Soil Health Activity Guide

BLACK Is The New GREEN

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Berlese Biodiversity

Grade Level: 7-12
Subject : Ecology, Biology
Time: 3-4 class periods
Standards:
See Appendix for table aligning activity with state and national standards.
Summary:
In this activity students will use a Berlese funnel to capture and identify invertebrates to study the biodiversity of soil communities.

Objectives

Students will:

- understand the importance of biodiversity in soil ecosystems.
- compare biodiversity and density of soil invertebrates in different locations.

Materials

- Berlese funnels
- Trowels
- Ruler
- Zip Loc ® style quart storage bags
- Lamps
- Ring stands
- Dissecting microscopes and/or hand lenses
- Petri dishes
- Forceps
- Dissecting needles
- Jars
- alcohol

Background

In a shovel full of healthy soil, there are billions of organisms, easily outnumbering all the humans that have existed in all of Earth's history. Healthy soil also has high biodiversity, with millions of different species that interact in complex food webs that help to cycle nutrients and energy beneath our feet. Those organisms, some big, some small, play a crucial role in soil health. Although most of the organisms are microscopic bacteria, many are invertebrates.

Annelids, specifically earthworms are one of the most apparent and important animals found in healthy soil. Being a 'keystone species', earthworms have a crucial role that many other species depend on, and in turn if the 'keystone species' were removed would greatly change the entire ecosystem. Earthworms ingest organic matter, specifically plant refuse, and excrete nutrient rich casts. In doing so their burrows help aerate the soil, reducing soil compaction and the need for tillage. Water infiltration is increased due to the network of burrows that extend deep in the soil, in turn increasing the capacity of the soil to store water, in turn reducing run-off. Plant roots are able to grow easily through the tunnels in the soil, and the earthworms help form stable aggregates of soil. The casts of the earthworms have high biodiversity of beneficial soil bacteria. Earthworms even secrete growth and regulatory hormones that directly help crops grow, as well as control populations of pest species which indirectly benefit the crop plants.

Nematodes, which are microscopic roundworms, are also found in abundance in healthy soil. They are in the middle of the food chain, and act as grazers of the microscopic world. Although some nematodes can be parasitic to plants, the majority are beneficial in mineralizing nutrients such as nitrogen, freeing up the organically bound nitrogen into forms that are available to plants.

In addition to the worms, arthropods are the other main type of small animal found in soils. Arthropods are animals with jointed legs with bodies covered with an exoskeleton. In soil ecosystems they include mites, millipedes, centipedes, as well as insects. Some arthropods are damaging to crop yields, while many others play important roles. Many arthropods are predators, reducing pest populations and preventing population booms, as well as preying on dominant species lower on the food chain allowing community succession and increasing biodiversity. Arthropods shred organic matter allowing bacteria and fungi to decompose what otherwise could not be broken down. They also are endophytic and epiphytic vehicles that transport bacteria and fungi to new locations to inoculate soil that they could not otherwise get to. For a bacterium, being moved a few millimeters, is like us moving to another country. Lastly, some arthropods play various roles similar to the worms mentioned earlier, such as mineralizing nutrients, creating burrows, and forming stable soil aggregates.

The Activity

1. Working in groups of two, students identify an area to study. Mark off a 10 x 10 cm area.
2. Use a trowel to dig down 5 cm and place soil and litter in the storage bag.
3. After returning to class or the next day, pour soil on large white paper. Carefully sift through soil for invertebrates that are visible with a hand lens. Use identification key in resources to identify invertebrates and record in data table.
4. Place soil and litter in Berlese funnel. Place funnel over jar with 2 cm alcohol in the bottom. See references for construction of funnel, or funnels can be purchased from science supply companies.
5. Put Berlese funnel approximately 20 cm away from lamp with 40 watt incandescent light bulb to aid in the drying of the soil.
6. As soil dries, invertebrates will drop through screen, fall into the alcohol and be euthanized.
7. After monitoring for 3-4 days, students will observe invertebrates in Petri dish under dissecting microscopes or hand lenses. Use identification key in resources to identify invertebrates and record in data table.

