/ac. The equation becomes AE= (5,600 – 2,800)/100 or AE=28.

It is important for farmers to keep the AE high, find the optimum right rate, and not exceed it. The goals are to be both agronomically and economically efficient, but it would be short-sighted to consider a high AE the only factor to judge success. For instance, productivity, such as a high yield, is also an indicator on effective nutrient use. This means maximizing nutrient uptake by the crop in a cost-effective manner, while limiting losses from the root zone.

Right Time

An understanding of crop uptake dynamics and patterns is an important component in determining appropriate timing of fertilizer applications. The rate of plant nutrient uptake is not consistent throughout the growing season. The pattern is characterized by a rather slow early uptake, in-

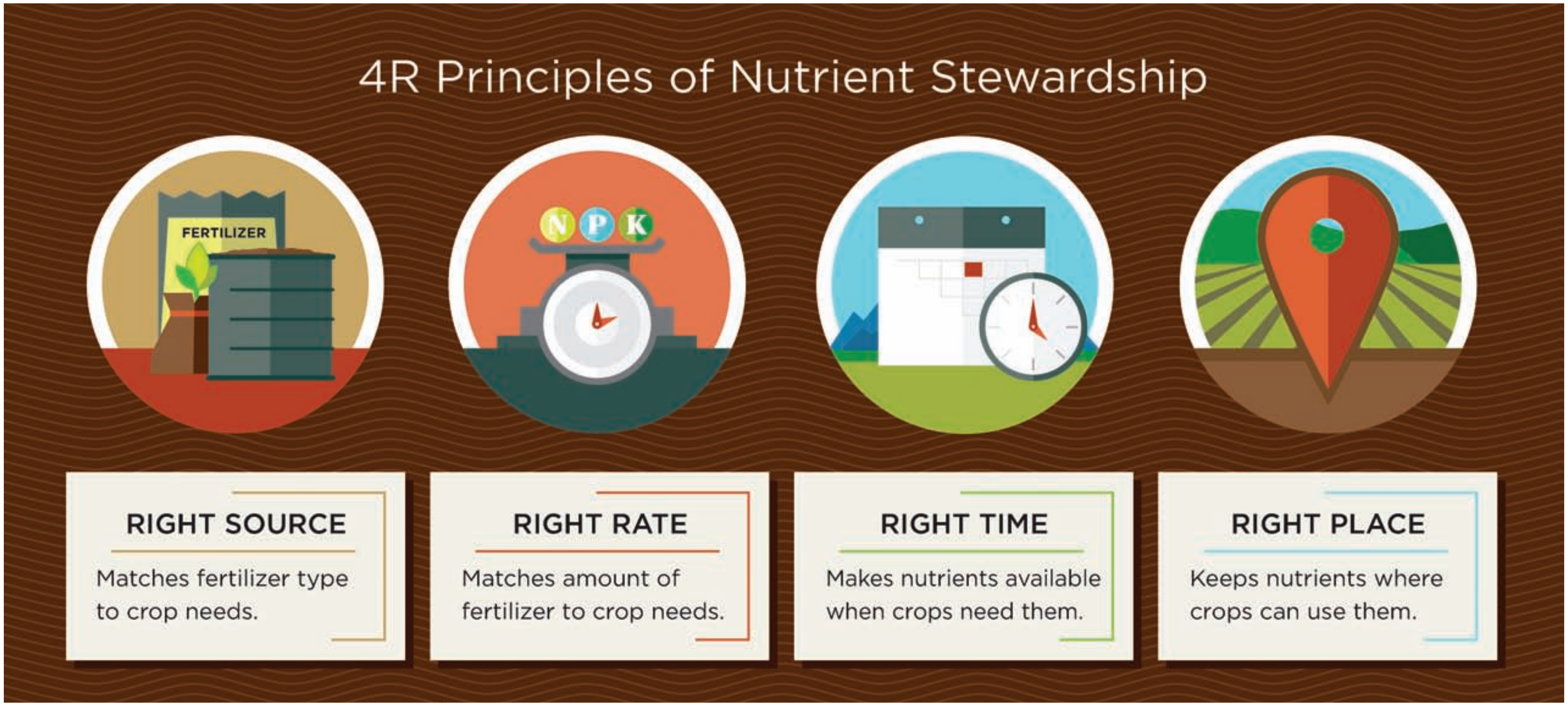


Figure 6. The basic 4R Nutrient Stewardship principles.

creasing to a maximum during the rapid growth phase, and then a decline as the crop matures. Applications timed and targeted at specific growth stages can benefit crop yield and/or quality. For instance, too much nitrogen and potassium can hinder early plant growth but are needed in larger quantities as the plants move into rapid growth and reproductive phases of growth. Timed and targeted applications also can reduce environmental impacts of nutrient loss from soil. This is especially true for nitrogen, which can undergo a number of transformations in the soil and is a particularly mobile nutrient.

Right Place

Right place means positioning the nutrients so that a plant has access to them. Proper placement allows a plant to better uptake nutrient, and in turn, allows it to develop properly and realize its potential yield, given the environmental conditions where it grows. Determining the right place is, in practice, always evolving. Plant genetics, placement technologies, tillage practices, plant spacing, crop rotation or intercropping, weather variability, and other factors can affect appropriate placement. There is much to learn about what constitutes the "right" in right place and how well it can be predicted when management decisions are needed.

Farmers have many decisions to make when considering the right place for nutrients. Nutrients need to be placed where they can be taken up by growing roots. Knowledge about a plant's specific root architecture helps growers determine the spatial configuration of a root system. Additionally, farmers consider soil chemical reactions. For example, concentrating soil-retained nutrients like phosphorus in bands or smaller soil volumes can improve availability. In some instances, farmers can also apply subsurface placement techniques to place the nutrient closer to the root zone and maintain crop residue cover on the soil and therefore help conserve nutrients and water.

Source, rate, time and place are interconnected in nutrient management (Figure 6). None of the four can be right when any one of them is wrong. It is possible that for a given situation there is more than one right combination.

The farmer, the manager of the land, is the final decision-maker although he may seek expert advice from a number of sources, including seed and fertilizer specialists, Cooperative Extension agents, marketing consultants and certified crop advisers (CCA). An understanding of the transformations of nitrogen and other nutrients in the soil is fundamental to assessing the dynamics of soil nutrient supply.

Nitrogen and phosphorus from cropping systems are generally of the greatest concern since the loss of each not only has negative economic impacts, but can create specific environmental problems. Nitrogen can be lost through several pathways, including leaching of nitrate, surface runoff from fields, and gaseous loss. Nitrogen in soils tends to be converted to the nitrate form. Because of its negative charge, nitrate is not attracted to negatively charged particles of clay and organic matter. Thus, it is free to leach as water moves through the soil profile. Phosphorus is much less susceptible to leaching, but small losses of phosphorus can have large impacts on water quality. While phosphorus-bound to sediment can be lost as erosion and dissolved, reactive phosphorus is immediately available to aquatic flora. Losses of phosphorus from fields occur mainly in surface runoff. In some soil, losses through drain tiles can be substantial. Placement of phosphorus fertilizer below the surface reduces the risk of loss due to surface runoff and erosion.

Multiple Choice QUESTIONS

Nourishing Crops with Fertilizers

1. The growth of agricultural production from 1950-2000 has been described as the "Green Revolution." Which of the following is not an aspect of the Green Revolution?

A. Application of commercial fertilizers.
B. Better water management practices.
C. Cross breeding plants to produce higher yields plants.
D. Development of GMOs.
E. Use of pesticides

2. Which of the following are considered the fuel that powered the Green Revolution?

I. Improvement seeds
II. Mineral fertilizers
III. Pesticide development

A. I only
B. II only
C. III only
D. I and II
E. I, II and III

3. Plant growth depends on the support of the soil, water, air, light and temperature. These linked factors influence plant growth. When seeds are planted, what are the most important factors for seed germination?

A. Air and soil
B. Light and soil
C. Light and temperature
D. Soil and temperature
E. Temperature and water

4. Plant yields will be decreased if the plant's growth is stressed, all of the following can cause plant stress except

A. absent or presence of microbial organisms in the soil.
B. soil compaction.
C. soil depth.
D. solar intensity.
E. too little or too much of required nutrients.

5. Seventeen (17) essential elements are needed to complete plant life cycles. They include 3 non-mineral elements and 14 mineral elements. Which set of elements below are the 3 non-mineral elements?
A. Carbon, hydrogen and nitrogen
B. Carbon, hydrogen and oxygen
C. Carbon, nitrogen and oxygen
D. Carbon, nitrogen and phosphorus
E. Carbon, phosphorus and potassium

6. While carbon, hydrogen and oxygen make-up 96% of a plant's elements, the mineral components are needed for structural, growth and nutritional quality. The mineral elements can be divided into two groups depending on the amounts needed, macronutrients and micronutrients. The macronutrients can be broken into primary and secondary macronutrients. Which of the following is the set of primary macronutrients?
A. Calcium, nitrogen and phosphorus
B. Calcium, nitrogen and potassium
C. Iron, nitrogen and sulfur
D. Nitrogen, phosphorus and potassium
E. Nitrogen, phosphorus and sulfur

7. Nutrient deficiency is the lack of enough nutrients, while nutrient toxicity is a plant's physiological response to too much of a particular nutrient. Which of the following is not a sign of nutrient deficiency?
A. Accelerated diffusion
B. Poor fruit development
C. Reduce drought tolerance
D. Stunted growth
E. Yellowing leaves

For Questions #8-11, use the following answers regarding the nutrient cycles. (*Note: answers may be used more than once.)*
A. Carbon
B. Nitrogen
C. Phosphorus
D. Sulfur
E. Water

8. Nutrients move through the ecosystems in varies cycles between air, animals, plants, soil and water; they are often referred to as biogeochemical cycles. Which cycle is more likely to tie most of the other cycles together?

9. The nutrient cycle that has little in the air or water.

10. This cycle and the nitrogen cycle produce primary pollutants that combine with water to form acids that are major contributors to acid rain.

11. Another name for this cycle is the hydrologic cycle.

12. Students have learned the basics of the water cycle from an early age and the cycle grew in depth the older you became. The basic cycle includes water evaporating into the atmosphere to condense and fall as one of the many forms of precipitation. Which of the following process(es) works against gravity?
I. Evaporation
II. Precipitation
III. Transpiration
A. I only
B. II only
C. III only
D. I and III
E. I, II, and III

13. While the atmosphere is 78% nitrogen, only certain chemical forms of nitrogen are usable by plants. Which of the following forms do plants most likely use?
A. N_2
B. N_2O
C. NH_3
D. NO_2-
E. NO_3-

14. Which of the following is the process by which usable nitrogen from the atmosphere becomes available to plants?
A. Ammonification
B. Assimilation
C. Denitrification
D. Nitrification
E. Nitrogen fixation

15. Nitrogen loss is major concern for farmers. The loss of nitrogen can be negated to a large degree with basic conservation practices. Which of the following includes loss due to the conversion of nitrate to nitrogen gas and nitrous oxide?
A. Ammonia volatilization
B. Denitrification
C. Leaching
D. Runoff
E. Soil erosion

16. The availability of nitrogen for plant growth is a limiting factor in the natural system. In order to provide enough food for today's population, usable nitrogen must be produced. Soil microbes convert ammonia into

Multiple Choice QUESTIONS

nitrite and then into the usable form, nitrate. In the presence of high pressure, heat, and a catalyst, ammonia is produced in the following chemical reaction $N_2 + 3H_2 = 2NH_3$. What is the name of the primary process used?

A. Ammonification
B. Bosch
C. Haber
D. Haber-Bosch
E. Rutherford

17. Phosphorus is an important component of all living organisms. Phosphorus plays a role in the structure of DNA and RNA as well as cycling energy between ADP and ATP. It plays a role in the capture of sunlight during photosynthesis and in seed germination. Which of the following is a source for phosphorus?

I. Gaseous forms in the atmosphere
II. Decomposition of organisms
III. Weathering of rock

A. I only
B. II only
C. III only
D. II and III
E. I, II, and III

18. The natural biogeochemical cycles continuously cycle nutrients between the air, living organisms, soil and water, but with today's population and the need to grow more food, many of the needed nutrients have been depleted from the soils. Which of the following best explains why we need to replace nutrients?

A. Human interference with the natural biogeochemical cycles, such as climate change.
B. Loss of nutrients through high winds that blow away the soil along with the nutrients.
C. Loss of nutrients through soil erosion due to excessive water flowing over the soil.
D. Plant and animal food sources that are removed from the fields and their nutrients are not returned to the fields through decomposition.
E. The natural climate change that occurs over the eons.

19. Since the mid-1970s, there has been a growing movement to grow organic food. Which of the following terms best describes a method that many do not consider organic?

A. Farmer eliminates the external use of synthetic pesticides, hormones and antibiotics.
B. Farmers emphasize the biodiversity of the agricultural system and the surrounding environment.
C. Farmers use rotational grazing and mixed forage pastures for livestock to maintain animal wellbeing.
D. Farmers using crop rotation, green and/or animal manures, and cover crops.
E. Farmers use human generated sewage sludge from the community as a form of fertilizer.

20. Commercial fertilizers are created from natural mineral deposits or synthetic processes that have been subject to a chemical process that makes a fertilizer with an increased concentration of nutrient content. All of the following are aspects of commercial fertilizers except:

A. Chemically there is no difference in the nutrients processed in a factory or found "naturally" in nature.
B. Commercial fertilizers are created from naturally occurring mineral deposits such as phosphate and potash.
C. Commercial fertilizers have a known amount of each nutrient that is labeled on the bag.
D. Commercial nitrogen based fertilizers are usually in the form of ammonia.
E. Commercially produced fertilizers contain nitrogen and phosphorus that must first be processed into usable forms.

21. A major distinction between organic and synthetic fertilizer is the quantities of nutrients they contain. Unlike synthetic fertilizers, organic nutrient sources typically do not come with a guarantee of nutrient content. All of the following are advantages of organic fertilizers except:

A. Organic fertilizers add humus to the soil that helps reduce soil compaction and increase water penetration into the soil.
B. Organic fertilizers benefit microbes making the soil easier to till.
C. Organic fertilizers increase the water holding capacity of soil by adding humus and carbon to the soil.
D. Organic fertilizers may be too high or too low in an important nutrient creating an imbalance.
E. Organic fertilizers must decay before they can be used, thus providing nutrients at a later time.

22. Any fertilizers, organic or commercial, may become a nutrient pollutant. Which of the following best explains nutrient pollution?

I. Excessive growth of plants because of large quantities of nutrients.
II. Leaching of excessive nutrients into the aquifer.
III. Runoff of excessive nutrients into the water or dispersed into the air.

A. I only
B. II only
C. III only
D. I and II
E. I and III

23. Which is the best description of sustainability?

A. Considering both the natural and human resources while meeting the economic needs of the society now and in the future.
B. Development of resources that emphasize the economic, environmental and social needs of the present population without compromising the ability of future generations to meet their needs.
C. Emphasizing the environmental needs of species while providing for the economic and social needs of the society.
D. Meeting the economic demands of a society by using resources as needed to provide economic growth now and into the future.
E. Promoting social development for the poor and underprivileged to gain equity for all generations in all societies and cultures.

24. Sustainable agriculture integrates the three main goals: economic profitability, environmental health and social and economic equity. Part of this concept is the stewardship of human resources including social responsibility. All of the following are part of this stewardship except:

A. Economic needs of communities.
B. Production and maintenance of an affordable, healthy food supply.
C. Consumer health and safety in the present.
D. Health and safety of workers.
E. Future human consumer health and safety.

25. As the population continues to grow especially in the developing countries, increased food production is a must. Many of the developing countries have limited financial resources to help develop additional agricultural resources. Continued development is needed to increase the world's food supply. Which of the following best fits the needed development of increasing the world's food supply?

I. The development of plants using cross breeding techniques and genetically modification of the plant to increase yields and the development of resistance to diseases and pest.
II. Continuing the movement towards organic farming that uses "green technologies," such as manure, composting, and crop rotation to reduce disease and pest and build nutrients into the soil.
III. The use of nutrient stewardship to use commercial fertilizers as a key component of sustainable agriculture to place nutrients at the right nutrient source, the right rate, the right time and in the right place.

A. I only
B. II only
C. III only
D. I and III
E. I, II and III

26. Commercial fertilizer is manufactured with a guaranteed minimum analysis of the three primary macronutrients. The numbers on the bag represent the weight of each of the fertilizers. Which is the correct order of the three primary macronutrients in a bag of fertilizers?

A. Potassium: Nitrogen: Phosphorus
B. Nitrogen: Phosphorus: Potassium
C. Nitrogen: Potassium: Phosphorus
D. Phosphorus: Potassium: Nitrogen
E. Phosphorus: Nitrogen: Potassium

For Questions #27-30, use the following agricultural concepts on the use of fertilizers.
(Note: answers may be used more than once.)

A. 4R Nutrient Stewardship
B. Agronomic efficiency
C. Fertilizer use efficiency
D. Law of the Minimum
E. Mineral theory

27. All 17 essential elements must be present in the balanced quantities to meet the needs of growing crops.

28. States that crop yield grows or diminishes in proportion to the amount of nutrients applied.

29. The crop yield is determined by the most limiting nutrient quantity.

30. Uses the concept of that the best performance can be obtained from fertilizer use while preserving the natural environment.

4R Case Study

Best Management Practices on a Chesapeake Bay Farm

A study of best management practices involves a Chesapeake Bay area farm with a 2,200-acre corn and soybean operation and includes 700 acres of irrigated ground. The farmers also raise 150 head of beef cattle and maintain their own grain handling and storage system, and they run a custom straw bailing operation for the mushroom industry.

This farm has implemented a number of Best Management Practices (BMPs). BMPs are recognized voluntary practices that improve agronomic efficiency and reduce environmental impact.

Here are the BMPs on this farm:

The farmers utilize a digital decision support tool (smartphone or tablet) with GPS and data collection technology to make better overall crop decisions that result in higher nutrient use efficiency and profitability. For instance, a farmer can analyze the NPK levels on a field with a GPS system collecting the exact location. Then the farmer can amend the soil based on the exact location and nutrients required.

The farm's equipment has **Real Time Kinematic** (RTK) guidance, which enables more precise application of crop inputs. Strip tillage and banding of fertilizer are part of the cropping system. They ensure the right placement of critical nutrients and minimize the risk of erosion and runoff. With strip tillage, only a narrow strip of crop residue is removed to create room for a seedbed.

Soil maps are utilized for variable rate application of fertilizer and seed populations to ensure the right rate is matched to each productivity environment on the farm.

Fertilizer application consists of liquid N, P, and K injected six to eight inches underground to prevent runoff and volatilization.

A nitrogen stabilizer is used to reduce risk of N loss further by slowing the conversion of N to nitrate form.

Fertigation (fertilizer application through the irrigation system) is used to apply nutrients to the most productive field areas.

Tissue samples are taken from plants throughout the season to assess plant nutrition at each stage of plant development for N, P, and K as well as minor elements.

Daikon forage oilseed radishes are planted as a cover crop to reduce soil compaction and retain residual N, P, and K through winter; in addition, these cover crops minimize tillage and erosion.

4R Case Study

Forms of nutrients applied: A custom blend of liquid UAN (urea ammonium nitrate), liquid phosphorus and potash are mixed with proven nitrogen inhibitors. Micronutrients are added based on soil and tissue results and are derived from highly plant available ammoniated or chelated sources. These are balanced to ensure maximum uptake of both the micro and macro elements.

Nutrient use efficiency: Last year, the farm documented a 17 percent improvement in nutrient use efficiency of nitrogen even in drought conditions by utilizing a 4R management approach.

Average Yield for each crop:

Corn Yields = 150 bushels / acre

Soybean Yields = 40 bushels / acre
(Full Season and Double Crop Beans Combined)

Five Pathways of Soil Nitrogen Loss

■ **Soil erosion**
Nitrogen can be lost from the soil surface when attached to soil particles that are carried off the field by wind or water. Overall, little nitrogen is lost when basic conservation practices are in place.

■ **Runoff**
Surface runoff can remove nitrogen in dissolved form (generally nitrate). Runoff is only a concern when fertilizer is applied on the surface and is carried away.

■ **Ammonia volatilization**
Significant amounts of nitrogen can be lost to the atmosphere as ammonia if animal manure or urea is not injected or immediately incorporated into the soil.

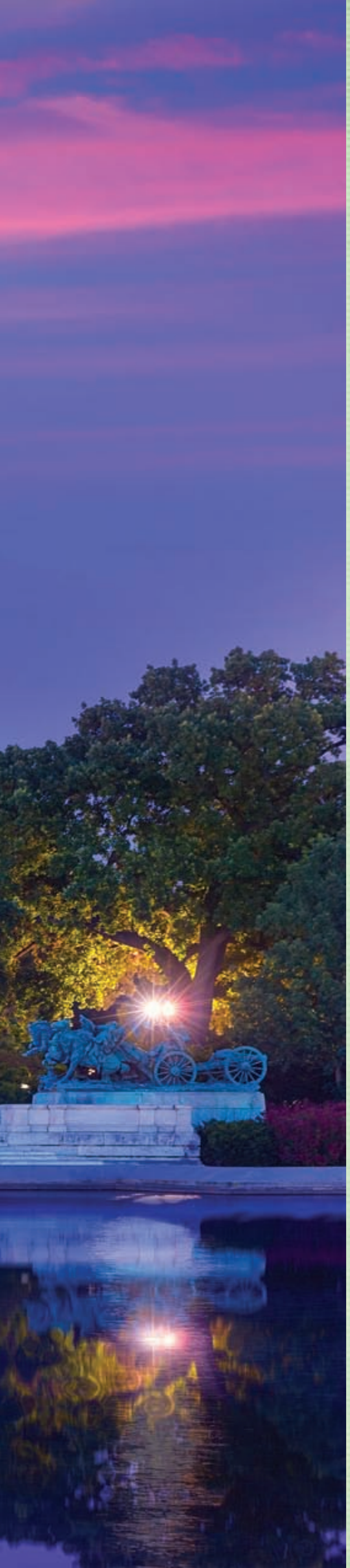
■ **Denitrification**
When oxygen levels in the soil are low, microorganisms called denitrifiers convert nitrate to nitrogen gas and nitrous oxide. Nitrous oxide is a greenhouse gas.

■ **Leaching**
Leaching occurs when there is sufficient rain and/or irrigation to easily move the dissolvable nitrate through the soil profile. The nitrate can eventually end up in aquifers or in surface water via drain tiles and groundwater flow.

31. Soil scientists have identified five pathways for nitrogen losses from farm fields. Considering the five pathways of nitrogen loss and the best management practices used on the Chesapeake Bay area farm, but find THREE examples of how the farm has addressed likely pathways for nitrogen loss. Many of the best management practices mentioned in the case study will require outside research.

32. Research and describe two things residential communities can do to control runoff from urban areas.

To ensure safe practices and products are used, the fertilizer industry works with associations and government agencies to develop policies, standards, and systems that protect the environment.



Fertilizers, the Environment, and Regulation

For the fertilizer industry, there is a delicate balance in using resources available in a way that maximizes benefits and minimizes adverse consequences to society and the environment. Scientists and policymakers work to develop more effective and extensive nutrient management strategies to address environmental concerns, especially those associated with water quality. For those providing fertilizer, this means making sure products are safe to use, and that practices of sound, responsible use are understood and followed. To achieve this, the fertilizer industry works with associations and government agencies to develop policies, standards, and systems that protect the environment. Fertilizer manufacturing and distribution employees are educated and trained to measure and work to improve the performance of the industry's environmental systems.

Numerous environmental, health and safety laws and regulations govern fertilizer manufacturing and distribution facilities. These include laws and regulations relating to minimizing air and water emissions; **land reclamation;** the generation, treatment, storage, disposal and handling of hazardous wastes; the cleanup of hazardous substance releases; and the protection of facility workers and surrounding communities. Nutrient suppliers have a tradition of implementing more than the required minimums with their environmental, health, and safety management systems.

Individual states also create fertilizer labeling and application laws. Soil qualities vary from state-to-state and must be governed accordingly. Maryland, for instance, requires that each brand and grade of commercial fertilizer be accompanied by a legible label stating net weight, brand, grade of fertilizer, guaranteed analysis giving the minimum percentage of every plant nutrient claimed to be contained in the fertilizer, name and address of the manufacturer.

Air Quality

Protecting air quality is important to the fertilizer industry. Fertilizer manufacturing facilities implement a number of environmental management systems to control air emissions of particular concern—for example, nitrogen oxides (NO_X), sulfur oxides (SO_X), **particulate matter** (PM) and ammonia (NH_3).

Particulate Matter (PM) is a term for particles that float in the air. Most of these particles cannot be seen with the naked eye. PM is considered a type of air pollution and is measured in micrometers. Coarse PM refers to particles greater than 10 micrometers in size and are often geologic in nature such as windblown dust. Large PM refers to particles between 2.5 and 10 micrometers (about 25 to 100 times thinner than a human hair). These particles cause less severe health effects than particles 2.5 micrometers or smaller. Some examples of Fine Particles (PM 2.5) include particles resulting from the combustion of fossil fuels or the formation of particles in the atmosphere from the chemical reaction of different air pollutants.

The industry uses a number of different technologies to control air emissions. Wet scrubbers or fabric filters are used to control particulate, fluoride or sulfur dioxide emissions from production operations. Scrubbers and fabric filters (often called baghouses) are also commonly used to control fugitive emissions and dust emissions from bagging operations. Nitrogen oxide emissions are reduced by the use of technologies, such as non-selective catalytic reduction (NSCR) and selective catalytic reduction (SCR). Ammonia recovery units and wet scrubbers are used to minimize NH_3 emissions, and fugitive NH_3 emissions.

At the bulk product handling level (including distributorships, retail outlets and blending facilities) regulations govern the enclosure of conveyor belt systems, fugitive emissions, product spills, dust control in truck loading and unloading areas, and other factors. Often fabric filters are used to control the "dust" emissions that arise from fertilizer handling and blending. Dust control is also aided by regular sweeping, and by enclosing transfer, mixing and handling facilities in either permanent or temporary structures, such as a tent or curtain.

Regulations: Clean Air Act (CAA)

■ **National Ambient Air Quality Standards (NAAQS)**
The CAA requires the United States Environmental Protection Agency (EPA) to set National Ambient Air Quality Standards (NAAQS) for six common air pollutants in order to protect public health and the environment. Three of these pollutants are relevant to the fertilizer industry: sulfur dioxide (SO_2); Particulate Matter (PM) 10 and 2.5 microns; and nitrogen oxides (nitrogen dioxide (NO_2) is the indicator for this larger group of gases). The other three common air pollutants are ozone, carbon monoxide and lead. Ozone is also a challenge for the nitrogenous fertilizer manufacturing sector; in part, because NOx is a precursor for ozone.

Primary emission standards protect the public health, especially among "at risk" population groups, such as asthmatics, children, and the elderly. Secondary standards protect the public from emissions that impair visibility, injure animals, or damage vegetation and buildings. Nitrogen dioxide (NO_2) is the largest air quality concern to fertilizer production. NO_2 is primarily emitted from nitric acid production facilities where fertilizers are made. Ammonia can be a precursor to PM 2.5, thus ammonia can be regulated by states in their "State Implementation Plans."

EPA ensures that the NAAQS are met by requiring air permits for a new or modified source of air emissions. The type of permits issued varies and can be issued by the EPA, state environmental agencies or local air quality agencies. In most instances, a manufacturer applies for a permit to build or modify a source of emissions. The permit includes atmospheric dispersion modeling wherein the applicant must prove that the air emissions will not exceed the NAAQS.

The process to obtain a preconstruction permit is called a New Source Review (NSR). Permits specify the type of construction allowed, what emission levels must be met and how often the source can operate.

A Prevention of Significant Deterioration (PSD) permit is required for a new source in an attainment area, defined as a geographic area where air quality already meets or exceeds primary and secondary ambient standards.

A nonattainment permit (NAA) is required to build or modify a source in a nonattainment area. A minor source permit may be issued in a facility that has the potential to emit less than the threshold for a major source.

The agency writes the permit based on the various emission standards to ensure the NAAQS are met.
Permits are very detailed and site-specific.

■ **National Emissions Standards for Hazardous Air Pollutants (NESHAPs)**
These are emission standards set by EPA for air pollutants that have potential to cause serious health issues (referred to a "hazardous air pollutants"). The standards are set for a particular source category, such as phosphate fertilizer production and require the maximum degree of emission reduction that EPA determines to be achievable, known as Maximum Achievable Control Technology (MACT). The CAA requires that these standards be reviewed at least every eight years to take into account changes in practices, processes and control

technologies. NESHAP requirements apply when HAP emissions exceed specified thresholds.

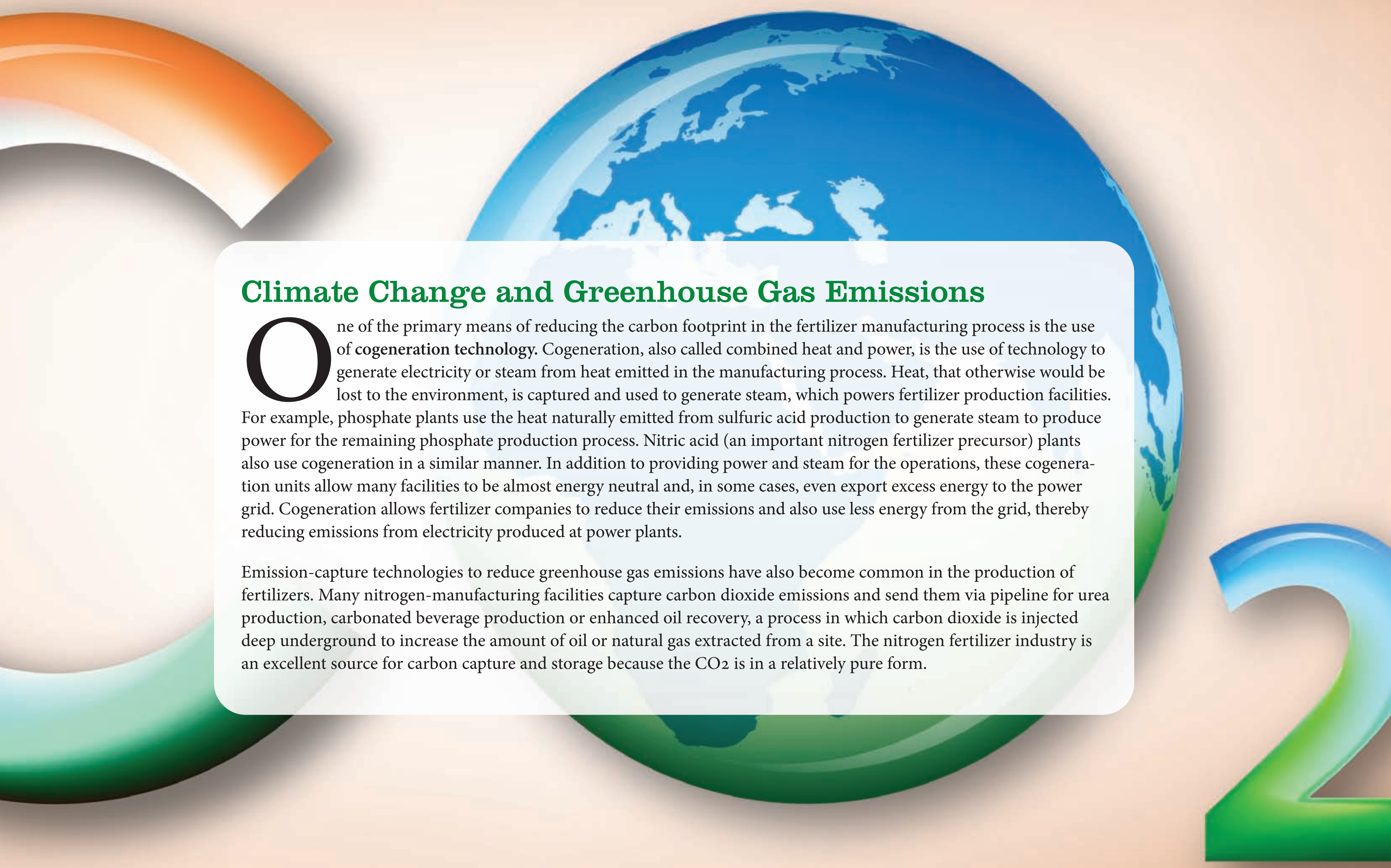
- **New Source Performance Standards (NSPS)**
  These standards establish the minimum performance level of controls for air emissions. The standards are industry-specific, including the testing and monitoring methods to measure whether the performance standard is met. Like NESHAPs, the CAA requires that EPA review these standards at least every eight years.

- **Title V Operating Permits**
  These permits are intended to be a compilation of all air quality requirements that apply to a facility. Title V of the CAA requires a major source (defined as emitting more than 100 tons/year of a given pollutant) to obtain a permit to continue operating. The major source threshold for any hazardous air pollutant (HAP) is 10 tons/year for a single HAP or 25 tons/year for any combination of HAPs. In other words, the threshold is the maximum ton amount a source is allowed to emit. For sources that emit less than these thresholds, states or local authorities often require an air operating permit.

- **Risk Management Program Rule**
  The Chemical Accident Prevention Provisions (CAPP) of the CAA require facilities that produce, handle, process, distribute or store certain chemicals, including anhydrous ammonia and aqua ammonia (when present above designated thresholds) fertilizers, to develop a risk management plan (RMP) and submit it to the EPA. The RMP includes:
  - Hazard Assessment;
  - Prevention; and
  - Emergency Response.

  The RMP is submitted to EPA and to local emergency planning organizations. Facilities are encouraged to take the developed RMP and work with local responders to familiarize them with the facility, discuss the hazards and potential emergency response to these hazards.

Facilities are encouraged to take the developed RMP and work with local responders to familiarize them with the facility, discuss the hazards and potential emergency response to these hazards.



Climate Change and Greenhouse Gas Emissions

One of the primary means of reducing the carbon footprint in the fertilizer manufacturing process is the use of **cogeneration technology.** Cogeneration, also called combined heat and power, is the use of technology to generate electricity or steam from heat emitted in the manufacturing process. Heat, that otherwise would be lost to the environment, is captured and used to generate steam, which powers fertilizer production facilities. For example, phosphate plants use the heat naturally emitted from sulfuric acid production to generate steam to produce power for the remaining phosphate production process. Nitric acid (an important nitrogen fertilizer precursor) plants also use cogeneration in a similar manner. In addition to providing power and steam for the operations, these cogeneration units allow many facilities to be almost energy neutral and, in some cases, even export excess energy to the power grid. Cogeneration allows fertilizer companies to reduce their emissions and also use less energy from the grid, thereby reducing emissions from electricity produced at power plants.

Emission-capture technologies to reduce greenhouse gas emissions have also become common in the production of fertilizers. Many nitrogen-manufacturing facilities capture carbon dioxide emissions and send them via pipeline for urea production, carbonated beverage production or enhanced oil recovery, a process in which carbon dioxide is injected deep underground to increase the amount of oil or natural gas extracted from a site. The nitrogen fertilizer industry is an excellent source for carbon capture and storage because the CO_2 is in a relatively pure form.

Another emission-capture technology implemented by fertilizer manufacturers is non-selective catalytic reduction (NSCR). This technology uses a fuel and a catalyst to consume free oxygen from nitrogen production emissions and to convert nitrogen oxides to elemental nitrogen. Various technologies are being considered by nitric acid producers, which can reduce nitrous oxide emissions by a significant percentage, thereby reducing the amount of this greenhouse gas (GHG) emitted to the atmosphere.

■ **The CAA and Greenhouse Gas Emissions**

In April 2007, the Supreme Court decided that greenhouse gases (GHGs), including CO_2, fit within the definition of an air pollutant under the CAA for purposes of mobile sources. The EPA has interpreted that it also has the authority to regulate GHGs emitted from stationary sources. In the fertilizer industry, GHG emissions are primarily associated with three industrial processes: ammonia production, phosphoric acid production and nitric acid production. EPA uses the Prevention of Significant Deterioration (PSD) and Title V Operating Permit programs to assist state and local authorities in implementing CAA permitting for GHG emissions.

- The Greenhouse Gas Reporting Program (GHGRP) requires fertilizer manufacturers to report their CO_2 equivalent emissions to EPA annually.
- GHG Tailoring Rule requires fertilizer manufacturers to install the Best Available Control Technology (BACT) to reduce GHG emissions from a plant that is newly constructed or subject to a major modification and exceeds certain designated GHG emission thresholds.

Non-selective catalytic reduction technology uses a fuel and a catalyst to consume free oxygen from nitrogen production emissions and to convert nitrogen oxides to elemental nitrogen.

NAME

PERIOD

Air Quality Organizer

Directions: Describe the Clean Air Act and its associated acronyms.

CAA

NAAQS

NESHAPS

NAME

PERIOD

Air Quality Organizer

Directions: Describe the Clean Air Act and its associated acronyms.

NSPS

RMP

GHG

Water Quality and Quantity

Clean water, essential for life, is the most critical natural resource for growing the food supply. Agriculture accounts for 80 percent of consumptive water use in the United States. Consumptive water is water removed from available supplies and not returned to a stream, river, or water treatment plant. Consequently, those involved in agriculture work diligently to protect water quality and quantity. Efficient cropping systems using fertilizers require minimum amounts of water per unit of crop production. Only well-nourished plants use water efficiently through an expanded root system and decreased evaporation. For instance, potassium helps soil retain water. Farmers also minimize water use and save energy by using low pressure, dropped-nozzle center pivot irrigation systems. Sprinkler heads are suspended two-feet off the ground just above the canopy of the crop. This reduces drift and loss of water to evaporation.

Since the 1970s, 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, among others.

The federal Clean Water Act (CWA) mandates that if a pollutant impairs a water body, a total maximum daily load (TMDL) must be created for that pollutant. A TMDL is a scientific determination of the maximum amount of a given pollutant that a surface water body can absorb and still meet water quality standards that protect human health and aquatic life. Water bodies that do not meet water quality standards are identified as "impaired" for the particular pollutants of concern—heavy metals, bacteria, dioxane, Persistent Bioaccumulative and Toxic (PBT) Chemicals, nutrients, etc. TMDLs are then developed, adopted, and implemented for those pollutants to reduce them and clean up the water.

The CWA act requires the federal government to work with the states, and the states have primary authority, to

Clean water, essential for life, is the most critical natural resource for growing the food supply.

implement water quality standards and TMDL. Only when states fail to fully implement a TMDL or WQS does EPA step in.

Maintaining a clean, adequate water supply is also important in the production of fertilizer. Whether the fertilizer is mined and processed or produced synthetically from a chemical reaction, as in the case of nitrogen, steps must be taken to ensure water quality of water emitted from the production process.

Because fertilizer production facilities are large and cover a lot of ground, storm-water management plans are necessary. Under these plans, materials and chemicals are stored under shelter, and spills are avoided or contained and cleaned up rapidly. Grounds are kept clean, and waterway conveyances, such as ditches and stream banks, are maintained and monitored to ensure that rainwater running over the surface of facility grounds do not carry nutrients or chemicals to surface waters and water treatment plants. More stringent oversight and better technologies have led to a significant reduction in discharges from facilities over time.

Fertilizer manufacturers also work to minimize the quantity of water used in the process of making fertilizer. For example, the companies that operate phosphate mines and processing facilities typically recycle more than 90 percent of the water they use, reducing the amount of fresh water used by 50 percent. Many manufacturing facilities use treated process water to supplement mining and water processing needs. Fertilizer manufacturers also fund research to explore ways that the industry can help provide for future water supply needs, including reservoir construction and pilot tests of aquifer augmentation strategies.

Regulations: Clean Water Act (CWA)

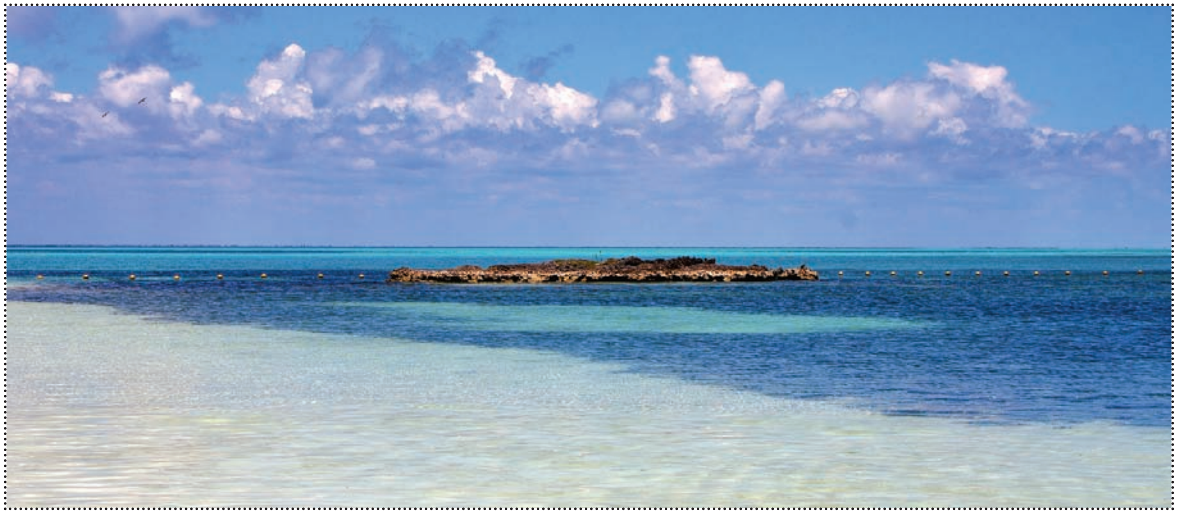
- **National Pollutant Discharge Elimination System (NPDES)**

  Under the NPDES program, facilities that discharge pollutants from point sources into waters of the United States are required to obtain a permit. Permits set technology-based and water-quality based effluent levels to maintain water quality standards and ensure safe water. In most cases, EPA delegates authority to states to administer the NPDES permitting program; however, where states have not taken on the program, EPA administers the permits. Pollutant is a very broad term in the NPDES program. It essentially means any waste discharged from industrial, municipal or agricultural point sources. NPDES permitting applies to both the mining and processing of fertilizer (phosphorus and potash) and the production of nitrogen fertilizer. Fertilizer nutrients can spur algal growth or impair water quality in high quantities both nitrogen (nitrate or ammonia form) and phosphorus can be pollutants of concern.

  Manufacturing operations must treat wastewater, or water that was used during the manufacturing process, that will be discharged. They also must control and treat storm water runoff. Mining generates waste in the form of mine water, waste rock, tailings and overburden. While tailings are the byproducts left over from mining and extracting resources, overburden is the waste rock or materials overlying an ore or mineral body that are displaced during mining without being processed. Impoundments are constructed as repositories for the tailings and treatment of waste from mining operations. Discharges from these impoundments into waters of the United States are regulated by Section 404 of the CWA, and 402. The United States Army Corps of Engineers (COE) is responsible for issuing permits under the CWA.

Hypoxia

One of the most vexing environmental challenges is the occurrence of hypoxic zones in various water bodies around the world. The EPA defines hypoxia as "low oxygen and is primarily a problem for estuaries and coastal waters. Hypoxic waters have dissolved oxygen concentrations of less than 2-3 ppm." Since about 1980, scientists have studied hypoxic zones and are trying to come up with answers. They know that eutrophication (excessive nutrient enrichment) promotes overgrowth of opportunistic bacteria, cyanobacteria, and algae in surface waters. After these organisms grow, die, and fall through the water column to the bottom sediments, which explains how bacterial decomposition leads to anoxic conditions that drive hypoxia. Runoff of agricultural fertilizers is one source of nutrients that can contribute to eutrophication of bodies of water and subsequent hypoxic conditions. Two examples of hypoxic zones that have garnered significant media attention, the Gulf of Mexico and the Chesapeake Bay, illustrate the challenges associated in identifying the cause of hypoxic conditions.



Gulf of Mexico

A closer look at the hypoxia issue in the Gulf reveals that the cause and magnitude of the problem are quite complex. The hypoxic events in the Gulf typically occur during the summer because of warmer temperatures. Upstream water, even as far as Montana and Pennsylvania, flows into the Gulf of Mexico. The freshwater from the rivers, primarily the Mississippi River, is warmer, especially in the summer, and less dense than the deep ocean water. This freshwater also has the potential to carry nitrogen and phosphorus into the Gulf. Hypoxic conditions are caused by nutrient loading, complex interactions between climate, weather, basin morphology, circulation patterns, water retention times, freshwater inflows, and stratification (layering).