Assessment

After filling out the data table, students will analyze their data by comparing the different locations from the different groups in the class.

Extensions

Students could sample soils from multiple locations and compare the density of invertebrates or compare the biodiversity of invertebrates in different areas. Students could compare different land use practices and how they affect soil life.

Resources

Soil Invertebrate Key
tiee.esa.org/vol/v3/experiments/soil/pdf/soil[Invertebrate_Key].pdf

Buffer Blitz

Grade Level: 5-8
Subject : Ecology, Geology, Biology, Agriculture
Time:: 30 Minutes
Standards:
See Appendix for table aligning activity with state and national standards.
Summary:
In this activity students will play tag to show how riparian buffer strips slow runoff and reduce environmental pollution from nitrogen.

Objectives

Students will:
- Understand how vegetation in riparian buffer strips slow runoff.
- Understand the connection between agricultural practices and environmental issues.

Materials

- Open space such as a gymnasium, classroom with desks moved, or outdoor area
- Four different colors of flagging tape (blue to simulate water, green to simulate vegetation, yellow to simulate nitrogen, and pink to simulate phosphorus)
- Stopwatch or timer

Background

Agricultural runoff is a major contributor to pollution of water resources. One way of reducing runoff is to have buffers of natural vegetation between the agricultural land and the waterways. The land area next to a body of water is called the riparian zone. There are many benefits to having a riparian zone covered with perennial vegetation.

One benefit of vegetative riparian buffers is increased water absorption. Up to ten times more water can infiltrate soil that is covered by natural vegetation compared to bare soil or soil with crops. This results in reduced runoff, less flooding, and fewer agricultural chemicals entering waterways. The deep rooted grasses, forbs, and woody plants also help to stabilize the soil reducing soil erosion. This results in reduced sediment ending up in waterways as well as stabilizing steep banks.

Another major benefit of vegetative riparian buffers is the reduction of nutrients entering waterways. Nutrients such as phosphorus and nitrogen allow for more growth of plants, algae, and cyanobacteria in waterways resulting in eutrophication. Nitrogen typically enters waterways by leaching down through the soil and entering the waterways in groundwater. Shallow groundwater can be absorbed by deep rooted riparian plants, and the nitrates can be used by the plants. More importantly, denitrifying soil bacteria thrived in the water saturated soil. The bacteria convert the nitrates into harmless nitrogen gas.

Phosphorus gets into waterways differently than nitrogen. Phosphorus usually is not found in a soluble form, instead is adhered to soil particles. Therefore phosphorus enters waterways by surface runoff and erosion resulting in sediments entering waterways. Vegetative riparian buffers have need shown to reduce sediment load in by up to 90%, effectively reducing nonpoint pollution by phosphorus.

In addition to to reducing sediment loading and nonpoint source pollution to waterways, vegetative riparian zones also serve as important habitats for wildlife. Many animals use the buffer strips as travel corridors connecting larger natural habitats. The buffer zones also often provide suitable habitat for important pollinators.

Current Minnesota law requires a vegetated buffer of at least 16.5 feet adjacent to public drainage ditches, and at least 50 feet next to navigable waters.

The Activity

Setup:

- Inform students that if they have blue flagging, they are water.
- If they are wearing green flagging they are riparian vegetation.
- Have approximately one third of the class assigned to be vegetation. The other two thirds of the class will be water.
- Have students follow the each scenario listed below. The instructor should time each round.

Round 1: Riparian zone without vegetation:

1. All students wearing blue flagging line up at one end of the gym, room, or outdoor area to simulate them being water molecules.
2. Students will then run across the room to the other side that represents a stream.
3. After running across the room, gather the students and discuss the ease that the water was able to move down the slope. Discussion points could include erosion and flooding.

Round 2: Riparian zone with small vegetation buffer:

1. Do the same as round 1, but now the students assigned to be "vegetation" with try to tag the "water".
2. Since the riparian zone is small, only use half of the space you have
3. Once tagged, "water" students will have to wait 5 seconds before they can run again. They can count (1 riparian… 2 riparian… 3 riparian… 4 riparian… 5 riparian…) before they can run again.
4. "Vegetation" cannot tag the same "water" two times in a row.
5. Instructor records time taken and then students gather to discuss how runoff was different with a riparian zone with vegetation.