In the hypoxic zone, dissolved oxygen is too low for many aquatic species to survive. Low dissolved oxygen is a serious environmental concern that can disrupt ecosystems and affect valuable fisheries. Exposure to hypoxia can cause severe health effects, such as reduced reproduction and growth. Some animals, like fish, are able to survive hypoxic events by moving to areas of higher oxygen, typically around the edge of the hypoxic zone. However, this may lead the animals to insufficient habitats. A hypoxic event can kill less-mobile animals, such as worms and clams. All of these animals are part of a sensitive ecosystem and often serve as a food source for other animals.

Efforts to decrease the Gulf's hypoxic zone continue through gradual changes in policies and practices, evolving science about the cause and prevention of hypoxia, ongoing nutrient reduction activities, and nutrient load reductions. There are beginning to be indicators of improvement. According to data in the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force's Gulf Hypoxia Action Plan 2008, scientific data indicates that the average total nitrogen load declined 21 percent when comparing the 2001 to 2005 period with the 1980 to 1996 period. However, when comparing these two time periods there was a 12 percent increase in phosphorus load. While incremental improvements are a positive sign, complex influence of factors, like drought, continue to provide challenges to measuring success.

Hypoxia in the Chesapeake Bay Watershed

Hypoxia issues in the Chesapeake Bay watershed are different from those in the Gulf of Mexico. The Chesapeake Bay is the United States' largest estuary stretching through six states and a district: New York, Pennsylvania, Delaware, Maryland, District of Columbia, Virginia, and West Virginia. The Chesapeake Bay Program reports that the watershed is home to more than 17 million people.

Unlike the Gulf, the Bay is largely enclosed, and therefore, water turnover is limited, which contributes to dissolved oxygen. Dissolved oxygen is a major stricture in the quality of water because of the organisms in that body of water's dependence on oxygen. Changes in the volume of freshwater inflow and resulting oxygen levels contribute to hypoxia in the Chesapeake Bay. Some of the other factors that can influence dissolved oxygen levels are temperatures, nutrient pollution, water flow, and the shape of the Bay's floor.

Temperature can limit the amount of oxygen that can dissolve in the water. Cool water in the winter allows the water to hold more oxygen than in the summer. Scientists have also found that dissolved oxygen levels drop at night for unknown reasons.

The depth of the Bay's floor can quickly vary from shallow to deep. In certain sections of the Bay's floor, bowl-shaped areas inhibit the bottom waters from receiving oxygen because of poor water flow. Water flowing into the Bay from the ocean and the Bay's freshwater watershed rivers greatly influence dissolved oxygen levels. The Chesapeake Bay receives about half of its water volume from the Atlantic Ocean, and the rest drains into the Bay from an enormous 64,000-square-mile watershed. The ocean water has a higher salinity and is typically cooler than the fresh and warm river water. The warmer fresh water weighs less than ocean water, and therefore floats on top of the ocean water. Pycnocline describes the boundary area where the fresh watershed layer meets the salty ocean water layer below and acts as a barrier between the two layers. In summer when algae is most active, the pycnocline segregates the low-oxygen bottom layer of water from the oxygen-rich surface water. This creates a build-up environment on the bottom layer of dissolved oxygen and high algae population.

The Bay is located in one of the heaviest populated areas of the country, and there are many point sources contributing to the nutrient load. Sewage treatment plant effluent, nutrient runoff from residential and commercial lawn care, and agricultural runoff from dairy, poultry, and crop farms in the Bay's watershed are often attributed to the nutrient loading in the water. Inputs of both nitrogen and phosphorus have stimulated algal growth, which has decreased water clarity and depleted oxygen levels resulting in a hypoxic environment. Filter feeders remove some algae; however, eutrophication often overwhelms large sections of the Bay's ecosystem because of the aforementioned factors. The caveat to the agriculture factor is that farmers cannot simply stop growing crops or reduce their yield in consideration of the world's growing population and local food

production. Therein lies the challenge the two areas have faced for many years. Considerable investment in policies and practices, such as the 4R Nutrient Stewardship framework, have led to reduced nutrient loss on the national and local level; yet allow essential food production to continue.

Filter feeders, such as oysters, are important to the Chesapeake Bay ecosystem. Oysters consume phytoplankton, a free-swimming alga, and filter the water. Unfortunately, their population has dwindled over the last hundred years. The National Oceanic and Atmospheric Administration reports that the Bay's oyster population is less than one percent of what it once was due to habitat, disease, and over-harvesting. Algae not filtered by oysters or other bottom feeders falls to the Bay's bottom, where it is decomposed by bacteria. The bacteria consumes oxygen during this process, which lowers the oxygen levels in the water.

The culmination of the many factors affecting the Bay have required a considerable amount of time and attention from policymakers, scientists, and residents of the watershed and Bay. Numerous ongoing efforts continue improving the health of the Bay, and the goals of these efforts are to restore the beauty and functionality of the Bay for future generations. For more information on these efforts, visit the Chesapeake Bay Program: www.chesapeakebay.net.

NAME

PERIOD

Water Quality Organizer

Directions: Describe the Clean Water Act and its associated acronyms.

Describe the Clean Water Act.

TMDL

NPDES

Mining

Phosphate: Surface Mining

The phosphorus in most commercial fertilizers comes from sedimentary phosphate rock. Scientists believe that the large phosphate deposits formed from the skeletons and decomposition from sea creatures living in the seas during the Miocene period more than 20 million years ago. Phosphorus, a mobile plant nutrient, plays key roles in photosynthesis, respiration (utilization of sugars), energy storage and transfer, cell division, cell enlargement, genetic coding and many other plant processes. Fertilizer manufacturers mine deposits of phosphate rock to provide phosphorus for a variety of commercial fertilizer blends.

Much of the phosphate used in the United States comes from mines in Florida; although other states, including North Carolina, Idaho, and Utah have phosphorus deposits as well. Internationally, Morocco contains a significant portion of global phosphate rock reserves.

In the United States, the first significant deposits of phosphate rock were found near the surface of the earth. In Florida, for example, most of the abundant deposits of phosphate are only 15 to 50 feet below the soil surface of the Florida peninsula. Because the ore is so close to the

Figure 7. Draglines perform the heavy lifting with phosphate mining in Florida. With a touch of the controls, the dragline can dig over 140,000 pounds of matrix (sand, clay, and phosphate) at a time.

Figure 8. The dragline bucket is large enough to hold a car. It weighs 110,000 pounds and is secured by ten 4-inch thick steel chains.

surface in the Southeastern United States, surface-mining techniques, using a piece of specialized equipment called a dragline, are used to recover the phosphorus-bearing ore (Figure 7 & 8). The dragline's bucket collects a mixture of sand, clay, and phosphate-bearing ore, which is then separated to recover the phosphate rock.

In the Southeastern United States, phosphate is mined on private land owned by the mining companies. In the west, mining generally takes place on public lands managed by the Bureau of Land Management (BLM), a branch of the Department of Interior. In both cases, mining plans must be reviewed under the National Environmental Policy Act (NEPA) to determine potential environmental effects. The NEPA compliance process includes performing an Environment Assessment (EA) to determine if an Environmental Impact Statement (EIS) is required. NEPA is a process-oriented law rather than an outcomes-based law, and the EIS is a detailed analysis of any actions that may significantly affect environmental quality. All permits must undergo a comment process to allow the public to voice concerns. Additionally, phosphate companies must have a reclamation plan before the actual mining begins. This plan outlines native vegetation and wildlife in the area, describes plans for overburden storage, and bond funds for all reclamation activities.

The phosphorus in fluorapatite, the most common phosphate mineral, is nearly unavailable to plants in the form in which it is mined from the earth. The remedy is an industrial process called "phosphate rock acidulation." The facility treats crushed fluorapatite ore with sulfuric, phosphoric, or nitric acid. This yields either one of the superphosphates that contains a large percentage of phosphate, or "wet-process" phosphoric acid. From there, the product is processed into various forms for use in blending with other nutrients (Figure 9). Phosphogypsum is a byproduct of phosphate ore processing. Phosphogypsum can have many beneficial uses as a soil conditioner that improves soil composition fill material, glass/ceramic production and more. However, the EPA has set levels of radiation regulation at a point where the gypsum cannot be used for these secondary purposes in the U.S. In other parts of the world, gypsum is used for soil conditioner, road building, housing and more, especially since a March 2013 study from the International Atomic Energy Agency modernizing the framework for safe and sustainable use of phosphogypsum based on current health and science information. The life of phosphate rock mines vary depending on factors like production cost, available technological development, and market prices.

In 2012–2013, the United States produced 14 percent of the world's phosphate rock. As of 2015, China is the world's largest exporter of phosphate fertilizer, and the United States is the second largest. These exports contribute to global food security and the U.S.'s balance of trade.

Figure 9. This warehouse in Tampa Bay, Fl stores finished fertilizer and phosphate rock before it is shipped to its Louisiana manufacturing facility, or to customers around the world.

Figure 10. Actual reclamation land in Central Florida.

Land Restoration

Because some fertilizer manufacturing involves surface mining of natural resources, the fertilizer industry works with government agencies, environmental groups and other organizations to determine how reclamation plans can assist in attaining goals for habitat protection, economic growth and recreational opportunities.

Today, reclamation land is used as wetlands, lakes, uplands, wildlife habitats, housing developments, farms and pastures, industrial sites, power plants, parks, golf courses, and forested land. Reclamation planning allows for the integration of habitat networks or corridors, which improve wildlife habitat and still allow for traditional uses on other reclaimed lands. Through mining and reclamation planning, buffer strips along stream and river corridors often are incorporated into post-reclamation landscapes. Much of the most sensitive habitat is preserved and, along with some of the reclaimed habitat, protected through conservation easements and deed restrictions that prohibit future development.

Land reclamation programs assure that mined land is returned to the best possible condition for use and that land resources are restored and available for new economic development or public use.

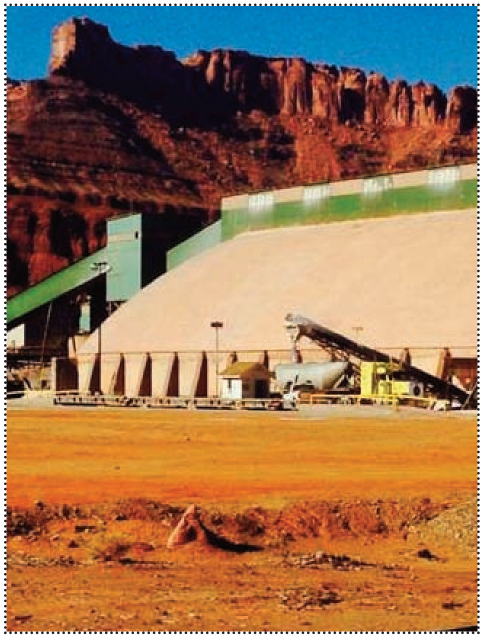


Figure 11. After the water evaporates, the potassium chloride crystals are harvested and processed into granular fertilizer products.

Potassium: Deep-down Mining

Potassium, also known as potash, can be mined from the earth using several different techniques. Some potash is recovered from surface lakes, such as the Great Salt Lake, through surface brine evaporation. Large deposits of potash are mostly found in North America, especially the Canadian provinces of Saskatchewan and New Brunswick, where the largest deposits in the world are found. Other important potassium deposits are located in Russia, Belarus, and Germany.

Canada is the largest producer and exporter of potash in the world. In the United States, about 90 percent of the potash is imported and most of those imports come from Canada. Most of the world's largest potash producers export a majority of their production, with the exception of China. China's population growth and rising living standards put significant demands on domestic food production, which requires large amounts of potash, nitrogen and phosphorus fertilizers.

Potash mines tend to be shaft mines, because potash deposits are found much deeper underground. At the Rocanville potash mine in southern Saskatchewan, Canada, the main ore deposits are 3,150 feet below the surface. At another mine in Moab, Utah, the potash seam lies about 3,281 feet underground.

At some mines, specialized machines remove ore containing potash, or potassium chloride, from the mine. The ore is crushed, cleaned, and further processed to separate the potash from impurities, such as clay. As stated earlier, some potash is recovered from surface lakes, such as the Great Salt Lake, through surface brine evaporation. At other mines, water is injected into the potash seam. The potash dissolves in the water, creating potash brine, and is then pumped to the surface and evaporated by sunlight in shallow ponds. After the water evaporates, the potassium chloride crystals are harvested and processed into granular fertilizer products, which can be blended with other nutrients or used alone (Figure 11 & 12).

FEDERAL REGULATIONS

Federal Mining Regulations

Potash and phosphorus are both considered non-metallic minerals for environmental regulatory purposes, differentiating them from gold, silver and other metallic mining. Mines operated on public lands usually fall under the jurisdiction of the Bureau of Land Management (BLM). In addition to CWA and CAA, these regulations affect mining operations:

- **National Environment Policy Act (NEPA)**
  NEPA requires that all federal agencies prepare detailed statements assessing the environmental impact, and alternatives to, major federal actions that may significantly affect the environment.

  - Environmental Impact Statement (EIS) prepared by a lead federal agency must provide a full and fair discussion of environmental impacts and inform decision-makers and the public of reasonable options. Approval of plans for mining on federally-managed lands may require an EIS.

- **Endangered Species Act (ESA)**
  The ESA protects threatened and endangered species and the habitat that supports them on public and private lands. In a BLM review of a proposed mining operation on public lands, the agency must consult with the United States Fish and Wildlife Service, and an EIS is prepared if any significant adverse impact is anticipated.

- **Secretary's Potash Area (SPA)**
  SPA is an area in the Permian Basin of Southeast New Mexico that was first established in 1939 by order of the Secretary of the Department of Interior. Today, the SPA covers nearly a half-million acres, 75 percent of the potash mined in the United States, and sets rules and plans for the development of potash, oil and gas in the area.

Other Federal Environmental Regulations Affecting Fertilizer Production

- **Resource Conservation and Recovery Act (RCRA)**
  RCRA applies to solid and hazardous waste generation, storage, treatment, and disposal. Facilities that generate, treat, store or dispose of hazardous waste must obtain a permit, either from EPA or from a state agency authorized to implement the permitting program, or operate without a permit and in accordance with EPA or state requirements.

  - Land Disposal Restrictions (LDRs) are regulations prohibiting the disposal of hazardous waste on land without prior treatment.

- **Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)**
  Also known as Superfund, this act authorizes EPA to respond to releases or threatened releases of hazardous substances that may endanger public health, welfare or the environment. Parties responsible for environmental contamination can be forced to clean it up or reimburse Superfund for response costs incurred by EPA.

- **Emergency Planning and Community Right-to-Know Act (EPCRA)**
  This law promotes the community's right-to-know about hazardous and toxic chemical uses and releases into the environment from industries located in the community. Provisions require information that could be critical in the event of an emergency.

Figure 12. A mound of potash fertilizer stored in a warehouse.

Potash and phosphorus are both considered non-metallic minerals for environmental regulatory purposes, differentiating them from gold, silver and other metallic mining.

NAME

PERIOD

Federal Mining Regulations Organizer

Directions: Describe the regulations that affect mining operations.

NEPA

ESA

SPA

NAME

PERIOD

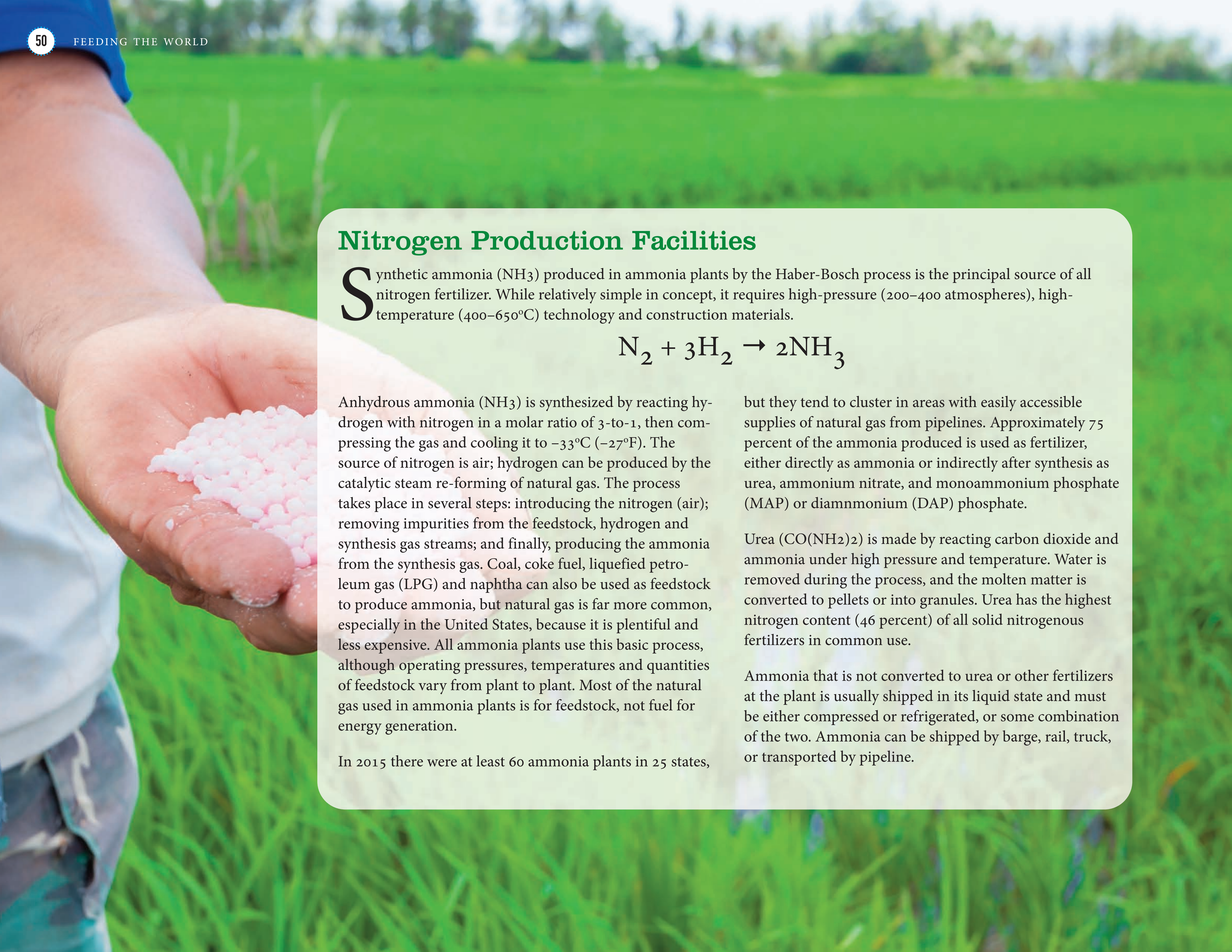
Federal Mining Regulations Organizer

Directions: Describe the regulations that affect mining operations.

RCRA

CERCLA

EPCRA



Nitrogen Production Facilities

Synthetic ammonia (NH3) produced in ammonia plants by the Haber-Bosch process is the principal source of all nitrogen fertilizer. While relatively simple in concept, it requires high-pressure (200–400 atmospheres), high-temperature (400–650°C) technology and construction materials.

$$N_2 + 3H_2 \rightarrow 2NH_3$$

Anhydrous ammonia (NH3) is synthesized by reacting hydrogen with nitrogen in a molar ratio of 3-to-1, then compressing the gas and cooling it to −33°C (−27°F). The source of nitrogen is air; hydrogen can be produced by the catalytic steam re-forming of natural gas. The process takes place in several steps: introducing the nitrogen (air); removing impurities from the feedstock, hydrogen and synthesis gas streams; and finally, producing the ammonia from the synthesis gas. Coal, coke fuel, liquefied petroleum gas (LPG) and naphtha can also be used as feedstock to produce ammonia, but natural gas is far more common, especially in the United States, because it is plentiful and less expensive. All ammonia plants use this basic process, although operating pressures, temperatures and quantities of feedstock vary from plant to plant. Most of the natural gas used in ammonia plants is for feedstock, not fuel for energy generation.

In 2015 there were at least 60 ammonia plants in 25 states, but they tend to cluster in areas with easily accessible supplies of natural gas from pipelines. Approximately 75 percent of the ammonia produced is used as fertilizer, either directly as ammonia or indirectly after synthesis as urea, ammonium nitrate, and monoammonium phosphate (MAP) or diamnmonium (DAP) phosphate.

Urea (CO(NH2)2) is made by reacting carbon dioxide and ammonia under high pressure and temperature. Water is removed during the process, and the molten matter is converted to pellets or into granules. Urea has the highest nitrogen content (46 percent) of all solid nitrogenous fertilizers in common use.

Ammonia that is not converted to urea or other fertilizers at the plant is usually shipped in its liquid state and must be either compressed or refrigerated, or some combination of the two. Ammonia can be shipped by barge, rail, truck, or transported by pipeline.

Production Facility Case Study

Considerations in Developing a New Phosphate Mine

The Matrix Company owns 10,000 acres of land that they plan to mine ten years from now as their currently operating mines are depleted of phosphate ore. The mine is closer to a major resort area than previous mining, and this has raised some concerns. On the other hand, residents know that Matrix Company is a big economic driver in the state. It pays real estate taxes and state severance taxes on the phosphate ore it extracts, and it employs thousands of people and has a good record of environmental stewardship and land reclamation.

You are a spokesman for Matrix Company at an informational meeting held at the local high school. You are going to outline some of the considerations and careful steps necessary to open the mine, operate it, and later reclaim the land for other uses.

33. What are TWO environmental concerns and TWO federal environmental laws that Matrix Company need to consider before proceeding with the mine.

34. Matrix Company is developing a reclamation plan for their proposed 10,000-acre phosphate mine, as required by state and federal regulation. Describe THREE considerations the company must make in this plan.

35. Once mining has begun, overburden will be removed to reveal the phosphate rock underground. The rock is then extracted and transported to a processing facility. Next, beneficiation occurs, which is the process of removing sand and gravel through a largely mechanical washing process. Acidulation occurs after beneficiation has taken place. What are the next TWO details of this process?

Alchemy of Air Excerpts and Questions

Looking at the fertilizer industry today, one would not think for a moment that the history of nitrogen fertilizer is the stuff of adventure novels with suspense, intrigue, war, great discovery, fortunes made and lost; all played out on a world stage. This true story can be found in Thomas Hager's book, *The Alchemy of the Air: A Jewish Genius, a Doomed Tycoon, and the Scientific Discovery That Fed the World but Fueled the Rise of Hitler.*

In this first excerpt from his book, Hager describes the early use of natural fertilizers, some of which we would find repulsive today, but that was all that was known and available at the time.