Round 3: Riparian zone with large vegetation buffer:

1. Do the same procedure as round 2, but use the full space available to simulate a larger riparian zone.
2. After this round, discuss how a larger riparian buffer zone changes the rate of runoff.

Round 4: Field runoff with no riparian buffer zone.

1. Repeat the same process as round 1, but have students that are simulating water also add yellow or pink flagging to represent nitrogen and phosphorus moving with the water.
2. Without vegetation, the water containing the pollutants will quickly move across the riparian zone.
3. Discuss nonpoint source pollution, as well as how eutrophication occurs as a result.

Round 5: Field runoff with large vegetative riparian buffer.

1. Repeat the same process as round 3, but have students that are simulating water also add yellow or pink flagging to represent nitrogen and phosphorus moving with the water.
2. When the students are tagged, they give their pink or yellow flag to the students representing vegetation.
3. The students representing water can then continue with the game by counting to five before resuming play (same as round 2).
4. Discuss how the plants changed the amount of phosphorus and nitrogen entering the waterway. Discuss the importance of vegetative riparian buffers.

Assessment

After each round, students will be lead in a discussion about what was learned.

Students use the RERUN method to summarize what they did in the activity.

- R=Recall: Describe what they did in the activity.
- E=Explain: Explain what the purpose was of the activity.
- R=Results: Describe what happened in each round of the activity.
- U=Uncertainty: What is unclear about the topic or activity? What questions do you have?
- N=New: What did you learn about the topic by doing the activity?

Extensions

Students could research the Minnesota Buffer Law by going to the link in the resources. Also read the short article from the EPA on buffers that includes data of buffer effectiveness.

Student then could then role play a "stakeholder meeting" where students are assigned roles such as

Resources

Minnesota Buffer Law
https://mn.gov/portal/natural-resources/buffer-law/

EPA - Effectiveness of Riparian Buffers for Managing Nitrogen
www.waterboards.ca.gov/.../EPA_Effectiveness_of_Riparian_for_Nitrogen.pdf

Carbon Crusade

Grade Level: 5-12
Subject : Ecology, Geology, Biology
Time:: 50 Minutes
Standards:
See Appendix for table aligning activity with state and national standards.
Summary:
In this activity students will roll dice to dictate how an atom of carbon moves through the biosphere and lithosphere. This is a fun and interactive way to introduce or review the carbon cycle.

Objectives

Students will:

- understand how carbon moves naturally between living and nonliving things.
- identify carbon sources and carbon sinks.
- identify the role of soils in the carbon cycle.
- understand various ways that humans can interfere with the carbon cycle.

Materials

- Dice
- Printed copies of carbon stations
- Printed copies of student handouts

Background

Carbon is essential to life on earth. It makes up the backbone of all organic molecules including lipids, proteins, nucleic acids, and carbohydrates. Carbon naturally cycles between many different forms in living and nonliving things. The atmosphere, oceans, soil, rocks, fossil fuels, and living things such as forests store carbon in the long and short term. Something that absorbs more carbon that it releases is called a "sink". Something that releases more carbon than it absorbs is called a "source".

Soil is one of the largest reservoirs of carbon on the planet. Soils store three times more carbon than the atmosphere and four and a half times more than found in living things. Soils store approximately 2500 billion metric tons of carbon. With atmospheric carbon dioxide being one of the major greenhouse gasses, sequestering carbon from the atmosphere obviously has important implications in regards to the Earth's climate. While burning of fossil fuels have contributed to most of the increase in atmospheric carbon dioxide, changes in land use practices have accounted to one third of the post industrial revolution anthropogenic increase. Deforestation and cultivation of soils are the significant factors responsible for that change.