Excerpt #1: *The Alchemy of Air,* page 4-5

> Every agricultural society in every age has had its own methods, rites, and prayers for ensuring rich crops. Homer sang of farmers gathering heaps of mule and cow dung. The Romans worshipped a god of manure, Sterculius. Rome made an early science of agriculture, ranking various animal excrements (including human), composts, blood, and ashes according to their fertilizing power. Pigeon dung, they found was the best overall for growing crops, and cattle dung was clearly better than horse manure. Fresh urine was best for young plants, aged urine for fruit trees.

Both the Romans and the ancient Chinese also understood that there was another key to a healthy farm: crop rotation. No one knew why or how it worked, but never planting the same crop twice consecutively in the same land, instead of alternating it with certain crops like peas and clovers, managed to replenish the fertility of fields. Every few years the Chinese made sure to rotate in a crop of soybeans; chickpeas were the crop of choice in the Middle East, lentils in India, and mung beans in Southeast Asia; and Europeans used peas or beans or clover. "Oats, peas, beans, and barley grow" was more than a children's rhyme. It was a timetable for successful farming.

Healthy farms had compost pits, plenty of domestic animals for manure, and a system of crop rotation. But it was never enough. It took scores of tons of manure per acre to grow great crops. Manure gathering and handling grew into a small industry, employing thousands of workers who scoured the countryside for cow and pig excrement, cleared city streets of horse manure, and then sold it by the stinking ton to farmers and gardeners. There was never enough. A heavy application of manure helped for a season or two, but then the fertility of the soil declined and more was needed. In the most intensively cultivated land in Europe—the Marais district of Paris—owners of small city-garden plots applied dung at rates as high as hundreds of tons per acre, and every year they had to repeat the process. By 1700 or so, hungry Europeans were experimenting with other soil additives in an attempt to increase their yields, trying sea salt, powdered limestone, burned bones, rotting fish, anything that might keep their soils producing.

■ EXCERPT #1 WRITING PROMPTS

36. Research the effect of ashes and burned bones on soil. Which plant macronutrients were they unknowingly replacing?

37. Use a scientific conjecture to explain what ONE plant nutrient the Marais district of Paris (mentioned above) replaced the most.

38. Describe TWO forms of nutrient replacement that modern agriculture uses.

Just prior to World War I, the bulk of nitrates used for fertilizer came from surface mines on Chile's Atacama Desert, a 1,600-mile strip of land west of the Andes Mountains on the Pacific Coast. During the war, shipping nitrates was dangerous if not impossible. Allied ships blockaded South American ports to stop German vessels and German U-boats patrolled sea lanes to stop Allied shipments. Only Germany had the Haber-Bosch method of nitrogen fixation and used it mainly for explosives. The method of nitrogen fixation used in the United States required enormous amounts of electricity to mimic the breakup of nitrogen molecules in nature by lightning.

In this excerpt from *The Alchemy of the Air,* Hager writes about the Haber-Bosch plants today, all descended from the first factory opened in Oppau, Germany a little over a hundred years ago.

Excerpt #2: *The Alchemy of Air,* page 270–271

Today hundreds of Haber-Bosch plants are drinking in air and turning out ammonia, producing enough fertilizer not only to support a burgeoning human population but to improve average diets worldwide. All the plants run on the same principles Haber and Bosch pioneered and are filled with the same basic catalyst that Alwin Mittasch found almost a century ago. They are, however, ever larger and more efficient. In Carl Bosch's day, the tallest ammonia ovens were thirty feet high. Now they top one hundred feet. In 1938, it took an average of sixteen hundred workers to produce a thousand tons a day of ammonia. Today it takes fifty-five

Ancient farming practices may have evolved over thousands of years, but the essential nutrients that plants need have not.

workers to make the same amount. In the early days it took four times as much energy to make a ton of fertilizer as it does now. Still, the demand for their products is so great that Haber-Bosch plants today consume 1 percent of all the energy on earth, and the largest factories produce so much ammonia that is has to be transported in pipelines (one of the first ammonia pipelines in the United States, built in the late 1960s, for instance, runs from the plant in Texas to the corn fields of Iowa). This huge, almost invisible industry is feeding the world. Without these plants, somewhere between two billion and three billion people—about 40 percent of the world's population—would starve to death.

■ EXCERPT #2 WRITING PROMPTS

39. Research how the carbon dioxide (CO_2) produced as a byproduct of the Haber-Bosch process can be reused without releasing it into the atmosphere as a greenhouse gas.

40. Explain whether, in chemical terms, the Haber-Bosch process is really alchemy? Is one element transmuted into another through the process?

Alchemy is the medieval chemical science of turning something ordinary and into something special. The best example is turning base metals into gold, which as far as anyone knows, was not successful. Haber-Bosch succeeded where alchemists failed. In this third excerpt from his book, Hager sums up this extraordinary achievement.

Excerpt #3: *The Alchemy of Air,* page 273

Think of nitrogen atoms as riding on a series of big circles, like fairgoers on Ferris wheels. The wheel representing the natural, pre-Haber-Bosch "nitrogen cycle" begins in the air, with N_2 molecules. The next step is to break apart the N_2, fix the nitrogen, and begin moving it through living systems, starting with either bacteria (the process of **biological nitrogen fixation**) or with lightning strikes ripping apart the atmospheric nitrogen and combining it with other elements. Once it is fixed and available for living things, the nitrogen is passed from molecule to molecule and organism to organism, from bacteria to plants and plants to animals, in a series of subcycles, wheels within wheels. The living organisms release the fixed nitrogen back into the dirt when they die and rot. Some of it goes back into plants and cycles again, and some of it returns to the air (different types of bacteria can reverse the process, turning fixed nitrogen back in to N_2). The intricacy and interconnectedness of these cycles, the paths spreading from the air to the land to the water and back, from nonliving to living systems, makes tracking difficult, research costly, and predictions almost impossible. We know only that Haber-Bosch has altered these cycles enormously by injecting the world with a gigantic dose of synthetic nitrogen. It is as if we made our planet the subject of an experiment, doubling its food to see what would happen. Scientists are just beginning to grapple with the results.

The Haber-Bosch process has had profound influence on the world we live in. The population of the planet has grown tremendously, yet fewer people work in agriculture while more food is produced. The United Nations predicts that by the end of the 21st century, the population of Earth will increase from 7.1 to 10.8 billion people.

■ EXCERPT #3 WRITING PROMPTS

41. Describe how an increase by half in the world population will affect the need for chemical fertilizers.

42. Research and review the natural biogeochemical nitrogen cycle. Describe how the Haber-Bosch process fits into the cycle.

Multiple Choice QUESTIONS

Fertilizers, the Environment, and Regulation

43. Laws and regulations have been passed to address environmental concerns, especially those regarding air quality. What role does the EPA play in regards to the Clean Air Act?

A. The Clean Air Act governs the National Environmental Policy Act.
B. The EPA sets the national standards for air quality under the Clean Air Act.
C. The EPA studies the effects of Resource Conservation and Recovery Act with the Clean Air Act.
D. The EPA applies solid and hazardous waste statistics to the Clean Air Act.
E. The Clean Air Act requires that the EPA report environmental changes.

44. Which of the following air pollutants did the Clean Air Act not initially regulate, but later the Supreme Court upheld that it could be regulated as a pollutant?

A. CO
B. CO_2
C. NO_2
D. Particular Matter (PM)
E. SO_2

For Questions #45-48 use the following answers regarding the national acts. *(Note: Answers may be used more than once.)*

A. Clean Air Act
B. Clean Water Act
C. Endangered Species Act
D. National Environment Policy Act
E. Resource Conservation and Recovery Act

45. Applies to solid and hazardous waste generation, storage, treatment and disposal.

46. Protects habitat that supports endangered or threatened species on both public and private lands.

47. Requires that all federal projects prepare a detailed environmental impact statement.

48. Requires that facilities that discharge pollutants into the waters from point sources are require to obtain a permit.

49. All of the following are established by the Clean Air Act except:

A. National Ambient Air Quality Standards
B. National Emissions Standards for Hazardous Air Pollutants
C. National Pollutant Discharge Elimination System
D. New Source Performance Standards
E. Title V Operating Permits

50. Cogeneration technology is used to help reduce the carbon footprint of manufacturing fertilizers. Which of the following best explains cogeneration?

A. Uses technology to combine coal and natural gas to cogenerate power for the manufacturing process.
B. Uses technology to combine coal generated electricity with solar and wind generated electricity.
C. Uses technology to generate electricity from heat emitted in the manufacturing process.
D. Uses technology to generate electricity from the benefication taking place in the manufacturing.
E. Uses technology to generate enough electricity with solar and wind to power the manufacturing process.

51. The fertilizer industry is broad, from mining and chemical manufacturing to transportation and retail. Transportation, waste disposal and retail outlets are covered by many laws and regulation not just the actual manufacturing facilities. Dust is often a concern in many of the locations, which of the following helps control dust in the manufacturing process?

I. Fabric filters
II. Regular sweeping
III. Enclosing areas

A. I only
B. II only
C. III only
D. II and III
E. I, II, and III

52. The Chemical Accident Prevention provisions of the Clean Air Act provides for the development of a Risk Management Plan (RMP). Which of the following are provisions of the RMP?

A. Developing an emergency response plan.
B. Developing a hazard assessment and prevention plan.
C. Developing a hazard assessment and emergency response plan.
D. Developing a hazard assessment, prevention plan and emergency response plan.

E. Developing a prevention and emergency response plan.

53. Carbon dioxide is a coproduct of the nitrogen manufacturing facilities. Emissions capture and reuse technologies have become common to help reduce greenhouse gas emissions. Which of the following is not commonly the end use for the captured CO_2?

I. Sent to the carbonated beverage industry (soda's carbonation is CO_2).
II. Use in greenhouses to grow plants (photosynthesis needs CO_2).
III. Enhances oil recovery (CO_2 is injected deep underground to increase extraction).
A. I only
B. II only
C. III only
D. I and II
E. I and III

54. Farmers use a variety of methods to irrigate croplands. Which method is the most water efficient?

A. Center-pivot
B. Drip irrigation
C. Flooding
D. Furrow
E. Gravity

55. Center-pivot irrigation systems have been designed to use less water and save energy. Which of the following are parts of the center-pivot design?

I. Dropped –nozzle
II. High pressure
III. Sprinklers heads two-feet above the crop canopy
A. I only
B. II only
C. III only
D. I and III
E. I, II, and III

56. Fertilizer manufacturers and wastewater treatment facilities must process wastewater to remove nitrogen and phosphorus. In the production of fertilizers, why are these two primary pollutants targeted for removal?

A. The release of nitrogen and phosphorus into aquatic ecosystems causes water to become cloudy.
B. The release of nitrogen and phosphorus into aquatic ecosystems can lead to toxicity in fish.
C. The release of nitrogen and phosphorus into aquatic ecosystems can lead to chemical reactions that produce the corresponding acids.
D. The release of nitrogen and phosphorus into aquatic ecosystems could lead to algae blooms.
E. The release of nitrogen and phosphorus into aquatic ecosystems makes the water unusable for recreation purposes.

57. Hypoxia refers to reduced oxygen content of air or a body of water detrimental to aerobic organisms. While nutrient runoff is a concern in the Chesapeake Bay, there appears to be other factors involved in the Gulf of Mexico. Hypoxia is caused by a complex interactions of all of the following except:

A. basin morphology.
B. circulation patterns.
C. climate.
D. pollution.
E. weather.

58. Phosphorus in plants plays a role in all of the following except:

A. Cellular respiration.
B. Energy storage and transfer.
C. Genetic coding.
D. Photosynthesis.
E. Uptake of water.

59. One method to determine the effectiveness of fertilizer application is the calculation of the crop's agronomic efficiency (AE). The amount of agronomic efficiency is the difference between the crop yield with added fertilizer and the crop yield without the added fertilizer per unit of fertilizer added: AE= (Y-Yo)/FO. The agronomic efficiency is 24 with 50 pounds of fertilizers added to the area and the crop yield was 3400 pounds, what would the calculated yield without fertilizer have been?

A. 1960
B. 2080
C. 2200
D. 2320
E. 2440

60. Surface mining is the primary method used to mine for phosphorus. Mining plans must be prepared and reviewed under the National Environmental Policy Act (NEPA) to determine potential environmental effects. Before any mining can be approved, the mining company must complete which of the following?

I. An environmental assessment (EA) and potentially an environmental impact statement (EIS)
II. A public comment process
III. A reclamation plan
A. I only
B. II only
C. III only
D. II and III
E. I, II and III

Physical and Chemical Characteristics of Soil

Apply appropriate safety precautions and laboratory protocols before performing the following laboratory activities. Follow all manufacturer warnings, procedures, and proper storage instructions.

Introduction:
Soil is a vital natural resource that is the cornerstone of all terrestrial life on Earth. Soil provides a structure for plants to grow their roots, provides the support for them to grow, and supplies the plants with needed water and nutrients. Today, soil can become depleted of nutrients as we grow food for an ever-growing population. These essential nutrients can be replenish through several methods, including commercial fertilizers.

Soil composition and its function within an ecosystem vary greatly from one location to another. A helpful way to consider soil variations is CIORPT: Climate (Cl), Organisms (O), Relief (R), Parent Material (P), and Time (T). Another word for "relief" is topography. Climate includes precipitation, wind, temperature; parent material includes the chemical elements available. Relief is the location of the soil in the terrain, such as on a slope or at the bottom of a slope. Much of the soil type depends on the availability of water. Soil rich in humus, or organic matter, can have large plant growth and plenty of air/water space. Eventually through the crop cycle, this plant growth will decompose and replenish nutrients and humus in the soil. This cycle can be interrupted by harvesting large amounts of the plant, wherein not allowing the plant material to break down. Forest and grasslands are usually rich in humus. Deserts lack water and contain small amounts of humus. Soil type also varies by the parent material. As rocks break down, they ultimately becomes part of the A horizon of the soil profile.

Many professionals consider a soils profile when making decisions about a building, what crops to plant, or even if a basement will flood if it rains. Soil scientists, such as an agronomist, help solve these and many additional questions.

In this lab, you will work with tests similar to what a farmer uses to decide on which crops to plant, when to plant, when and where to add fertilizer (organic or commercial), or when is the best time to water. When farmers test their soil, they typically send it to a laboratory for more accurate and specific results.

Comments:
- Work in groups of 3 – 4 students.
- Plan to get dirty! Yes, you will touch the soil with your hands.

Purpose:
Students will study the basic physical and chemical properties of soil. By the end of this lab, students will begin to understand the complexity of both the physical appearance and chemical composition of soil.

Materials:
- Soil samples (at least two distinctly different samples)
- Soil Chemistry Kit (available from local garden stores)
- Possible kits:
  - Mosser Lee Soil Master Testing Kit, model #1210
  - Ferry-Morse Soil Test Kit, model #920
  - Luster Leaf Rapitest Soil Test Kit, model #100061284
- Soil Color Booklet
- Possible books:
  - Munsell Soil Color Book
  - The Globe Soil Color Book
- Beakers
- Dish soap
- Graduated cylinders
- Plastic spoons
- Soil Triangle
- Spray bottles

Procedure:

Activities

1) Soil Description: record all information in the data table below. After you obtain your samples, first prepare your samples and then proceed as instructed below.

Sample A Name: ____________________________________

Sample B Name: ____________________________________

Sample Preparation:

I. You will need approximately 100 mL of each soil sample.
II. Weigh your sample.
III. Remove all rocks and humus and weigh the rock and humus.
IV. Break up large dirt "balls" being careful not to lose any of the soil.
V. Weigh the sample a second time and determine the percentage of weight remaining.
VI. Determine the amount lost.
VII. Repeat for Sample B:

	Sample A (g)	Sample B (g)
Weigh #1		
Weigh rock & humus		
Weigh #2		
Percent soil (#2/#1 x 100)		
Percent humus (Humus/#1 x 100)		

Complete the following steps one sample at a time.

a. Describe the color of the sample. Be as descriptive as possible.
b. Using either the soil color book or a soil numbering system from the testing kit, record the color hue.
c. Put some soil in your hands. Feel the soil with your fingers, rub it in your hands, and record your description of how the soil feels. Share and discuss the soil with your group. Gritty soil has a lot of sand while smooth soil is high in clay or silt.
d. Describe the water content of the soil.
e. Smell the soil. Add some water if the soil is dry and smell the soil a second time. Record what you smell, be descriptive. Share and discuss the soil with your group.
f. Repeat for Sample B:

Description	**Sample A**	**Sample B**
a. Color		
b. Color (using book)		
c. Texture		
d. Water Content		
e. Smell		

2) Ribbon Test: The ribbon test is a quick indicator of the amount of sand or clay in the soil. A longer ribbon means more clay, and a shorter ribbon means sand or silt.

a. Place a small amount of soil in your hand.
b. Moisten with water from a spray bottle.
c. Squeeze out any excessive water.
d. Using your fingers try to form a ribbon. Roll the soil out from your fingers much like a Tootsie Roll©.
e. The longer the ribbon, the more clay in the soil sample.

Data: Describe the ribbon that is formed, determine the length of the ribbon.

	Description	Ribbon length (cm)
Sample A		
Sample B		

3) Chemical Characteristics: follow the instructions on the kit. Note that home soil test kits are not as precise as laboratory analysis. For instance, nitrogen is highly mobile in soil and is hard to accurately measure in simpler tests. The test kit will test for the three primary macronutrients: Nitrogen (N), Phosphorus (P), and Potassium (K) and the pH of the soil.

I. Follow all the instructions provided with the test kit. The kit may include instructions to fix the soil before completing the soil test.
II. Record the data below.
III. Repeat for Sample B:

Test	Sample A	Sample B
pH		
N		
P		
K		

4) Particle Size Distribution of Soil

Determine the distribution of different sizes of soil particles and using the soil triangle to determine the soil type.

a. Fill the 100 mL graduated cylinder to 40 mL with the soil sample.
b. Add water to the 100 mL mark on the cylinder. Mix vigorously by inverting to make sure all the soil is mixed.
c. Add a drop of soap. Gently mix by inverting. Careful not to mix too hard and create foam from the soap.
d. Allow the sample to sit for 24 hours.
e. Using the markings on the graduated cylinder:
1. Measure the total height of the sample.
2. Look for the three layers and measure each layer.
3. Record the information in the table below.
f. Using the texture triangle below, calculate the percent of each layer.

Data: The following size chart should be used to determine each layer. Measure the total height and the height of each layer. Record the data in the table. Calculate the percentage of each layer and use the soil triangle to determine the soil type. Round the numbers to the nearest whole number.

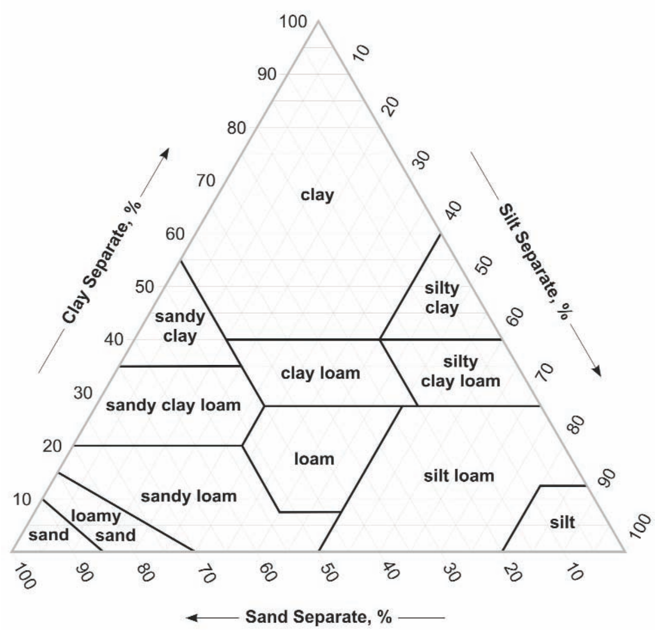
Clay: less than 0.002 mm
Silt: 0.065 – 0.002 mm
Sand: 0.065 – 2 mm

The top layer will be the clay layer and the bottom layer will be sand. Heavy, larger particles will sink faster.

	Sample A		Sample B	
Layer	Height	Percent	Height	Percent
Total				
Clay				
Silt				
Sand				

Using the soil triangle:

1. For each soil particle, place the number on the scale and draw a line across the triangle.
2. The area where the lines converge is the soil type.
   a. If the rounded percentages do not add up to 100, the lines will make a small triangle and not a single point.
   b. In addition, rounding may cause a small triangle.



Soil Particle Results:
Sample A: _______________________ soil type
Sample B: _______________________ soil type

Conclusion:

1) Why is it important to study and understand soils?
2) Is soil living, non-living, or something else? Research and support your answers. Please cite sources.
3) What can the physical description of soil provide us?
4) What does the ribbon test tell us about the soil? How does this compare to the percentage of clay and the texture triangle?
5) What is the importance in understanding the chemical composition of soils?
6) How does the pH of the soil affect the nutrients in the soil? Include information about how the pH influences the uptake of nutrients.
7) Why is it important to understand the particle composition of soils?
8) Research and describe what types of crops might grow in the soil in your region of the country, what factors contribute to the soils in your region, and what is commonly used to amend the soil. Visit www.thescienceofsoil.com and explore the "Not All Soils Are Created Equal" widget for part of your research.

Duckweed: Pest or Benefit?

Introduction:

Duckweed is high in protein and an important food source for waterfowl. It contains more protein than soybeans do and has the potential to be a food source for humans.

There are 40 species of duckweed belonging to the following 5 genus: Landoltia, Lemna, Spirodela, Wolffia and Wolffiella. Twenty of the species are found in the United States. All 40 species are free floating aquatic plants that float at or just beneath the surface and prefer still or slow moving water.

Duckweed is the smallest flowering plant species. The plant structure is simple; the largest part of the plant is the "thallus" or "frond" structure, which is only a few cells thick and often has air pockets to help the plant float. The fronds may look like small leaves; rather they are a combination of leaf and stem. Some species have no roots and in some species short, fine rootlets.

Duckweed rarely flowers, but more commonly, it reproduces through asexual budding. The new fronds grow from the buds of the parent plant and eventually break off to become new plants. Occasionally, small flowers are produced for sexual reproduction.

Duckweed tends to be associated with eutrophic water. Duckweed is also a density-dependent plant, and as the surface becomes covered in duckweed, plant growth slows down. Besides being a valuable food source for waterfowl, duckweed provides cover for a variety of species including the recently hatched of many species, frogs and bluegill. It also reduces water evaporation when the majority of the pond is covered.

In some areas, duckweed is considered invasive. Oftentimes, local plants cannot compete with duckweed, which can dominate the space, use available nutrients, and block sunlight. Waterfowl or small mammals easily spread duckweed as they move from ponds, lakes, rivers and streams. The plant attaches to the animal's feet, feathers or fur and is carried to the next body of water.

Some areas use duckweed to help control mosquitos and algae. If the surface of the pond is covered in duckweed, mosquito larvae cannot survive, because they cannot reach the surface for air. In addition, the duckweed will block the sunlight and prevent algae from growing. Other areas are using duckweed in wastewater treatment, as it is a good source of nitrate (and other nutrient) removal.

In addition to the use of duckweed in wastewater treatment, pesticide companies use duckweed as a test plant for the toxicity levels. When added to growth media, any effects on the growth rate is taken as a measure of the toxicity in the pesticide.

Background Information:

Population growth is a basic unit in studying ecology. Population dynamics refers to the changes in population over time and is tied to the carrying capacity of the environment. In a fundamental world with unlimited resources, a population will grow exponentially; in reality, there are both biotic and abiotic factors that influence population growth. The environment's carrying capacity is the maximum number of individuals that an area can support. The carrying capacity can change from season to season or from one year to the next.

In this lab, students will observe the growth of duckweed to determine how the population density changes over time in controlled environments with varying degrees of nutrients.

Materials:

- Duckweed - check a local pond and identify the species if possible.
- Fertilizer –with mixing instructions and given NPK values
- Spring water, or other dechlorinated water.
- Plant grow light, optional but useful.
- Small cups or containers with clear lids, the lids reduce evaporation. Check your local food distributor.
- Water test kits that test for NPK (optional).

Procedure:

1. Make up the fertilizer solution at 1X, 5X, and 10X times the recommended concentration for the fertilizer.

a. Optional: Determine the concentration of nitrogen, phosphorus and potassium for each solution using a water test kit.

Sample	N	P	K
Control (water)			
Fertilizer 1X			
Fertilizer 1X			
Fertilizer 5X			
Fertilizer 10X			

2. Determine the volume of the cups in metric; for instance, convert the ounce into milliliter. Determine approximately 75% of the volume in the cup, round to have an easy number to measure.

   a. How many mL per cup is added: _______

3. Label the cups with the name of the fertilizer, the concentration and the start date. Also, add the name of at least one group member.

4. Using toothpicks or tweezers, add 2-3 three-frond and add 2-3 two-frond duckweed plants. Record the starting number of fronds. This is "Day Zero."

5. Observe the duckweed every day for 4 weeks; count how many fronds are in each cup. Record the data in a table. Note: The table below is a sample table with only one week. Draw your own table.

   a. You can skip the weekends, but remember weekend days count in the total number of days.

6. Optional: Determine the concentration of NPK for each solution using a water test kit after the duckweed experiment has ended.

7. Graph your results on a spreadsheet.

Data Table:

	Date	# Plants Counted			
Day #	(day of week, date)	Control	1X	5X	10X
0					
1					
2					
3					
4					
5					
6					
7					

Include the day of the week along with the date. This helps keep track of the day numbers. If you do not collect data on one date, make a note that no data was collected.

Data Analysis:
Graph your results.

- A pie graph is great for comparing data that is fairly static (unchanging). The graph is drawn in a circle and each section of the pie graph is based on a percentage. The numbers shown are generally the data not the percentages calculated.
- Bar graphs are also great at comparing data. The actual numbers are drawn as bars on a graph. Similar data can be compared side by side on the graph.
- Line graphs are great for showing change over time and often used to compare various data sets. The plots show peaks and dips on the grid, which makes it easy to compare different data sets that change over time.

Since the data collected concerning the number of duckweed plants grow over time in different solutions, a line graph is best. There will be 4 lines (control, 1X, 5X, and 10X) on the graph.

The graph should include the following:

- Title
- x- and y-axis labeled with a title and units
- key or legend

Discussion Questions:

1. Discuss the population dynamics for each concentration. Compare population sizes and growth rates.
2. What are the limiting factors for the population growth of duckweed in this activity, if any? Explain your answer.
3. Using the graph, determine the carrying capacity for each concentration of fertilizer and the control. Record that number in your answer and draw the line on the graph.
4. In each concentration of fertilizer, does the population reach carrying capacity? Explain your answer.
5. If carrying capacity was reached, compare the populations for each concentration in which carrying capacity was reached. Is there a difference in carrying capacity between the different conditions? Explain your answers.
6. Explain why duckweed is used with treated wastewater from reclamation plants.
7. Is duckweed an r-strategist or a K-strategist. Explain your answer.
8. Some species have significant roles in the environment, including indicator, keystone or foundation species. Provide an argument that duckweed is at least one of these three types of species.
9. Discuss the factors that demonstrate duckweed is a density dependent species. Discuss the factors that demonstrate duckweed is a density independent species.
10. Discuss two positive effects and two negative effects to the pond's environment if the duckweed completely covered its surface.
11. Expanding your answers about density and species to the human population, do you think the human population has reached or will reach its carrying capacity? Explain your answer.

Extensions:

- Higher concentrations such as 20X or 25X
- Different fertilizers containing different concentrations of NPK.
- Direct sunlight; plant grow lights, setting times of light exposure.
- Determine the growth rate Nt = Noert

- No – starting number of fronds (plants)
- Nt – ending number of fronds (plants)
- e – Euler's number for natural decay (the inverse of the natural log)
- r – growth rate
- t – number of days in determining the growth rate

• Continue the activity for 8 total weeks.

Comparing Commercial Fertilizers

Purpose: Compare commercial fertilizers for different plant species and determine the nutrients that the various plant species need.

Procedure:

1) Visit a hardware store or plant nursery.
2) Collect data from the commercial fertilizer labels.
   a. Obtain information for different plants (fruit trees, citrus trees, rose, grass, African Violets, and any others you find).
   b. You can also find different brands for the same plant and compare the brands.

Commercial Fertilizer Comparison

Analysis:

1) For each of the three primary macronutrients: nitrogen, phosphorus and potassium, complete the following:
   a. Which fertilizer provided the highest concentration of each of the primary macronutrients?
   b. Which fertilizer provided the lowest highest concentration of each of the primary macronutrients?
2) If you have different brands for the same plants, is there a difference in the nutrient concentrations? If so, explain why there might be a difference.
3) Is there a difference between outdoor plants (fruits, vegetables, grass) and indoor plants (African violets, others)?
4) Briefly explain why different plants require different amounts of the three primary macronutrients.

Brand	Plant type	NPK (%)	Other nutrients	Other Comments
Example: Bayer Advanced Garden	*Rose & Flower 2 for 1*	*12:18:6*	*Sulfur: 11%*	*Insecticide*

Water Cycle Game

Objective: Students will learn about the water cycle by 'experiencing' it as a water droplet.

Preparation:

1. Use 10 envelopes, beakers in a science classroom, or other container with the title for each of the main categories below and post them in different locations around the room.
   a. Place them far apart from each other so students have plenty of room to walk around. This will allow them to experience the various paths that water travels through.
2. Copy the statements on color paper, if available.
3. Cut each statement under the categories into strips and put them into the corresponding envelopes or beakers.
4. Make copies of the worksheet for each student.

Procedure: Randomly assign students to a starting location in the water cycle so that each phase approximately has the same number of students at it.

1. Each water droplet (your students) writes down their starting location in the water cycle in the appropriate column on their worksheet.
2. Next, without looking, the student will pick a statement out from their starting location in the water cycle.
3. They will write that location down in the 'Destination' column and after explaining what happens under the middle column, put the statement back in the envelope, and move to their new location.
   a. In some cases, they will stay at the same location for the round and pick another statement.
   b. Remind them the goal is not to get to all the stations but to follow the path of water as they pull the strips of paper.
4. Complete this until their worksheet is filled.

Reflection:

1. Have the students write a story from the perspective of being the water droplet or draw a series of pictures as the water droplet journeys through the water cycle. If the student chooses to draw their story, they can make it a cartoon.
2. Have the students share their story or drawings.

Name: ______________________________

Water Cycle Game / *Student Worksheet*

Objective: Get your feet wet as you experience the various phases that a water droplet goes throughout its never-ending life in the water/hydrologic cycle.

To play:

1. Write down your starting location in the water cycle in the 'Location' column.
2. Next, WITHOUT LOOKING, pick one statement from your starting location in the water cycle.
3. Write that location down in the 'Destination' column and explaining what happens under the middle column, put the statement back in the envelope, and move to your new location.
   a. In some cases, you may be told that you stay in the same location. Write down that information for the round and pick again for the next round. Who knows! You may end up staying there for a while. Water doesn't always move quickly!
   b. Please make a note of anytime you had nutrients at a station.
4. Pick a statement from the next location and repeat until your worksheet is filled.

	LOCATION	WHAT HAPPENS	DESTINATION
Ex.	Cloud	Falls as rain	Mountain
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

5. Create a data table and count how many times you were at each location ('Location' column, not 'Destination' column). Count just the times in the location column.
6. Record your data in a spreadsheet on the computer and obtain the class average.

Station #	Your Locations	Class Average
1. Cloud		
2. Mountain		
3. Ocean		
4. Stream/River		
5. Groundwater/Aquifer		
6. Animal		
7. Plant		
8. Soil		
9. Lake		
10. Glacier		

Questions:

1. Why do you think most students spent the majority of their time in the ocean or the clouds?
2. Explain why students spend the least time at the glacier, in the soil or in an animal.
3. At which locations are you likely to find high concentrations of human habitats? Why would they live in these locations?

Reflection:

Write a story from the perspective of being the water drop or draw a series of pictures as the water drop journeys through the water cycle. If you choose to draw your story, you can make it a cartoon.

Statements:

AQUIFER/GROUNDWATER

You follow the aquifer as it moves and you become part of the OCEAN.
You become part of an underground stream that flows to an OCEAN.
You exit the aquifer as part of a STREAM on a mountain.
You become part of an underground stream that flows to a spring, where you become part of a STREAM.
You filter into a LAKE.
A PLANT takes you in through its roots.
You carry needed nutrients to the plant.
You are pumped out of the ground from a well to irrigate a farm. (Go to PLANT.)
You stay UNDERGROUND.
You stay UNDERGROUND.
You stay UNDERGROUND.

MOUNTAIN

You soak into the ground and get absorbed by a PLANT'S roots.
You carry needed nutrients to the plant.
You soak into the ground and get absorbed by a PLANT'S roots.
You carry needed nutrients to the plant.
An ANIMAL drinks you.
You flow down as runoff into a STREAM.
You carry needed nutrients downstream.
You roll downhill and become part of a STREAM.
You carry needed nutrients downstream.
You flow down as runoff into a STREAM.
You carry needed nutrients downstream.
You evaporate into the air. (Go to CLOUD.)
You soak into the ground and become part of the GROUNDWATER.
You get frozen in ice and stay there. (Stay at MOUNTAIN.)

PLANT

The plant dies and you evaporate as the plant dries out and become part of the CLOUD. You leave the nutrients behind.
The plant dies and you evaporate as the plant dries out and become part of the CLOUD. You leave the nutrients behind.
The plant transpires you through its leaves into the air as vapor. (Go to CLOUD.)
The plant transpires you through its leaves into the air as vapor. (Go to CLOUD.)
The plant transpires you through its leaves into the air as vapor. (Go to CLOUD.)
The plant uses you for photosynthesis. (Stay at PLANT.)
The plant uses you to grow. (Stay at PLANT.)

SOIL

You are absorbed by PLANT roots.
You carry needed nutrients to the plant.
You are absorbed by PLANT roots.
You carry needed nutrients to the plant.
The soil is saturated, so you run off into a RIVER.
You carry nutrients down river.
You flow down to a STREAM.
You are pulled by gravity and filter into the SOIL.
You absorb heat energy, evaporate, and go to the CLOUDS.
You leave the nutrients behind.
You absorb heat energy, evaporate, and go to the CLOUDS.
You leave the nutrients behind.
You remain on the surface (perhaps in a puddle, or adhering to a SOIL particle).

CLOUD

You fall as rain onto a MOUNTAIN.
You fall as snow onto a MOUNTAIN.
You fall as rain into a freshly tilled field and percolate through the soil and rock. (Go to GROUNDWATER.)
You fall as rain onto the leaves of a tree. (PLANT)
You fall as rain into a field of hay. (PLANT)
You fall as rain into the OCEAN.
You fall as rain into the OCEAN.
You fall as rain into the OCEAN.
You condense and fall as snow onto a GLACIER.
You condense and fall into a LAKE.
You remain as a water droplet clinging to a dust particle. (CLOUD)

STREAM/RIVER

You run down to the OCEAN.
You continue rolling downhill and become part of an OCEAN.
You evaporate to form new CLOUDS.
You evaporate to form new CLOUDS.
An ANIMAL drinks from the stream.
You are absorbed by a PLANT.
You flow into a LAKE.
You are pulled by gravity and filter into the soil. (Go to GROUNDWATER.)
You remain in the current of the RIVER.

ANIMAL

The animal sweats and you evaporate off the animal's hide and become part of the CLOUDS.
The animal sweats and you evaporate off the animal's hide and become part of the CLOUDS.
The animal dies and you evaporate as the animal dries out and become part of the CLOUDS.
The animal dies and you evaporate as the animal dries out and become part of the CLOUDS.
The animal urinates and you fall to the ground. (SOIL)
The animal urinates and you fall to the ground. (SOIL)
You remain incorporated into the body. (Stay at ANIMAL)

OCEAN

You absorb heat energy, evaporate, and go to the CLOUDS.
You absorb heat energy, evaporate, and go to the CLOUDS.
A kelp plant takes you in, releases you through its leaf, and transpires you into AIR.
You are one of the countless water molecules in an OCEAN and stay there.

You are one of the countless water molecules in an OCEAN and stay there.
You are one of the countless water molecules in an OCEAN and stay there.
You are one of the countless water molecules in an OCEAN and stay there.
Go to PLANT, but do not draw a card. Then go directly to CLOUD.
(Yes, this counts as 2 rounds. In the What Happens part, write that you transpired.)

LAKE

You are pulled by gravity and filter into the soil. (GROUNDWATER)
An ANIMAL drinks water.
You absorb heat energy, evaporate, and go to the CLOUDS.
You runoff into a nearby RIVER.
You remain within the LAKE.
You remain within the LAKE.

GLACIER

Ice melts and you filter into the *ground.* (GROUNDWATER)
Ice evaporates and you go to the CLOUDS.
Ice melts and you flow into a RIVER.
Ice stays frozen in the GLACIER.
Ice stays frozen in the GLACIER.
Ice stays frozen in the GLACIER.

Free Response Questions

Each question is worth 10 points for a total of 40 points per set of 4 questions. For the first set of questions, there will be a short description on how the points should be determined by the student. Each question is worth 10 points.

1. Read the following article below and answer the questions that follow.

> Over the last 50 years, crop production has more than doubled on roughly the same amount of land, out pacing population growth. This has been accomplished by increasing agricultural productivity, often called the Green Revolution. How has this been possible?
>
> This was accomplished through a variety of changes in agricultural production. The development of crop varieties through cross breeding that require less water, grow in warmer temperatures, and withstand a host of diseases.
>
> The development of fertilizers and pesticides following World War II. Commercial fertilizers were developed to replace nutrients lost when plants were removed from the environment for sale to far off markets. Over time understanding of nutrient need became clearer and farmers established better procedures to apply commercial fertilizers. The development of pesticides also help increase crop yield.

(a) Commercial fertilizers focus primarily on the three primary macronutrients. Identify the three primary micronutrients and describe the importance of one of the primary micronutrients.
(b) Describe one environmental benefit and one environmental consequence of using commercial fertilizers to increase crop production.
(c) Describe one economic benefit and one economic consequence of using commercial fertilizers to increase crop production.
(d) Describe one reason that the development of commercial fertilizers and pesticides increase dramatically after World War II.

(e) Many consider that we are in a second Green Revolution using recombinant DNA technologies. Describe how recombinant DNA is being used to increase crop production.

Point determination: For (a) answers, students may earn 1 point for each macronutrient (3 points total). Additionally, students may earn 1 point for the importance of one of the macronutrients. The total for (a) is 4 points. For answer (b) students may earn 1 point for the benefit and 1 point for the consequence (2 points total). For answer (c), students may earn 1 point for the benefit and 1 point for the consequence (2 points total). Answers for (d) and (e) are one point each. The total is 10 points.

2. Total world grain production has increased dramatically over the last 50 years, as the world's population has more than doubled. This has been accomplished in part by the increase use of fertilizers and the development of higher yielding crops. In 1960, world grain production was 824 million tons on 1,579 million acres. The total world grain production was 2,587 million tons on 1,707 million acres in 2012.

(a) What is the percentage change in world grain production from 1960 to 2012?
(b) What was the average yield per acre in 1960 and in 2012?
(c) If the average yield had not increased between 1960 and 2012, how many acres would be needed at the lower yield to have the same amount of grain grown?
(d) Describe how the use of fertilizers has increased crop yield.
(e) Crop yield has also increased due to changes in the genetic make-up of crops.
i. Describe hybridization of crops.
ii. Describe how crops are genetically modified in the lab.
(f) Other than fertilizer use or modifying the crop genetics, describe another method used to increase crop yield.

Point determination: For (a) answers, one point is earned for the correct setup and one point for the correct answer (total 2 points). For (b), answers can earn one point for set-up and one point for the correct answer (2 points each). For (c), answers can earn one point for set-up and one point for the correct answer (2 points each). For answer (d), students earn one point for the description. For answer (e), students earn one point for the hybridization and one point for genetically modifying (2 points total). For answer (f), students earn one point for the description of another method. The total is 10 points.

3. There are 17 elements needed for a plant to complete its life cycle. Within in that group are non-mineral, macronutrients and micronutrients. These nutrients cycle through the ecosystem moving between the biotic (living) and the abiotic (nonliving) system. The mineral theory states that crop yield grows or diminishes in proportion to the amount of nutrients applied and the "Law of the Minimum" states that crop yield is determined by the most limiting nutrient quantity. Nutrient deficiency or nutrient toxicity can alter the plant's life cycle.

(a) Identify the three non-mineral elements and describe how one of these elements enters the plant's life cycle.
(b) Describe one role that the mineral elements have in a plants life cycle.
(c) Describe the effects of one mineral nutrient deficiency and one mineral nutrient toxicity.
(d) Explain the difference between macronutrient and micronutrient.
(e) Identify one biogeochemical cycle and describe one component of the cycle.

Point determination: For answer (a), each of the three non-mineral nutrients is 1 point each. Additionally, students may earn 1 point for one of the elements enters the plant (4 points total). For answer (b), students may earn one point for describing one role. For answer (c), students may earn one point each for describing the effects for deficiency and toxicity (2 points total). For answer (d), students earn one point for explaining the difference. For answer (e), students earn 1 point for identifying the cycle and 1 point for describing a component (2 points total). The overall total is 10 points.

4. How do we become a more sustainable society? Sustainability is defined as "development that meets the needs of the present society without compromising the ability of future generations to meet their own needs." To become a sustainable society, every sector needs to make changes to how they use their limited resources.

(a) Sustainable agriculture is the ability to integrate the three main goals: environmental health, economic profitability, and social and economic equity. Discuss two of the three concepts and how it relates to sustainable agriculture.

(b) Describe two environmental benefits of commercial fertilizers to the crops that has helped agriculture become more sustainable.

(c) Describe one economic benefit to the use of commercial fertilizers.

(d) Describe one environmental consequence that the addition of commercial fertilizers may make them unsustainable.

(e) The concept of 4R Nutrient Stewardship is to obtain the best performance from the fertilizers while minimizing the negative effects on the environment. The core concept of 4R Nutrient Stewardship is the application of the right plant nutrients, at the right rate, the right time and in the right place. Choose two of these core concepts and explain their meaning.

(f) Describe two actions you can take that would make you more sustainable.

Point determination: For answer (a), students may earn 2 points - one point for each discussion. For answer (b), students may earn one point for each sustainable application. For answer (c), students may earn one point for a description of an economic benefit. For answer (d), students may earn 1 point for the consequence. For answer (e), students may earn one point for each description (total of 3). For answer (f), students may earn 1 point for each action described (2 points total). The overall total is 10 points.

Math Problems

Directions: Answer the following math questions without calculators.

A. Utilizing statistics that are available by USDA, research the data and then answer the questions.

Access the statistics:

Visit: http://quickstats.nass.usda.gov/ to find annual yield measured in bushels/acre of corn for grain. Steps:

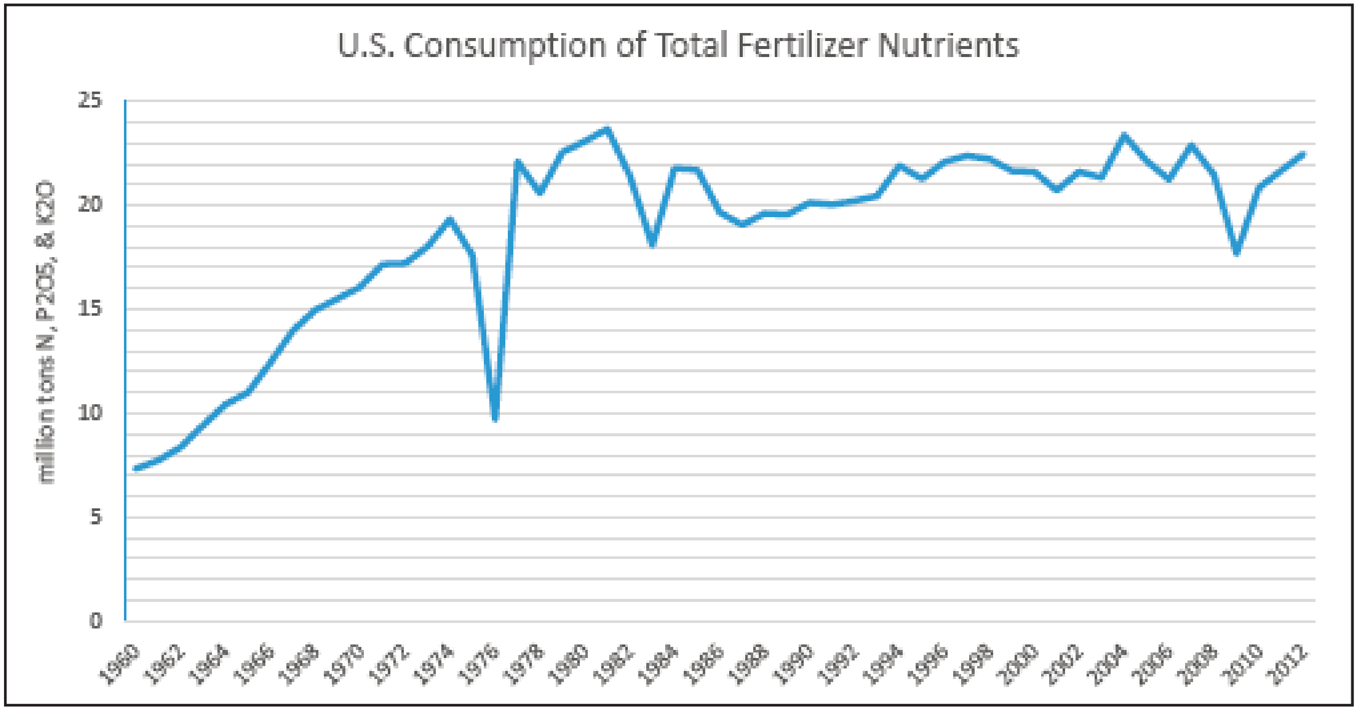
a. Program: survey
b. Sector: crops
c. Group: field crops
d. Commodity: corn
e. Category: yield
f. Data item: corn, grain – yield, measured in bu/acre
g. Domain: total
h. Location: national
i. State: U.S. total
j. Time: (current year) through 1960
k. Period type: annual
l. Period: year
m. Press "Get Data" Button

The steps above will lead students to a page with the data. The top right corner of the web page provides options for students to save the data or open as a spreadsheet.