Since there is a significantly larger pool of carbon in the soil than in the atmosphere, any factor enhancing respiration of soil organic matter (SOM) by soil microbes if of significant concern. Carbon dioxide is fixed by photosynthesis in plants, storing carbon in biomass that can be passed through the food chain. Plant litter, roots, and organisms that feed on them add organic carbon to the soil, later to be released during respiration in the process of decomposition by soil microbes. The amount of time the carbon stays in the soil depends on several conditions such as soil type, texture, moisture, temperature, and oxygen availability. Soil cultivation (tillage) and erosion results in increased rates of respiration by microbes, leading to loss of soil carbon. Conversely, the use of cover crops, reduced tillage, rotational grazing, and addition of organic residues such as manure, plant litter, and compost can aide in adding carbon to the soil in agricultural systems.

The Activity

1. Students will start at an assigned station. If the instructor chooses, all students could start at the “atmosphere” station.
2. At each station students will roll a die to determine where in the carbon cycle they will go to next.
3. On the student handout sheet, they will record where they are going to next, and will describe how they are going there.
4. After a determined number of rounds or time, students will stop, then be guided in a discussion about the game.
5. Discussion topics could include:
    a. Identifying carbon sinks and sources
    b. Human changes to the carbon cycle including fossil fuel consumption and land use changes.
    c. The role of soil in the carbon cycle
    d. Were there any specific locations where you were “stuck” in the game? What is the significance of those in regards to global carbon dioxide levels that lead to climate change.

One variation of the game would be to have stamps at each station that students would use to stamp their “passport” as they travel through the cycle.

Assessment

After the discussion, students will be asked to make a drawing of the carbon cycle. The drawing will include all of the sinks and sources included in the game, as well as the processes that are involved with the movement of carbon.

Students will also answer questions in the student handout. A scoring rubric is provided in the materials.

Extensions

Students could take samples of adjoining soils that are managed differently and send them to a soil lab to have them tested for how much carbon they contain, or the soil organic carbon (SOC) content. For example they could collect soil to be tested from a field that is tilled yearly as well as an area that undisturbed soil, such as a Wildlife Management Area. Compare the two soils in the amount of carbon stored in the soil. Soil labs would be able to test this using Loss On Ignition technique. Students could then research and discuss how management practices affect how carbon is cycled and stored in soils.

Students could also listen to the NPR podcast in the resources below followed by a discussion or debate on whether farmers should get paid to sequester carbon.

Resources

NPR Iowa Farmers Look to Trap Carbon in Soil
http://www.npr.org/templates/story/story.php?storyId=11951725

Cover Crop Capture

Grade Level: 7-12
Subject : Ecology, Geology, Biology, Agriculture
Time:: 50 Minutes
Standards:
See Appendix for table aligning activity with state and national standards.
Summary:
Student will simulate using how cover crops reduce runoff and leaching of nutrients such as nitrogen. They will plant cover crops in one cake pan and leave the other soil exposed, then have a simulated rain event. Students will compare the leaching and runoff of each using glucose to simulate nitrates, testing the leachate with glucose test strips.

Objectives

Students will:

- Understand how plants such as cover crops reduce runoff and leaching of nutrients.
- Understand how cover crops help reduce soil erosion.
- Understand the connection between agricultural practices and environmental issues.

Materials

- 9x13 disposable aluminum cake pans (three for each group)
- Watering can with sprinkle style spout
- Soil (preferably from a field instead of potting soil)
- Cereal rye seed
- Glucose (dextrose) powder (available from science supply companies)
- Glucose test srips for urinalysis (availbable form science supply companies)
- Test tubes, beakers, graduated cylinders
- Colorimeter or spectrophotometer (optional)

Background

Instead of leaving the soil bare between crops, farmers can plant cover crops to protect the soil. Cover crops can be planted between cash crops such as wheat, corn, or soybeans. There are many advantages to planting cover crops. They include improving the biological, chemical, and physical health of the soil.

Biologically, cover crops provide continual food (carbon) to soil microbes. Soil microbes are essential for nutrient cycling. Cover crops can also control pest populations such as parasitic nematodes. Weed pressure can be reduced by cover crops smothering competing weeds and keeping them from being established. Cover crops can act as a food source and habitat for wildlife, including nesting sites for ground nesting birds. Additionally cover crops help to improve or maintain the soils organic matter, a primary indicator of soil health.

Chemically, cover crops help in nutrient cycling. Some cover crops such as legumes help to fix nitrogen in the soil, reducing the amount of fertilizer added to meet crop needs. Some cover crops such as radishes and cereal rye scavenge unused fertilizer from the soil, then return the nutrients to the soil for the next year's crop.

Physically, cover crops increase soil porosity and infiltration, as well as reduce compaction and hardpans. Cover crops improve aggregate stability by releasing exudates that that act as glues to hold small soil particles together into larger aggregates. Cover crop leaves reduce velocity of raindrops which in turn reduces splash erosion. Roots of cover crops hold soil particles in place reduce sheet, rill, and gully water erosion. In addition, cover crops reduce wind erosion by keeping the soil covered and held in place.

The use of cover crops does not always result in immediate gains in productivity and profitability, but will over the long term.

The Activity

Setup:

1. Students will work in small groups of two to four students in this activity.
2. Three weeks prior to the activity, students will plant cereal rye in one pan. Students will monitor growth and water every two days.

3. Students will have a second pan with soil that is not planted with seed as a control group. Students should water the two the same over the three week period

Experiment:

1. Students will poke holes in the bottom of both pans in a grid-like pattern with both pans being identical.
2. In both pans students will add 10 grams of glucose (dextrose) powder to each pan. The glucose will simulate nitrates from fertilizers.
3. Under each pan that contains soil, place an additional pan to collect leachate that goes through the soil. It may be helpful to put wooden blocks or other objects between the pans to allow for water collection.
4. Students will pour 2 liters of water in a watering can over their soil to simulate a rain event. This is close to a one inch rain. Pan size 9"x 13" multiplied by 1" of rain = 117 cubic inches. That converts to 1.917 liters of water.
5. Collect leachate for 5 minutes.

Results:

1. Students will collect the leachate and measure the volume and record in data table in student handout.
2. Students will test the leachates for glucose using the test strips and record in mg/dl in data table in student handout. The glucose simulates nitrates added as fertilizer, as nitrates are water soluble like glucose.
3. Students will use a colorimeter or spectrophotometer to test the leachates for clarity. Phosphorus often adsorbs to soil particles, resulting in loss due to soil erosion. The lower the clarity, the more soil lost to erosion, as well as phosphorus lost.

Assessment

After the doing the activity students students analyze data that was collected and recorded in the data table. Data analysis and conclusion are recorded on student handout.

Extensions

Students could also investigate how cover crops reduce wind erosion. The same pans used during the simulation could be dried for several days to simulate a drought. Use a fan set on high to simulate strong winds. Use double sided carpet tape put on to microscope slides to capture lost soil particles. Students could also put petroleum jelly on microscope slides to capture soil particles.

The first part of the lab could be done as one large group as a demonstration. Individual students or small groups could view the slides to compare the soil loss. Results could be compared qualitatively by how the slides look, or quantitatively by counting soil particles within the field of view.

Resources

Cover crops for conservation tillage systems (2017)
Penn State Extension Service
https://extension.psu.edu/cover-crops-for-conservation-tillage-systems

Food Fight

Grade Level: 7-12
Subject : Ecology, Biology
Time: 50 minutes
Standards:
See Appendix for table aligning activity with state and national standards.
Summary:
In this activity students will pass a ball of yarn to represent the transfer of energy in a food web of a soil community.

Objectives

Students will:

- understand the relationship between organisms in a soil community.
- understand how energy and matter are transferred in a food web.
- Understand the importance of the niches of soil organisms.

Materials

- Different colored balls of yarn
- Student handouts

Background

There is a tremendous diversity of different organisms in the soil. The organisms interact in relationships that can be shown in a food web. In a food web, all organisms are connected either directly or indirectly. Too many or too few of one organism can have a cascade effect through the rest of the ecosystem leaving the community out of balance. The organisms in the soil community help clean water, recycle nutrients, prevent erosion, and help agricultural crops grow.

Below are specific niches or roles that various soil organisms play in different trophic levels:

Trophic Level - Producers

Plants - fix carbon dioxide into organic matter through photosynthesis. Produce residue, root exudates, and metabolites that support the soil community.