1. Graph the percentage change in corn yield from 1950 to present.

2. You learned about the best management practices farmers are implementing earlier in this resource. Through the implementation of these practices, farmers are producing more with less nutrients per bushel of corn. Using various data points provided by the USDA, farmers used 48.7 percent less fertilizer nutrients (nitrogen, phosphate, and potash) per bushel of corn produced in 2010 than in 1980. If farmers used 3.188 pounds of fertilizer nutrients per bushel of corn produced in 1980, how many pounds of fertilizer nutrients were used to produce a bushel of corn in 2010?

3. Determine the change in bu/acre in your state.



Source: *Commercial Fertilizers 2012, Association of American Plant Food Control Officials and The Fertilizer Institute*

B. US Consumption of Total Fertilizer Nutrients

4. Which year on the graph used the most commercial fertilizer? How much fertilizer was used that year?

5. If commercial fertilizer use was 7 million tons in 1960, what is the percentage change in commercial fertilizer use between 1960 and your answer above (#4)?

6. **Conversion Problem:** An all-purpose plant food is diluted to use for home gardens.

a. One cup is diluted into 24 gallons, how many gallons will a quart of the plant food dilute into?

b. If water has an approximate weight of 8 pounds per gallon, how many pounds does the total quart of plant food make? If one gallon equals 3.79 liters (rounded to two decimal places), how many liters are produced from the one-quart of plant food (rounded to the nearest whole number)? What is the weight in kilograms if 1 pound is 0.45 kg?

Glossary

Glossary

4R Nutrient Stewardship	Provides a framework to achieve cropping system goals, such as increased production, increased farmer profitability, enhanced environmental protection, and improved sustainability.
Agronomic efficiency	The amount of yield increase per unit of fertilizer (or other input) applied.
Biological nitrogen fixation	Reduction and assimilation of atmospheric nitrogen (N_2), a capability of certain free-living and symbiotic bacteria.
Clean Air Act	Requires EPA to establish primary and secondary air quality standards. Required states to develop implementation plans. Sets limits and goals to reduce mobile source air pollution and ambient air quality standards.
Clean Water Act	Regulates and enforces all discharges into water sources and wetland destruction/construction.
Cogeneration technology	Combined heat and power, is the use of technology to generate simultaneously both electricity and useful heat.
Commercial fertilizers	A manufactured material added to the soil in order to supply one or more plant nutrients. Commercial fertilizers contain nutrients in known amounts that plants can immediately use.
Dragline	A heavy piece of equipment often used in mining phosphate in the southeastern part of the United States.
Fertigation	The practice of fertilizer application through an irrigation system.
Fertilizer banding	Method of applying fertilizers where fertilizer is only applied onto or near rows of crops requiring fertilizer.
Fertilizer use efficiency	An expression of the units of yield per unit of nutrient provided for the crop.

Glossary

Green Revolution The huge gain in agricultural productivity from 1950–2000 and even into the present. It is associated with the work of Dr. Norman Borlaug, who received a Nobel Prize for his work to end world hunger. Borlaug introduced better plant varieties, commercial fertilizers and other technologies to farmers in the developing world.

Justus von Liebig Formulated the "mineral theory," which held that crops "grow or diminish in exact proportion" to the amount of nutrient applied.

Law of the minimum The excess of one nutrient cannot overcome the deficiency of another. All of the 17 essential elements must be present in quantities sufficient to meet the requirements of the growing crop.

Macronutrients The essential plant nutrients required in the largest proportions by plants (N, P, and K). The secondary macronutrients include calcium (Ca), magnesium (Mg), and sulfur (S).

Micronutrients Nutrients that plants need in only small or trace amounts. Essential micronutrients are boron (B), copper (Cu), chlodie (Cl), iron (Fe), manganese (Mn), molybdenium (Mo), nickel (Ni), and zinc (Zn). The non-mineral nutrients are hydrogen (H), oxygen (O), and carbon (C).

Nitrogen An essential primary nutrient, a constituent of every living cell, plant, or animal. In plants, it is a part of the chlorophyll molecule, amino acids, proteins, and many other compounds.

Nitrogen cycle The routes taken by nitrogen from the atmosphere through soils, plants, animals, and man, back to the atmosphere.

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.

Organic fertilizers Strictly speaking, an organic material is one containing carbon. This includes urea and calcium cyanamide, which are manufactured synthetically. The term generally applies to products derived from plant or animal materials, such as manure, sewage sludge, castor pomace, and process tankage.

Particulate matter A general term for a mixture of solid particles and liquid droplets suspended in air.

Phosphorus One of the essential nutrients required by plants and classified as one of the three primary nutrients. Phosphorus, a mobile plant nutrient, plays key roles in photosynthesis, respiration (utilization of sugars), energy storage and transfer, cell division, cell enlargement, genetic coding and many other plant processes.

Glossary

Plant uptake	The action of water and nutrients from soil entering the plant.
Potash	A term used to denote the potassium oxide (K_2O) equivalent of materials containing potassium. Actually, K_2O as such is never found in fertilizer, but historically has been a term expressing potassium content.
Potassium	Potassium is an essential element, one of the three primary nutrients including nitrogen and phosphorus. Most plants required approximately the same amount of nitrogen. Potassium has important roles in activation in enzyme systems, is vital to photosynthesis and maintenance of protein structure and helps the plant use water more efficiently.
Real Time Kinematics (RTK)	A guidance technology used in precision agriculture that provides high positioning performance in the vicinity of a base station.
Reclamation land	Land that has been restored and reclaimed back into high-quality ecosystems. Reclaimed lands may be used for commercial, agricultural uses, or even development.
Strip tillage	Method of plowing fields where only a narrow strip of crop residue is removed to form a seedbed.
Sustainability	Refers to the use of a resource in such a way that the resource is not depleted or irreparably degraded.
Wet Scrubbers	A device that removes air pollutants, like PM and acid gases, from stationary point sources.

Nutrients for Life Foundation

Nutrients for Life Foundation provides soil and crop nutrient education resources to teachers. Request free materials, like those listed here, at www.nutrientsforlife.org.

Phosphate Mining Video & Potash Production Video

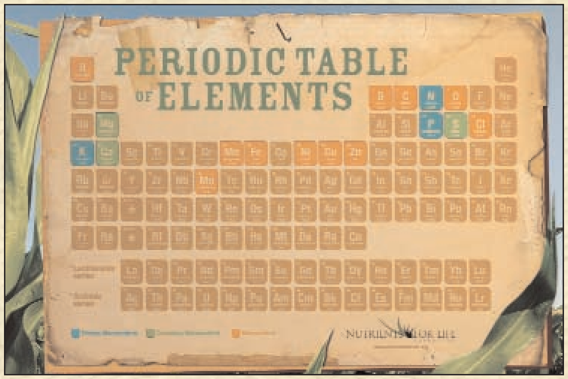
These lively videos show the amazing process of producing phosphate and potash fertilizer. Available to stream online!

Cross-curricular Magnets

Promote cross-curricular connections with these word magnets. Make sentences with agriculture buzz words color-coded by the part of speech.

Flashcards

Play a fun game (Around the World, Beat the Clock or Circle Up) and test your students' plant and soil science knowledge. Designed specifically for Lesson 4 of the high school curriculum.

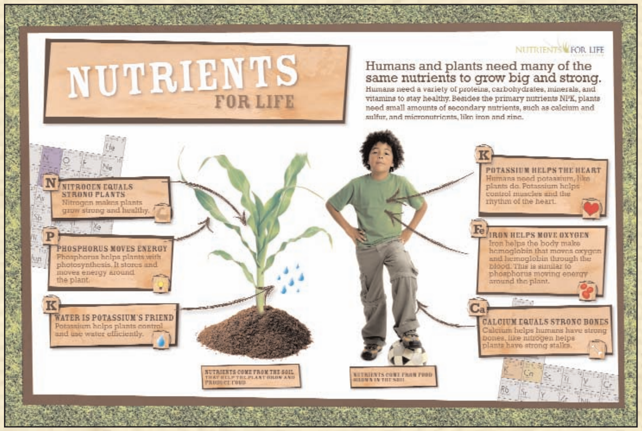


Periodic Table

Connect biology to chemistry in this colorful periodic table of elements poster. This piece highlights the primary macronutrients, secondary macronutrients, and micronutrients; all of which are essential for plants.

Apple Poster

Can a single apple slice feed the world? This is a great resource poster for teachers to use as they address the challenges of feeding a growing population. (Also available in Spanish)



NPK Poster

Plants, like humans, need nutrients. This resource poster is a great addition to your classroom showing the basics of primary nutrients.
(Also available in Spanish)

Teacher's Guide

Nourishing Crops with Fertilizers, page 7
Students should fill in the outline using the previous content in the "Nourishing Crops with Fertilizers" section. Answers will vary.

Nitrogen Cycle Organizer, Phosphorus Cycle Organizer, Potassium Cycle Organizer, pages 11-13
Refer to Figures 1, 2, and 3 in the text for the missing terms in the cycle.

Multiple Choice Questions
Assessment questions include Matching Questions, Roman Numeral Questions, and Negative Questions.
- Questions 1-30 appear on page 20 and are assessments for part 1, Nourishing Crops with Fertilizers.
- Questions 31 & 32 are associated with the 4R Case Study on page 26.
- Questions 33-35 are associated with the Production Facility Case Study on page 53.
- Questions 36-42 are associated with the *Alchemy of Air* Excerpts.
- Questions 43-60 appear on page 59 and are assessments for part 2, Fertilizers, the Environment, and Regulation.

1. D: Development of GMOs
The development of GMOs is helping to drive the current surge in the crop yield but is a recent development occurring after the years provided in the question.

2. D: I and II
Both the improvement of crops through cross breeding and the use of commercial fertilizers have improved crop production. The improvement of plants through cross breeding is stored in the seeds, which is where plant growth gets its start. While the use of pesticides has increased crop production, pesticides accomplish this not by increase crop yield but rather by decreasing crop lost to pest (insects and other organisms).

3. E: Temperature and Water
Seed germination needs water and warm temperatures. While light is needed for plant growth, especially in terms of photosynthesis to produce energy, the seed has all the energy it needs to grow until photosynthesis begins. Soil provides stability for the roots and nutrients for plant growth, but not needed for seed germination.

4. D: Solar Intensity
The amount of solar intensity has little influence on plant growth; photosynthesis actually uses less than 1% of light hitting the Earth's surface.

5. B: Carbon, hydrogen and oxygen
Nitrogen, phosphorus and potassium are all mineral elements, therefore only answer B contains all non-mineral elements.

6. D: Nitrogen, phosphorus and potassium
Calcium and sulfur are secondary macronutrients and Iron is a micronutrient. Only nitrogen, phosphorus and potassium are the primary macronutrients and the nutrients most commonly tested for in home soil test kits.

7. A: Accelerated diffusion
All the others are symptoms of nutrient deficiencies.

8. E: Water cycle
Carbon, nitrogen and sulfur are directly tied to the water cycle, many of the components of these cycles are water soluble, and they are carried in the atmosphere and are often brought to the Earth's surface in precipitation.

9. C: Phosphorus
The components of the phosphorus cycle are very water insoluble and phosphorus is often the limiting factor in aquatic systems.

10. D: Sulfur
SO2 and SO3 are released both in the decomposition of organisms and the burning of fossil fuels, they combine with water to form sulfuric acid (H_2SO_4).

11. E: Water
Another name for the water cycle is the hydrologic cycle.

12. D: I and III
Both evaporation and transpiration works against gravity. Evaporation is the conversion of a liquid to a gas that is then small and light and able to move into the upper layer of the troposphere. Transpiration is the process of plants losing water in the form of water vapor during photosynthesis.

13. E: NO_3-
Most plants prefer the nitrate ion (NO3-).

14. E: Nitrogen Fixation
Nitrogen can be fixed by either rhizobium bacteria in a symbiotic relationship with many of the legumes plants such as alfalfa, clover, peas, beans, lentils, soybeans, peanuts and others or by lightening.

15. B: Denitrification
Answers C and D involve the loss of usable nitrogen by water, answer E involves the loss of usable nitrogen due to water or wind. Answer A involves losing the nitrogen into the atmosphere in the form of ammonia. Denitrification involves the conversion of nitrate into nitrogen gas, the chemical equation is $NO_3^- \rightarrow NO_2^- \rightarrow NO + N_2O \rightarrow N_2$ (g).

16. D: Haber-Bosch
Fritz Haber and Carl Bosch developed the process of converting nitrogen gas (N2) into ammonia (NH3) that with few modifications is still used today.

17. E: II and III
Phosphorus is a sedimentary cycle, based in the Earth's crust. Very little if any phosphorus is found in the atmosphere.

18. D: Plant and animal food sources that are removed from the fields and their nutrients are not returned to the fields through decomposition.
When plants and animals are removed from the fields, their nutrients leave the fields as well, thus the nutrients that are in these food sources are not available.

19. E: Farmers using of human generated sewage sludge from the community.
All the other answers eliminate the use of any substance that is not considered "organic", answer E is taking the sewage waste generated in our homes and processing the waste and placing it on fields for nutrients. Generally such waste is not allowed in the US on fields used for growing crops for human consumption.

20. E: Commercially produced fertilizers contain nitrogen and phosphorus that must first be processed into usable forms.
The forms of nitrogen and phosphorus in commercial fertilizers are ready to be absorbed and used by the plants.

21. D: Organic fertilizers may be too high or too low in an important nutrient creating an imbalance.
Answers A, B and C are advantages that organic fertilizers provide to the soil and the crops. Answer E is an advantage for commercial fertilizers, organic fertilizers must decompose before the nutrients are available. Answer D is the best answer for this question as it best describes a disadvantage for organic fertilizers.

22. C: III only
One definition of nutrient pollution is "the process by which too many nutrients, especially nitrogen and phosphorus, flows into bodies of water and cause excessive plant growth of algae." Leaching of the nutrients into an aquifer is not going to lead to plant growth since the aquifers are underground and have no plant growth. Excessive plant growth may be due to excessive nutrients but is not due to nutrient pollution.

23. B: Development of resources that meet the needs of the present population without compromising the ability of future generations to meet their needs.
A sustainable society needs to consider the economic, environmental and social needs of the current society and looking into future generations. The other four answers do not include all three aspects, economic, environmental and social.

24. B: Production and maintenance of an affordable, healthy food supply
The production and maintenance of an affordable, healthy food supply is part of the stewardship of land and natural resources, which is separate from the stewardship of human resources.

25. E: I, II and III
The most obvious answer is I and III, as both address the need for increase agriculture production. II is also a valid answer, while not playing a huge role in the increase in agriculture production, there is a growing movement for more organic options and will fulfill a small niche within the overall agriculture production.

26. B: Nitrogen: Phosphorus: Potassium
The best way to remember this is the three letters, NPK, this is mentioned on the test kits, in textbooks and if you read the labels on fertilizers, you will always see this order.

27. D: Law of the Minimum
All the essential elements must be present in the needed concentration for the plants to grow, each plant has its own set of essential elements.

28. E: Mineral Theory
Plant growth is based on the need for the essential elements.

29. D: Law of the Minimum
The limiting factor is the nutrient that has the least amount of the essential elements as a ratio of all the essential elements.

30. A: 4R Nutrient Stewardship
States that the right plant nutrient is used, applied at the right rate, at the right time for grow, and in the right place. This is done to maximize the growth and reduce the impact on the environment.

31. The farm uses scientific tests to determine the exact amount of fertilizer needed so that no excess is applied. The farm employs strip tillage and fertilizer banding to prevent runoff and limit the amount of fertilizer needed. The farm uses a cover crop to hold nutrients during the winter.

32. Best management practices that could apply to homes and businesses include: Don't overuse lawn fertilizers and pesticides that end up in water bodies or groundwater. Plant natural grasses and wildflowers as borders to act as filters, much as farmers do with filter strips at the edge of fields. Contour land to reduce storm water runoff and wind erosion. (For more ideas check out www.cnt.org, the website of the Center for Neighborhood Technology).

33. One environmental concern is that the proposed mine is nearer a resort community than previous mines. This means there are high expectations for the quality of the environment, both air and water. Another concern would be returning the land to a condition similar to the way it was before mining. One environmental law that needs to be considered by the Matrix Company is the Endangered Species Act. The company would need to know if it is disrupting the habitat of any endangered or threatened species, currently listed or proposed for listing. Section 404 of the Clean Water Act prohibits the dredging or filling of navigable waters, including wetlands, without a permit. If the Matrix Company has wetlands on the property, the United States Army Corps of Engineers would have to approve removal of them and possible mitigation.

34. In its reclamation plan, Matrix Company would have to consider all of these things: safety, hydrology, land contouring, re-vegetation, wildlife habitat and the timing of the reclamation. (Florida law requires that each individual acre impacted by mining be made suitable for beneficial use or habitat).

35. During phosphate rock acidulation the crushed ore is treated with sulfuric, phosphoric or nitric acid to yield either one of the superphosphates or "wet process" phosphoric acid. From there, the product is processed into various forms for blending with other nutrients.

36. There are two macronutrients that Europeans would have been replacing by using burned bones and wood ashes as soil amendments: phosphorus from burned bones and potassium from wood ash.

37. We can assume that manure, animal dung, was available in greater quantities than other organic fertilizers. Manure contains nitrogen in a number of forms and would have been the nutrient they replaced the most by applying manure.

38. Nutrient replacement is achieved by modern agriculture by using commercial fertilizers or planting crops like soybeans (legumes) that restore nitrogen to the soil.

39. The CO_2 produced as a byproduct of the Haber-Bosch process can be used in other processes where CO_2 is needed, or used to increase petroleum extraction.

40. In a chemical reaction, atoms are conserved, so no transmutation of elements takes place. The nitrogen remains nitrogen, but is bonded to hydrogen instead of to itself.

41. The need for chemical fertilizers will increase. Advanced agricultural practices will have to be used everywhere in order to produce enough food for so many people.

42. The Bosch-Haber process is an artificial form of fixing nitrogen, so it occurs in the cycle in the same place as natural processes that fix nitrogen, such as lightning and the action of bacteria on the roots of certain plants.

43. B. The EPA sets the national standards for air quality under the Clean Air Act.

44. B: CO_2
The other 4 in the list as well as a few other air pollutants were initially part of the Clean Air Act. California tried to regulate CO_2 but the auto companies sued them. The case went all the way to the Supreme Court and they ruled that CO_2 could be regulated as an air pollutant.

45. E: Resource Conservation and Recovery Act
One of many provision of the RCRA.

46. C: Endangered Species Act
One of many provision of the ESA.

47. D: National Environment Policy Act
One of many provision of the NEPA.

48. B: Clean Water Act
One of many provision of the CWA.

49. E: National Pollutant Discharge Elimination System
The National Pollutant Discharge Elimination System is part of the Clean Water Act; the other 4 along with Risk Management Program Rule are part of the Clean Air Act.

50. C: Uses technology to generate electricity from heat emitted in the manufacturing process.
The heat is captured and used to convert water into steam. The steam then turns a generator to produce electricity that is used in remaining processes.

51. E; I, II and III
All three are used to control dust at various stages of the manufacturing, distribution and retail of fertilizers.

52. D: Developing a hazard assessment, prevention plan and emergency response plan.
All three provisions must be part of the Risk Management Plan.

53. E: I and III
Carbon dioxide is capture for both the soda industry and the enhancement of oil recovery. While CO_2 is important in photosynthesis, it is currently not captured and used in growing plants.

54. B: Drip Irrigation
Drip irrigation is the most water efficient; it delivers water directly to the root system.

55. D: I and III
Center-pivot systems use dropped-nozzle sprinkler heads that adjust to be approximately two-feet above the top of the crops (canopy) under low water pressure not high water pressure.

56. D: The release of nitrogen and phosphorus into aquatic ecosystems could lead to algae blooms.
Nitrogen and phosphorus are limiting primary macronutrients in the environment, both are important for plant growth, an excessive concentration of nitrogen and phosphorus can lead to an overgrowth of algae.

57. D: Pollution
All of the other answers along with water retention times, freshwater inflows, stratifications and mixing play an apparent role in the hypoxia zones in the Gulf of Mexico.

58. E: Uptake of Water
Phosphorus is used in all of the processes, except the uptake of water. Phosphorus is in the water that is absorbed by plants but not involved in the process.

59. C: 2200
Below are the steps to solve the problem
a. AE = (YF-YO)/F
b. 24 = (3400 – Yo)/50
c. 1200 = 3400 – Yo
d. 2200 = Yo

60. D: II and III
The public comment process and a reclamation plan are required before a mine can be operated. An Environmental Impact Assessment is completed for every mine, that assessment is evaluated and if deemed necessary, an Environmental Impact Statement is prepared.

Air Quality Organizer, page 35-36
Students should fill in the organizer with relevant information. Answers will vary.