Trophic Level - Primary consumers

Bacteria - feed off of organic matter in the soil.

Saprophytic fungi- feed off of organic matter in the soil.

Mycorrhizal fungi - get energy from plants that they engage in mutualistic relationships with.

Root eating nematodes - eat plant roots.

Trophic Level - Secondary consumers

Millipedes - feed off of bacteria and fungi. Act as shredders as they chew up the dead plants that the fungi and bacteria feed off of.

Sowbugs - feed off of bacteria and fungi. Act as shredders as they chew up the dead plants that the fungi and bacteria feed off of.

Mites - feed off of bacteria and fungi. Act as shredders as they chew up the dead plants that the fungi and bacteria feed off of.

Grazing nematodes - roundworms that eat bacteria and fungi.

Protozoans - graze on bacteria.

Trophic Level - Higher level consumers

Predatory nematodes - eat other nematodes and protozoans.

Predatory arthropods - arthropods such as **centipedes**, **ants**, **spiders** and **ground beetles**.

Mammals - mammals such as **moles** eat arthropods and earthworms.

Birds - birds such as **robins** eat arthropods and earthworms.

Trophic Level - Generalists

Earthworms - eat many smaller organisms including soil organic matter from plants, bacteria, fungi, and protozoans.

The Activity

1. Students are assigned the following roles that are shown in bold in the background information. If you have extra students that do not have roles, they can be assigned plants. One or two students can be assigned as facilitators, moving the yarn (representing energy) from student to student.
2. After being assigned a role, students write the name of their organism on a piece of paper. Below the name of the organism, they will write what trophic level that organism belongs and what the organism eats or how it obtains its energy.
3. Students can use a hole punch and a length of yarn to make a lanyard to hold their paper.
4. Students then sit in a large open circle. Students assigned as producers (plants) start with the balls of yarn.
5. Taking turns each producer reads their own information.
6. Next the primary consumers read their information
7. On the cue of the teacher, the facilitator(s) carry the ball of yarn representing energy from the producers to the first level consumers. In doing so, they will leave a trail of yarn creating a web.
8. Continue the same process for the secondary consumers, where they read their information. Follow this by the facilitators carrying the yarn from the primary consumers to the secondary consumers.
9. Repeat the same process for the higher level consumers and generalists.
10. When done, a complex web should be produced showing the complex relationships in the soil food web.
11. Teacher leads the students in discussion about the about the importance of each trophic level.
12. If age appropriate, students continue to explore the specific benefits of each type of organism by going to the "extension" section in the activity guide.

Assessment

After creating the class soil food web, students will draw a soil food web on the student handout. Students will then pick two organisms that they think are keystone species, and predict how the loss of those organisms would have a cascade effect in the soil community.

Extensions

Advanced or older students could investigate the USDA - NRCS Soil Food Web that is referenced in the resources below. Students can learn in depth information about the specific niches of bacteria, fungi, protozoans arthropods, and nematodes. Students investigate the role that those organisms play in mineralization and immobilization of nutrients in the soil. Students also explore the role of the various organisms for soil health.

Resources

USDA - NRCS Soil Food Web
https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/health/biology/?cid=nrcs142p2_053868

Microbe Mania

Grade Level: 7-12
Subject : Ecology, Biology, Agriculture
Time: 2-3 class periods
Standards:
See Appendix for table aligning activity with state and national standards.
Summary:
In this activity students will determine the biological health of soils by measuring the amount of carbon dioxide released after rewetting of a dried soil sample.

Objectives

Students will:

- understand the role of microbes in healthy soils.
- understand the relationship between microbial activity and nutrient mineralization.

Materials

- Air dried soil samples
- Rolling pin
- Coarse soil sieve
- Aluminum cake or bread pans
- Small plastic beaker with holes in bottom
- 10 oz. jars with lids
- Solvita® CO2 paddles
- Solvita® color guides
- Printed student handouts

Background

Soil microbes play a vital role. They are involved with nitrogen fixation, nitrogen conversion, as well as acting as decomposers in the soil ecosystem. Healthy soils should have a robust and diverse microbial population. Without microbes no litter would decompose, and important nutrients would not be recycled back into the soil to be used again in the ecosystem.