Water Quality Organizer, page 42
Students should fill in the organizer with relevant information. Answers will vary.

Federal Mining Regulations Organizer, page 48-49
Students should fill in the organizer with relevant information. Answers will vary.

Labs

Physical and Chemical Characteristics of Soil

1. Why is it important to study and understand soils?
Soil is vital for most plant growth. Soil supports microorganisms and bacteria that help decompose dead material to supply several key macronutrients to the plant. Soil supports the root structures that holds the plant upright in place. It captures and retains water for use by the plant. Soil contains the mineral salts for the plants need.

2. Is soil living, non-living, or something else? Support your answers; you will have to use your book and other sources to get your answer. Please cite sources.
Soil is non-living. It contains living organism such as bacteria, worms, insect species and a host of other microorganisms. The main component, sand, silt, clay, minerals, nutrients, water and air are non-living.

3. What can the physical description of soil provide us?
A physical description of soil can tell us the color, which often is tied to the nutrient content. For instance, soils high in Fe are reddish in color. The physical description can tell if the soil is high in sand content. Soil with organic debris has high nutrient contents as the organic material breaks down.

4. What does the ribbon test tell us about the soil? How does this compare to the percentage of clay and the texture triangle?
The longer the ribbon, the higher the clay content. When the soil's particle distribution is completed, the higher clay content will show on the soil triangle and will correspond to the ribbon test.

5. What is the importance in understanding the chemical composition of soils?
Different plants require different amounts of the three primary macronutrients, namely, nitrogen (N), phosphorus (P) and potassium (K). If the soil does not have the needed ratio, the soil will have to be supplemented with the nutrients.

6. How does the pH of the soil affect the nutrients in the soil? Include in your description, how the pH influences the uptake of nutrients.
The pH of the soil affects the availability of nutrients. Some nutrients become more readily available while others become less available as the pH changes. In alkaline soils, Mo, N and K are more readily available, while most other nutrients levels are reduced. Nitrogen is best available between pH 6-8 while phosphorus prefers pH 6-7.5. Below pH 6, P forms an insoluble compound with Fe and Al.

7. Why is it important to understand the particle composition of soils?
The particle distribution of soil determines the percentage of sand, clay and slit that a soil contains. Soils that are high in sand do not hold water. Soils high in clay do not allow the water to soak into the ground.

8. Research and describe what types of crops might grow in the soil in your region of the country, what factors contribute to the soils in your region, and what is commonly used to amend the soil. Visit www.thescienceofsoil.com and explore the "Not All Soils Are Created Equal" widget for your research.

- **Northwest (Idaho, Oregon, and Washington)**
  Cl: Cool to cold, with a mix of wetter and semi-arid areas.
  O: Evergreen forests and grassland meadows.
  R: Mountainous.
  P: Volcanic eruptions created layers of ash and sedimentary rocks.
  T: The soils are generally fertile.

  Major crops include apples, alfalfa, barley, corn, blueberries, vegetables, wheat and grassland for grazing.

  Home garden crops include apples, onions, peas, potatoes, tomatoes, summer squash, chard, and lettuce.

  Native plants include Firs, Large Leaf Maple, Serviceberry, Red Columbine, Dwarf, and Dogwood.
  - Preparation: Till, or dig over, the ground and remove rocks and debris. If needed, add organic matter to help with soil drainage.
  - Test: Use a soil test kit to test the soil for a correct balance of nutrients.
  - Care: Vegetable gardens need additional nutrients. Sulfur lowers pH for highly alkaline soil. Nitrogen (N) promotes plant growth and chlorophyll formation so leaves will be green. Phosphorus (P) assists in root and fruit production for onions and potatoes, and potassium (K) fights disease. Crops, such as peas, create nitrogen so including peas in a garden would help if nitrogen (N) is low.
  - Irrigation may be required to grow crops every year in the southeastern part of this region.

Volcanic ash has created a soil that is light in texture. The soil composition gives it the ability to retain water, an important requirement for healthy plants.
There are thick deposits of windblown sediments in the east. These are loamy, very fertile and productive soils.

- **West (California, Nevada)**

Cl: Dry and hot desert with dry and warm summer along coast. Some precipitation in winter.
O: Scarce vegetation in desert, shrubs and grasslands along the coast, and forests in mountains.
R: Mountains that slope gently to the coast.
P: Higher salt sediments eroded from the mountains.
T: Most soil formed during glacial periods.

Major crops include in California alfalfa hay, citrus fruits, grapes, apples, peaches, strawberries, cotton, nuts and vegetables. In Nevada, grassland for grazing.

Home garden crops include artichoke (CA), grapes, citrus fruits, and vegetables (ex. lettuce, onions, broccoli, carrots, tomatoes, and asparagus).

Native plants in the western part of the region include Giant Redwoods Black Oak, Chokecherry, Mountain Lilac, Tarweed, Mariposa Lily and Western Redbud; in the eastern part of the region, many varieties of cactus are native.

- Preparation: Till, or dig over, the ground and remove rocks and debris.
- Test: Use a soil test kit to test the soil for a correct balance of nutrients.
- Care: In the east of the region, vegetable gardens may need nitrogen (N, for leaf growth), and sulfur (S) or gypsum for highly alkaline soils. Asparagus grows well in alkaline soil, so sulfur may not need to be added.
- Irrigation is required to produce crops because there is little precipitation.

When growing plants with irrigation in salty soils, more water is added than the plants need to flush the salts below the plant roots.

Native Americans had to remove the salt from the soil in order to grow crops. Today, the salt is removed and used in some foods and for salting roads.

Desert soils are often shallow and have little organic matter. Sometimes all fine sediments have blown or washed away leaving a "stone pavement."

- **Rockies & Plains (Colorado, Kansas, Montana, North Dakota, South Dakota, Wyoming, Nebraska)**

Cl: Cold in the north and at high elevations, and warmer in the south and at lower elevations. Most of the precipitation is in the summer.

O: Grasslands and forests.

R: The plains and basins are flat while mountains are steep.

P: The soil is fertile and comes from a mix of glacial and wind-deposited sediments.

T: Due to erosion, soils in the mountains are younger than soils in the basins.

Major crops include alfalfa, hay, flaxseed, sorghum, soybeans, sugar beet, wheat and grassland for grazing.

Home garden crops include tomatoes, spinach, onions, carrots, and peas. There is not enough rain for growing citrus fruits.

Native plants include Yuccas, Indian Paintbrush, Common Yarrow, and wheat grasses.

- Preparation: till, or dig over, the ground and remove rocks and debris.
- Test: Use a soil test kit to test the soil for a correct balance of nutrients.
- Care: The loam texture makes it ideal for growing vegetables. If the layer of topsoil is thin, the soil may need to be improved by adding more nutrients. Nutrients that may be needed include nitrogen N, (for leaf growth) and potassium (K, fights disease) and magnesium (Mg).

In much of the region, irrigation may be needed to grow crops every year.
The rich, fertile soil has created large expanses of grassland once grazed by antelope, deer, and bison.
The soils on the grassland prairies are generally dark-colored due to organic matter accumulations, deep, and fertile.

- **Southwest (Arizona, New Mexico, and Utah)**

Cl: Cool deserts in the north and hot deserts in the south. Dry soil most of the year.

O: Sparse shrubs, grass, and forests.

R: Steep mountains, flat basins, and rolling plains.

P: Ancient marine deposits and sediments eroded from the mountains. Some volcanic deposits.

T: Soils range from young to older with more fertile soil in plains than desert.

Major crops include durum wheat, vegetables, cotton (south), barley (north) and grassland for grazing.

Home garden crops include potato, garlic, cherry tomato, onion, carrots and squash. Native plants include Yucca, Bunny Ears Cactus, Green Flowered Hedgehog Cactus, and Desert Sunflowers.

- Preparation: Till, or dig over, the ground and remove rocks and debris. In clay soil, till many times to break particles apart. Adding organic matter will help break up soil and improve drainage.
- Test: Use a soil test kit to test the soil for a correct balance of nutrients.
- Care: Irrigation is required, and must be managed differently in sand and clay soils, and to control salts in the plant root zone. To improve the soil, add nutrients, or organic matter. When plant matter begins to decompose, it will replenish nitrogen in the soil. Nitrogen helps in leaf growth.

Irrigation is required to produce crops because there is too little precipitation.

In the western part of the region Sodium salts cause the surface to crust and seal so rain does not soak into the soil. Salts move to the surface and remain there. The water evaporates, creating salt flats. Since the rain stays on top of the soil, there are many puddles that reflect the sun and make the area look like a mirror. Desert soils are often shallow and have little organic matter. Sometimes all fine sediments have blown or washed away leaving a "stone pavement."

- **Midwest (Illinois, Indiana, Iowa, Kentucky, Minnesota, Missouri, Michigan, Ohio, Tennessee, and Wisconsin)**

Cl: Warm in the south and cool in the north. Moderate precipitation.

O: Tall-grass prairies and deciduous forests.

R: Gently rolling plain with streams and rivers.

P: Soils are slightly acidic formed by glacial lakes, or wind-deposited sediments.

T: Soils are older in the south than the north.

Major crops include alfalfa hay, hay, corn, soybeans, wheat, blueberries (MI), apples (MI) and grassland for grazing.

Home garden crops include tomatoes, carrots, sweet peppers, corn, soybeans, onions, and beans.

Native plants include Sugar Maples, Shagbark Hickory, Jacob's Ladder and varieties of ferns.

- Preparation: Till, or dig over, the ground and remove rocks and debris.
- Test: Use a soil test kit to test the soil for a correct balance of nutrients.
- Care: Some vegetables, like tomatoes, require (Ca) calcium, (Mg) magnesium and (S) sulfur (for highly alkaline soil). Cucumbers, corn, soybeans, and legumes may require lime to raise the pH of highly acidic soil. Loamy soils are ideal for growing vegetables and many other crops. Citrus fruits cannot be grown because of the risk of frost.

The area has earned the nickname "breadbasket" because of these highly productive, fertile soils. The grassland soils are very dark, very deep, and very fertile.

- **South (Arkansas, Louisiana, Mississippi, Oklahoma, and Texas)**

Cl: Warm in the northwest and hot in the south. Precipitation ranges from semi-arid to humid.

O: Short and mixed grasses and forests.

R: Flat to gently rolling plains, with some hills and valleys.

P: Soils are slightly acidic and come from a range of wind-deposited sediments, ancient marine and river sediments, and rocks.

T: Soils range from younger to older based on weathering and erosion.

Major crops include hay, cotton, rice (east), sorghum, and wheat and grassland for grazing (Texas).

Home garden crops include sweet and hot peppers, beans and squash.

Native plants include False Indigo, Witch Hazel, Wild Ginger, Rain Lilies and varieties of ferns and grasses.

- Preparation: Till, or dig over, the ground and remove rocks and debris. In clay soil, till many times to break particles apart. Adding organic matter will help break up soil and improve drainage.

- Test: Use a soil test kit to test the soil for a correct balance of nutrients.

- Care: For soil with high clay content, add organic matter to improve water drainage. In the western part of this region, have a plan for irrigation. Additional nutrients include lime for highly acidic soil. Phosphorus (P) might be needed to assist with root and fruit production. Potassium (K) helps fights disease, and nitrogen (N) promotes leaf growth. In the eastern part of the region replenish lost nutrients with the addition of nutrients that may include magnesium (Mg).

The soil in the eastern part of the region is yellow/reddish in color due to oxidation of iron in the sediments and soil caused from the reaction of the sediment deposits with water and air.

• Northeast (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont)

Cl: Cold to cool humid region with moderate precipitation.

O: Evergreen and deciduous forests with some tall-grass meadows.

R: Mountains and valleys with gently rolling coastal plains, rivers, and streams.

P: Small areas of glacial deposits. The acidic soil is composed of many minerals. Coastal plains soils come from marine sediments and weathering sedimentary rocks.

T: Very old soil, thin on mountain slopes.

Major crops include hay, blueberries, apples, vegetables and grassland for grazing.

Home garden crops include carrots, tomatoes, cucumber, squash, onions, potatoes and beans.

Native plants include Maidenhair Fern, Woodland Iris varieties of trees and conifers.

- Preparation: Till, or dig over, the ground and remove rocks and debris.

- Test: Use a soil test kit to test the soil for a correct balance of nutrients.

- Care: The texture of the soil is suitable for vegetables such as carrots, onions, and potatoes. For soil depleted of nutrients, begin by adding organic matter. Decomposition of organic matter releases nitrogen (N) which is essential for leaf growth. Additional nutrients include sulfur to lower pH for highly alkaline soil and lime to raise pH for highly acidic soil. Magnesium (Mg), potassium (K) which fights disease, and phosphorus (P), which assists root and fruit production, might also be required to replenish the soil.

Some of this soil has an abundance of aluminum (Al) and iron (Fe).

• Mid-Atlantic (Delaware, Maryland, New Jersey, New York, Pennsylvania, Virginia, West Virginia)

Cl: Cool in the north and warm in the south with high humidity. Moderate precipitation.

O: Deciduous and evergreen forests with some meadows and tall grasses.

R: Mountains and valleys, low hills, and gently rolling coastal plains.

P: These mountains are composed of many types of crystalline minerals made from igneous and metamorphic rocks. The coastal plains soils are from marine sediments and weathering sedimentary rocks.

T: The region contains acidic soils that are very old.

Major crops include alfalfa hay, hay, apples, barley, blueberries, cranberries, grapes, peaches, vegetables and wheat and grassland for grazing.

Home garden crops include sweet peppers, tomatoes, beans, beets, carrots, chard, kale and leek.

Native plants include varieties of maple and oak trees, Columbine and Phlox.

- Preparation: Till, or dig over, the ground and remove rocks and debris.

- Test: Use a soil test kit to test the soil for a correct balance of nutrients.

- Care: Add lime to raise pH for highly acidic soil. In areas where the topsoil is thin or the soil has been depleted of nutrients, add organic matter to enrich the soil and release nitrogen (N) for leaf growth. Depleted soil usually requires magnesium (Mg) and potassium (K), which fights disease. Vegetables, such as carrots, beets and leeks, require loose rich organic soil and may not do well in areas where the topsoil is still forming or thin.

Some of the organic matter in the coastal plain soils came from decomposing marine life which contributed to the fertility of the soil in this region.

- **Southeast (Alabama, Florida, Georgia, North Carolina, South Carolina)**

Cl: Hot, humid region with moderate precipitation.

O: Deciduous and evergreen forests, some meadows, and river valleys with tall grasses.

R: Mountains and valleys, low hills, flat coastal plains and some swamps.

P: The mountains are composed of many types of crystalline minerals made from igneous and metamorphic rocks. Coastal plain soils are from marine sediments and sedimentary rocks. Thick organic matter may cover sediments.

T: The region contains acidic soils that are very old.

Major crops include blueberries, cotton, peanuts, and citrus fruits. Home garden crops include onions, carrots tomatoes, and berries. Native plants include Magnolia tree, Holly, Swamp Hibiscus Doll's Eyes and Rain Lily.

- Preparation: Till, or dig over, the ground and remove rocks and debris. In clay soil, till many times to break particles apart. Adding organic matter will help break up soil and improve drainage.

- Test: Use a soil test kit to test the soil for a correct balance of nutrients.

- Care: Add lime to raise the pH of highly acidic soil. In areas where the soil has been depleted of nutrients, add organic matter to enrich the soil and release nitrogen (N) for leaf growth. Depleted soils usually require the addition of magnesium (Mg) and potassium (K) that fights disease. To grow vegetables, such as carrots and onions, make sure the soil is loose and contains organic matter to loosen the clay-like soil.

Chemical changes due to oxidation have given some soils bright orange, red, or yellow colors. In Southern Florida. The Everglades are a vast system of wetlands that are poorly drained and unsuitable for farming. Decomposition of organic matter is limited by lack of oxygen in the soil due to the high water tables. Sometimes the organic layers are a few meters thick.

Information provided by Clay Robinson, PhD, CPSS, PG, aka Dr. Dirt

Duckweed: Pest or Benefit?

1. Control (no fertilizer added) – limited growth as there are few nutrients
   1X – limited growth because the nutrients will be used fairly rapidly.
   5X – strong growth, initially the growth rate will mimic the 1X but will surpass it rather quickly. I believe that the duckweed will cover the surface area completely.
   10X- will be similar to the 5X but will continue to grow faster and reach the surface area coverage earlier.

2. The limiting factors will be the three primary macronutrients, N, P and K. This is especially true in the control and the 1X solution.

3. A sigmoidal curve should be present in the graph. Then add the carrying capacity line. The control and 1X solution probably will not reach carrying capacity and both the 5X and 10X will reach carrying capacity.

4. In the control and the 1X, the carrying capacity will be reached.

The carrying capacity will be low for both solutions. The duckweed will completely cover the surface of the dish in the 5X and 10X without reaching carrying capacity.

5. Both the control and 1X will have low carrying capacity. I believe that the 5X and 10X will not reach carrying capacity as they will reach density by covering the surface and stop increasing population size.

6. Duckweed grows rather fast and can be harvested and used as potential food source. It easily uses the nitrogen, phosphorus and potassium in the water.

7. An r-strategist, it is readily adaptable for a variety of weather conditions, needs little care, generalist niche, early successional species, and early reproductive stage.

8. Indicator species show the health or lack of health in an environment. Duckweed needs lots of nutrients to thrive and is an indicator that the area has high concentrations of N, P and K.

9. Density dependent variables are generally biotic in nature. These variables include the availability of food/nutrients, disease, predators, and competitors. The major factors that contribute to the density dependent of duckweed are the competition for nutrients with other plant species. Density independent variables are generally abiotic in nature. Density independent factors include environmental stressors and catastrophes. Other factors include food or nutrient limitations, pollutions, climate extremes and seasonal changes. The major factors that contribute to the density independent of duckweed include limitation on nutrients, pollutants and seasonal climate change. Catastrophic events like hurricanes that flood the ponds and streams causing a huge loss of the population of duckweed.

10. Positive effects: Will reduce the algae population since it blocks the sunlight at the surface and will reduce the mosquito population, since the surface is blocked the larvae will not be able to breath.

Negative effects: Will reduce the light penetration and thus reduce photosynthesis of underwater plants. Out compete other aquatic species for the nutrients thus stress or eliminating other plant species.

11. Answers will vary. An example:
No, I do not think that the world's population has reached its carrying capacity. Total the calorie count for 2012 and 1950 and look at the per capita unit. The per capita amount in 2012 far exceeds the 1950 per capita yet people today are starving at high rates than in 1950, the issue is not growing enough food but rather transporting the food to where the people are located. With the development of better crops and farming techniques, we can still increase the amount of crop yield per acre.

Brand	Plant type	NPK (%)	Other nutrients	Other Comments
Bayer Advanced Garden	Rose & Flower 2 for 1 (pellets)	12:18:6	Sulfur: 11	Insecticide
Kellogg Organic	Fruit Tree Fertilizer (pellets)	4:5:4	None	Contains some soil bacteria
Vigoro	Citrus & Avocado (pellets)	6:4:6	Mg 1, S 6, Fe 1, Trace amounts of B, Cu, Mn, Mo & Zn	
Miracle-Gro	All purpose plant food (liquid)	12:4:8	Fe 0.1, Mn 0.05; Zn 0.05	Mix with water to use. Different concentrations for indoor and outdoor plants.

Comparing Commercial Fertilizers

1. Answers will vary.
2. Answers will vary.
3. Answers will vary.
4. Plants have different needs for the macronutrients. The need is based on the type of plant and the type of fruit that is produced.

Water Cycle

1. The majority of the water on Earth is in the oceans and only a small part is evaporated in the atmosphere. Water spends long periods in the clouds, plus cycling between living organisms and the atmosphere.
2. Only a small amount of water is locked in a glacier that water may be trapped for millions of years but the small percentage of the total amount of water is in the glaciers. Water is cycled through the soil rather rapidly. It may percolate through the soil to an aquifer. The plant will take up the water only to lose water during photosynthesis or when it decays. Water also flows through the soil to the streams, rivers, lakes and oceans. Animals drink some water, but they also lose water to sweat, urination and decomposition.
3. Throughout history, humans tend to gather near large bodies of water, oceans, lakes, and rivers. Water provides power, transportation, freshwater for drinking, and an aesthetic value.

Free Response Questions

(a) Commercial fertilizers focus primarily on the three primary macronutrients. Identify the three primary macronutrients and describe the importance of one of the primary macronutrients.

- Nitrogen, Phosphorus, Potassium – 1 point each, 3 points

- Nitrogen
  - o Proteins
  - o Amino acids
  - o Chlorophyll production

- Phosphorus
  - o Formation of DNA and RNA
  - o Used in the ADP – ATP energy transfer
  - o Plays a role in capturing light during photosynthesis
  - o Help fight external stress
  - o Prevent diseases

- Potassium
  - o Activates enzymes that catalyze chemical reactions involved in plant growth
  - o Regulator for water balance
  - o Regulator for the rate of photosynthesis

(b) Describe one environmental benefit and one environmental consequence of using commercial fertilizers to increase crop production.

- Environmental benefit
  - o Increasing the yield equates to less habitat destruction since the land usage will not increase to produce the additional crops.
- Environmental consequence
  - o The run off from the fertilizers can lead to algae blooms downstream.
  - o Fertilizer can build up in the soil and cause toxicity to plants.

(c) Describe one economic benefit and one economic consequence of using commercial fertilizers to increase crop production.

- Economic benefit
  - o Increase profit, increasing yield provides increase in sales and was more than the cost of fertilizers.
- Economic consequence
  - o The cost of purchasing the fertilizer
  - o The cost of applying the fertilizer
  - o Cost to store fertilizers
  - o Cost to buy equipment to apply the fertilizer
  - o Increase labor cost to apply the fertilizer

(d) Describe one reason that the development of commercial fertilizers and pesticides increase dramatically after World War II.

- Factory production increased dramatically during the war. Some of this production was converted to fertilizers and pesticides. Petroleum usage had increased during the war, some of the byproducts are used in the production of fertilizers and pesticides. After the war there was a jump in population, crop production increased and there was a need for more nutrients in the soil, so commercial fertilizers became the norm.

(e) Many consider that we are in a second Green Revolution using recombinant DNA technologies. Describe how recombinant DNA is being used to increase crop production.

- A gene from another organism is inserted into the plant genome. When the gene is expressed, it helps the plant crop yield increase. This can be a total increase in production or the inclusion of a pesticide that reduce crop damage by reducing the pest thus increasing crop yield.

2.

(a) What is the percentage change in world grain production from 1960 to 2012?

Formula: Percentage Change = $\frac{V2 - V1}{V1}$ x 100

$\frac{\text{2587 million tons} - \text{824 million tons}}{\text{824 million tons}}$ x 100 = $\frac{\text{1763 million tons}}{\text{824 million tons}}$ x 100

cancel the units

$\frac{1763\ \cancel{\text{million tons}}}{824\ \cancel{\text{million}}\ \text{tons}}$ x 100 = 2.14 x 100 = 214%

(b) What was the average yield per acre in 1960 and in 2012?

1960: $\frac{824\ \cancel{\text{million}}\ \text{tons}}{1579\ \cancel{\text{million}}\ \text{acres}}$ 0.522 tons/acres

2012: $\frac{2857\ \cancel{\text{million}}\ \text{tons}}{1707\ \cancel{\text{million}}\ \text{acres}}$ 1.674 tons/acres

(c) If the average yield had not increased between 1960 and 2012, how many acres would be needed at the lower yield to have the same amount of grain grown?

$\frac{824\ \cancel{\text{million}}\ \text{tons}}{1{,}579\ \cancel{\text{million}}\ \text{acres}} = \frac{\text{2,587 million tons}}{x}$

824 tons (x) = 4,084,873 million acres tons

x = $\frac{\text{4,084,873 million acres}\ \cancel{\text{tons}}}{824\ \cancel{\text{tons}}}$

x = 4,957 million acres

(d) Describe how the use of fertilizers has increased crop yield.

- Fertilizers provide the nutrients that a plant needs to grow, produce fruit, to multiple. Fertilizers contain nitrogen, phosphorus and potassium. Fertilizers contain NPK.

(e) Crop yield has also increased due to changes in the genetic make-up of crops.

i. Describe hybridization of crops.

- Cross pollinating different species to obtain desired characteristics,
- Hybridization is an offspring of plants of different varieties or species.

ii. Describe how crops are genetically modified in the lab.

- A gene from another organism is inserted into the plant genome.

(f) Other than fertilizer use or modifying the crop genetics, describe another method used to increase crop yield.

- Increase watering or alter the watering times
- Rotating crops – crop rotation with legumes, alpha and others that help improve the nitrogen in the soil.
- Pesticides – reduce eating the plant or fruits, thus increasing crop yield

3.

(a) Identify the three non-mineral elements and describe how one of these elements enters the plant's life cycle.

Element	Symbol	Enter plant's life cycle
Hydrogen	H	H_2O
Oxygen	O	O_2 and CO_2
Carbon	C	CO_2

(b) Describe one role that the mineral elements have in a plants life cycle.

Element	Symbol	Role in plant life cycle
Nitrogen	N	Component for proteins and nucleic acids also required for chlorophyll production
Phosphorus	P	Structural elements, catalyst for biochemical reactions, component for DNA and the ADP $\leftrightarrow$ ATP, role in capturing light during photosynthesis
Potassium	K	Activates enzymes that are catalyst for chemical reactions, regulator for water balance and the rate of photosynthesis
Calcium	Ca	Construction of numerous hormone and enzyme systems that can help protect the plant from insect and disease attack
Magnesium	Mg	Chlorophyll formation, synthesis of amino acids and cell proteins, uptake and migration of phosphorus in plants resistance to unfavorable factors (drought)
Sulfur	S	Component for amino acids, enzymes associated with photosynthesis and chlorophyll synthesis need sulfur
Boron	B	Considered as an essential element for plant growth and development, sexual reproduction in plant is more sensitive to low Boron concentrations
Chlorine	Cl	Involved in plant growth
Copper	Cu	Involved in the straw strength, which determines the standability of the plant, low copper can also cause increased disease
Iron	Fe	Involved in plant growth and is essential for the formation of chlorophyll
Manganese	Mn	The assimilation of carbon dioxide in photosynthesis, aids in the synthesis of chlorophyll and in nitrate assimilation, functions in the formation of riboflavin, ascorbic acid, and carotene, functions in electron transport during photosynthesis.

Element	Symbol	Role in plant life cycle
Molybdenum	Mo	It functions in converting nitrates (NO_3) into amino acids within the plant, essential to the symbiotic nitrogen fixing bacteria in legumes, essential to the conversion of inorganic P into organic forms in the plant.
Nickel	Ni	Involved in plant growth
Zinc	Zn	Plays a key role as a structural constituent or regulatory co-factor of a wide range of different enzymes and is involved in biochemical pathways

(c) Describe the effects of one mineral nutrient deficiency and one mineral nutrient toxicity.

Plant nutrient Condition Symptoms

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	Nutrient deficiencies in magnesium and possibly calcium
Calcium	Deficiency	Poor fruit development and appearance; symptoms appear in new leaves and shoots
	Toxicity	Deficiencies in magnesium or potassium (from precipitation in soil)

Plant nutrient	Condition	Symptoms
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
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

(d) Explain the difference between macronutrient and micronutrient.
Macronutrients are needed in large quantity while micronutrients are needed in much smaller quantities.

(e) Identify one biogeochemical cycle and describe one component of the cycle.

Carbon Cycle

Component	Description
Carbon storage	The long term storage of carbon from the atmosphere (CO_2) and depositing it in a reservoir in the biosphere (living organisms mostly plants), deposits in the sediment (coal, natural gas, petroleum) and water (dissolved CO_2)
Decomposition	Organisms breakdown dead organic material re leasing CO_2 and H_2O and other nutrients.
Diffusion	The movement of CO_2 between the atmosphere and the water.
Fuel Emissions	Emissions from burning fossil fuels in the form of CO_2
Photosynthesis	Plants convert sunlight, CO_2 and H_2O to glucose ($C_6H_{12}O_6$) and O_2
Respiration	Animals "burn" glucose ($C_6H_{12}O_6$) and in the presence of O_2 to release CO_2 and H_2O

Nitrogen Cycle

Component	Chemical Reaction	Description
Ammonification	$NH_3 \rightarrow NH_4^+$	The conversion of organic nitrogen to organic nitrogen to ammonium by the action of decomposers
Assimilation	Not a chemical reaction	The absorption of nitrogen from the soil in the form nitrate (NO_3^-) and ammonia (NH_3).
Denitrification	$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$	The process of nitrate reduction in the soil to nitrogen gas.
Nitrification	$NH_3 \rightarrow NH_2OH \rightarrow NO_2^- \rightarrow NO_3^-$	The conversion of ammonia to nitrate.
Nitrogen fixation	$N_2 + H_2 \rightarrow NH_3 \rightarrow NH_4^+$	The conversion of nitrogen gas to ammonia and ammonium in plants that have a root nodule symbioses. Many of the plants belong to the legume family.

Phosphorus Cycle

Component	Description
Bedrock	Phosphorus stored in the parent material
Biomass storage	The storage of phosphorus in plant and animal material
Sediments	Phosphorus is stored in sediments of the Earth's crust
Soil	Phosphorus is stored in the soil and is available for plants to be taken with water through the roots
Weathering	The breakdown of rocks, soil and minerals by physical or chemical processes. The process in cludes water, ice, snow, waves and gravity. Physical weathering involves the breakdown of rocks and soils through direct contact with atmospheric conditions, such as heat, water, ice and pressure. Chemical weathering, involves the direct effect of atmospheric chemicals or biologically produced chemicals in the break down of rocks, soils and minerals. Examples of chemical weathering include sulfuric acid ($H2SO4$) and nitric acid ($HNO3$), both of which can occur naturally.

Sulfur Cycle

Component	Description
Mineralization	Organic sulfur is converted into inorganic forms such as hydrogen sulfide ($H2S$), sulfide minerals and elemental sulfur.
Oxidation	Conversion of hydrogen sulfide ($H2S$), sulfide minerals ($S2-$) and elemental sulfur to sulfate ($SO42-$)
Reduction	Reduction of sulfate ($SO42-$) to sulfide minerals ($S2-$)
Absorption	Uptake of sulfate ($SO42-$) into plants through the roots.

Water Cycle (hydrologic cycle)

Component	Description
Aquifer	Porous, water saturated layers of sand or rock that can yield a significant amount of water.
Condensation	The change of the physical state of matter from gas phase into liquid phase.
Evaporation	Conversion of a liquid to a gas
Groundwater	Water that sinks into the ground that can renew the aquifer.
Infiltration	Downward movement of water through the soil
Percolation	Passage of a liquid through the spaces of porous material in the soil and rock.
Precipitation	Water falls as rain, snow, sleet or hail
Surface runoff	Water flowing off the land into bodies of water (streams, lakes, oceans).
Transpiration	Process of water being absorbed by a plant through he roots, moving through the plant and evaporating into the plant during photosynthesis.

4.

(a) **Sustainable agriculture:**
- Environmental health: maintaining the health of the environment is key to the ultimate survival of the human race. The addition of fertilizers can lead to an unhealthy environment if consideration is not given the 4R Nutrient Stewardship.
- Economic profitability: Companies and individuals need to make a profit or ultimately individuals will not have enough income to sustain themselves or a family.
- Social and economic equity: consideration of social responsibilities, such as the health and safety of workers, the economic needs of communities, and consumer health and safety both in the present and the future.

(b) Describe two environmental benefits of commercial fertilizers to the crops that has helped agriculture become more sustainable.
- Replace depleted nutrients
- Commercial fertilizers often contain higher quantities of nutrients than organic fertilizers thus requiring less material added to the fields
- Easier for application to the plant and reduces nutrient loss
- Describe one economic benefit to the use of commercial fertilizers.
- Commercial fertilizers are relatively inexpensive
- Increase crop yield which increases profit
- Known concentration of nutrients compared to compost where the exact nutrient content may not be known

(d) Describe one environmental consequence that the addition of commercial fertilizers may make them unsustainable.
- Algae blooms downstream of the fields
- Nutrient toxicity
- Nutrient pollution

(e) The concept of 4R Nutrient Stewardship is to obtain the best performance from the fertilizers while minimizing the negative effects on the environment. The core concept of 4R Nutrient Stewardship is the application of the right plant nutrients, at the right rate, the right time and in the right place. Choose two of these core concepts and explain their meaning.
- Right plant nutrient – select the right fertilizer that provides the nutrients that a plant needs
- Right rate – use soil testing to determine when the soil needs the nutrients and then add the nutrients when needed at a rate that they can be absorbed
- Right time – adding the nutrients at a specific growth stage of the plant can benefit crop yield
- Right place – means positioning the nutrients at a strategic location so the plant has access to the nutrients.

(f) Describe two actions you can take that would make you more sustainable.
Answers may vary.
- Turn down thermostat in the winter and turn it up during the summer
- Replace toilets with low flow ones
- Add insulation in your house
- Replace windows with double or triple pane glass
- Turn water off when shaving or brushing teeth
- Use an automatic dishwasher
- When washing in the sink, fill the tube to wash and the tub to rinse instead of running water
- Only wash full loads of laundry
- Go to a car wash to wash your car (they often recycle water)
- When buying a car buy cars that get higher gas mileage
- Weather strip around the doors

Math Problems

1. Answers vary since USDA continually updates statistics.

Example formula for graphing:
1960 is 55 bu/acre and 2010 is 153 bu/acre.

$$\text{Percentage Change} = \frac{V2 - V1}{V1} \times 100$$

$$\frac{153\text{ bu/acre} - 55\text{ bu/acre}}{55\text{bu/acre}} \times 100$$

$$\frac{98}{55} \times 100 = 1.78 \times 100 = 178\%$$

(178% increase in corn yield (bu/acre))

2. Calculate the pounds of fertilizer nutrients (nitrogen, phosphate, and potash) used to produce 1 bushel of corn in 2010 (V2):

% Change = ((V2 - V1)/V1)*100

-48.7% = ((V2 - 3.188)/3.188)*100

-48.7%/100 = (V2 - 3.188)/3.188

-.487=(V2-3.188)/3.188

-.487*3.188 =V2-3.188

-1.553 = V2-3.188

-1.553+3.188 = V2

1.653 pounds of fertilizer nutrients (nitrogen, phosphate, and potash) used to produce 1 bushel of corn in 2010 = V2

3. Answers vary by state and year.

4. 1981, 24 million tons

5. Commercial fertilizer use was 7 million tons in 1960.

$$\text{Percentage Change} = \frac{V2 - V1}{V1} \times 100$$

$$\frac{21 - 24}{24} \times 100 =$$

$$\frac{-3}{24} \times 100 =$$

-0.125 x 100 = -12.5%

6. **Conversion Problem:** An all-purpose plant food is diluted to use for home gardens.

a. One cup is diluted into 24 gallons, how many gallons will a quart (1 quart = 4 cups) of the plant food dilute into?

b. If water has an approximate weight of 8 pounds per gallon, how many pounds does the total quart of plant food make?

c. If one gallon equals 3.79 liters (rounded to two decimal places), how many liters are produced from the one-quart of plant food (rounded to two decimal places)?

d. What is the weight in kilograms if 1 pound is 0.45 kg?

a. 4 cups x 24 gallons/cup = 96 gallons

b. 96 gallons x 8 lbs./gallon = 768 lbs.

c. 96 gallons x 3.79 L/gallon = 364 L

d. 768 lbs. x 0.45 kg/lbs. = 345.6 kg

Bibliography

Selected Bibliography

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Hager, T. (2008). *The Alchemy of Air: A Jewish Genius, a Doomed Tycoon, and the Scientific Discovery That Fed the World but Fueled the Rise of Hitler.* New York: Three Rivers Press.

Hall, K. D., Nowels., K. E., Mathers, K., & Grasset, E. (2010). *Fertilizer 101: Nourish. Replenish. Grow.* Washington, D.C.: The Fertilizer Institute.

Nutrients for Life Foundation & BSCS. (2007). *Nourishing the Planet in the 21st Century.* Washington, D.C.: Nutrients for Life Foundation.

AP Environmental Science Topics Addressed in Feeding the World & Protecting the Environment

I. **Earth Systems and Resources**
   a. Soil and Soil Dynamics: composition; physical and chemical properties; main soil types; soil conservation

II. **The Living World**
   a. Natural Biogeochemical Cycles (nitrogen, phosphorus)

III. **Population**
   a. Population size (Strategies for sustainability)
   b. Impacts of population growth (resource use)

IV. **Land and Water Use**
   a. Agriculture
      i. Feeding a growing population (types of agriculture; Green Revolution; crop production; sustainable agriculture)
   b. Land conservation options (restoration)

V. **Energy Resources and Consumption**
   a. Energy Conservation (Energy efficiency)

VI. **Pollution**
   a. Air pollution (Sources — primary and secondary; remediation and reduction strategies; Clean Air Act and other relevant laws)
   b. Water pollution (Types; sources, causes, and effects; cultural eutrophication; groundwater pollution; Clean Water Act and other relevant laws)

VII. **Global Change**
   a. Global Warming (Greenhouse gases and the greenhouse effect; impacts and consequences of global warming; relevant laws and treaties)

Next Generation Science Standards (NGSS Comprehensive) Addressed in Feeding the World & Protecting the Environment

INDICATOR	**HS-PS3.CETS.1.1.**	**Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. (HS-PS3-3)** **<u>Feeding the World and Protecting the Environment</u>** **FTW Lesson 10: Fertilizers, the Environment, and Regulation: Hypoxia**
INDICATOR	**LS1.C:3.**	**As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. (HS-LS1-6), (HS-LS1-7)** **Feeding the World and Protecting the Environment** **FTW Lesson 01 Nourishing Crops with Fertilizers: Essential Plant Nutrients**

		FTW Lesson 02 Nourishing Crops with Fertilizers: Natural Biogeochemical Cycles
INDICATOR	HS-LS1.CC.3.1.	Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem. (HS-LS1-1) Feeding the World and Protecting the Environment FTW Lesson 01 Nourishing Crops with Fertilizers: Essential Plant Nutrients FTW Lesson 02 Nourishing Crops with Fertilizers: Natural Biogeochemical Cycles FTW Lesson 03 Nourishing Crops with Fertilizers: Organic and Commercial Fertilizer FTW Lesson 04 Nourishing Crops with Fertilizers: Roles in Sustainability FTW Lesson 05 Nourishing Crops with Fertilizers: 4R Nutrient Stewardship FTW Lesson 06 Nourishing Crops with Fertilizers: 4R Case Study FTW Lesson 17: Lab - Duckweed: Pest or Benefit?
PERFORMANCE EXPECTATION / FOUNDATION	HS-LS2-3.	Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions. Feeding the World and Protecting the Environment FTW Lesson 01 Nourishing Crops with Fertilizers: Essential Plant Nutrients FTW Lesson 02 Nourishing Crops with Fertilizers: Natural Biogeochemical Cycles
PERFORMANCE EXPECTATION / FOUNDATION	HS-LS2-7.	Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.* Feeding the World and Protecting the Environment FTW Lesson 06 Nourishing Crops with Fertilizers: 4R Case Study FTW Lesson 07: Fertilizers, the Environment, and Regulation: Air Quality FTW Lesson 10: Fertilizers, the Environment, and Regulation: Hypoxia FTW Lesson 12: Fertilizers, the Environment, and Regulation: Land Restoration
INDICATOR	LS2.C:1.	A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest

		biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. (HS-LS2-2), (HS-LS2-6) **Feeding the World and Protecting the Environment** **FTW Lesson 01 Nourishing Crops with Fertilizers: Essential Plant Nutrients** **FTW Lesson 02 Nourishing Crops with Fertilizers: Natural Biogeochemical Cycles** **FTW Lesson 03 Nourishing Crops with Fertilizers: Organic and Commercial Fertilizer** **FTW Lesson 04 Nourishing Crops with Fertilizers: Roles in Sustainability** **FTW Lesson 05 Nourishing Crops with Fertilizers: 4R Nutrient Stewardship** **FTW Lesson 06 Nourishing Crops with Fertilizers: 4R Case Study** **FTW Lesson 10: Fertilizers, the Environment, and Regulation: Hypoxia** **FTW Lesson 17: Lab - Duckweed: Pest or Benefit?**
INDICATOR	**LS2.C:2.**	**Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species. (HS-LS2-7)** **Feeding the World and Protecting the Environment** **FTW Lesson 01 Nourishing Crops with Fertilizers: Essential Plant Nutrients** **FTW Lesson 02 Nourishing Crops with Fertilizers: Natural Biogeochemical Cycles** **FTW Lesson 03 Nourishing Crops with Fertilizers: Organic and Commercial Fertilizer** **FTW Lesson 04 Nourishing Crops with Fertilizers: Roles in Sustainability** **FTW Lesson 05 Nourishing Crops with Fertilizers: 4R Nutrient Stewardship** **FTW Lesson 06 Nourishing Crops with Fertilizers: 4R Case Study** **FTW Lesson 07: Fertilizers, the Environment, and Regulation: Air Quality** **FTW Lesson 08: Fertilizers, the Environment, and Regulation: Climate Change and Greenhouse Gas Emissions**

		FTW Lesson 09: Fertilizers, the Environment, and Regulation: Water Quality and Quantity FTW Lesson 10: Fertilizers, the Environment, and Regulation: Hypoxia FTW Lesson 11: Fertilizers, the Environment, and Regulation: Mining FTW Lesson 12: Fertilizers, the Environment, and Regulation: Land Restoration FTW Lesson 13: Fertilizers, the Environment, and Regulation: Nitrogen Production Facilities FTW Lesson 14: Fertilizers, the Environment, and Regulation: Production Facility Case Study FTW Lesson 15: Fertilizers, the Environment, and Regulation: Alchemy of Air Excerpts and Questions FTW Lesson 17: Lab - Duckweed: Pest or Benefit?
INDICATOR	**LS4.D:2.**	**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. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value. (secondary to HS-LS2-7) (Note: This Disciplinary Core Idea is also addressed by HS-LS4-6.) Feeding the World and Protecting the Environment FTW Lesson 01 Nourishing Crops with Fertilizers: Essential Plant Nutrients FTW Lesson 02 Nourishing Crops with Fertilizers: Natural Biogeochemical Cycles FTW Lesson 03 Nourishing Crops with Fertilizers: Organic and Commercial Fertilizer FTW Lesson 04 Nourishing Crops with Fertilizers: Roles in Sustainability FTW Lesson 05 Nourishing Crops with Fertilizers: 4R Nutrient Stewardship FTW Lesson 06 Nourishing Crops with Fertilizers: 4R Case Study FTW Lesson 07: Fertilizers, the Environment, and Regulation: Air Quality FTW Lesson 08: Fertilizers, the Environment, and Regulation: Climate Change and Greenhouse Gas Emissions FTW Lesson 09: Fertilizers, the Environment, and Regulation: Water Quality and Quantity**

		FTW Lesson 10: Fertilizers, the Environment, and Regulation: Hypoxia FTW Lesson 11: Fertilizers, the Environment, and Regulation: Mining FTW Lesson 12: Fertilizers, the Environment, and Regulation: Land Restoration FTW Lesson 13: Fertilizers, the Environment, and Regulation: Nitrogen Production Facilities FTW Lesson 14: Fertilizers, the Environment, and Regulation: Production Facility Case Study FTW Lesson 15: Fertilizers, the Environment, and Regulation: Alchemy of Air Excerpts and Questions FTW Lesson 17: Lab - Duckweed: Pest or Benefit?
INDICATOR	**ETS1.B:1.**	**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. (secondary to HS-LS2-7) Feeding the World and Protecting the Environment FTW Lesson 06 Nourishing Crops with Fertilizers: 4R Case Study FTW Lesson 07: Fertilizers, the Environment, and Regulation: Air Quality FTW Lesson 10: Fertilizers, the Environment, and Regulation: Hypoxia FTW Lesson 12: Fertilizers, the Environment, and Regulation: Land Restoration**
PERFORMANCE EXPECTATION / FOUNDATION	**HS-ESS3-3.**	**Create a computational simulation to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity. Feeding the World and Protecting the Environment FTW Lesson 06 Nourishing Crops with Fertilizers: 4R Case Study FTW Lesson 07: Fertilizers, the Environment, and Regulation: Air Quality FTW Lesson 08: Fertilizers, the Environment, and Regulation: Climate Change and Greenhouse Gas Emissions FTW Lesson 09: Fertilizers, the Environment, and Regulation: Water Quality and Quantity FTW Lesson 10: Fertilizers, the Environment, and Regulation: Hypoxia FTW Lesson 12: Fertilizers, the Environment, and Regulation: Land Restoration FTW Lesson 15: Fertilizers, the Environment, and Regulation: Alchemy of Air Excerpts and Questions**