In agricultural systems, microbes play in a role in the mineralization of nutrients that are tied up in organic matter. Mineralization is when elements in organic matter are converted into soluble inorganic forms. The soluble inorganic forms then are available to other organisms including plants. This is especially important in releasing limiting nutrients such as nitrogen from organic matter in the soil and making it available to plants. As opposed to commercially applied fertilizers, nutrients released by mineralization from microbial activity are released slowly and are taken up by plants as needed. This limits nutrients lost by leaching and runoff.

Biological soil health can be assessed by measuring microbial activity. When living things break down organic matter, carbon dioxide is released as a waste product of cellular respiration. Scientists have developed a method of measuring the microbial activity by capturing carbon dioxide released by the soil bacteria. The higher the amount of carbon dioxide released, the more microbial activity in the soil, resulting in higher potential mineralization of nutrients like nitrogen.

Specific agricultural practices can either help or harm soil microbial populations. Excessive tillage can hinder soil microbe populations by infusing the soils with large amounts of air. The oxygen in the air allows microbes to quickly metabolize organic matter, this reduces total soil organic matter and the nutrients released by mineralization are not necessarily available when needed by the plants. As a result, reduced tillage practices improve the biological health of soils.

Another agricultural practice that improves the biological health of the soil is to feed the microbes. Microbes need a constant supply of carbon. The main source of the carbon are exudates released by roots of plants, as well as plant litter. Having plants growing in the soil throughout the year helps to maintain these populations. Planting cover crops before or after the primary crop will feed the microbes in the soil. The cover crops also help by immobilizing nutrients. by They do so by taking in the soluble nutrients that are vulnerable to loss from leaching and runoff. After the cover crops are terminated, the nutrients tied up in their organic matter are then available for mineralization by the soil microbes.

The Activity

1. Students collect soil samples from two or more different areas that have different land management practices.
2. Air dry soil samples in an aluminum pan for at least 48 hours until dry to the touch.
3. Grind soils by using rolling pin.
4. Sieve the soil through a coarse sieve to remove rocks and debris.
5. Add 40 g of sieved, dry soil from each sample to small plastic beaker with holes in the bottom.
6. Place small beaker containing soil inside jar.
7. Pipet 20 ml of distilled water to the bottom of the beaker (the water will re-wet the soil by capillary action allowing the bacteria in the soil to begin to metabolize the organic material in the soil).
8. Place Solvita® paddle into jars that contain soils.
9. Allow soils to incubate for 24 hours.
10. After 24 hours remove paddles from jars and use color chart to determine CO_2 released. Record in data table.
11. Analyze data and answer questions in student handout.

Assessment

After the activity, students will complete a data table and answer questions in the student handout.

Extensions

Students could send in soil samples from same locations to a soil lab, such as Next Level Ag, to test for soil organic matter. Scientists there would use the LOI (Loss On Ignition) test to determine soil organic matter. Typically results are received in less than a week from such labs. After results of received, students could make an X-Y scatter plot of class data to explore the correlation between organic matter and soil microbial activity.

You also could have students compare rates of decomposition in different soils by burying a piece of cotton fabric in different soils, and then unearthing them after two months. To catch the students attention, you could bury a pair of men's white cotton briefs. This is a common demonstration done by soil scientists to demonstrate the role of microbes in a healthy soil. If there is not much of the underwear left, the soil has a healthy microbial community. Soil conservationists across Canada and the United States are using the Twitter hashtag "#SoilYourUndies". Students and/or teachers could add to the hashtag to join that collective scientific community. A link to a description of the Soil Your Undies demonstration by the Soil Conservation Council of Canada is found in the resources.

Resources

Next Level Ag - Soil health testing laboratory
http://nlaglabs.com/

Solvita Soil Testing Website
https://solvita.com/soil/

Soil Conservation Council of Canada
www.soilcc.ca/soilsweek/2017/Soil-Your-Undies-Protocol.pdf

Nitrogen Knock Around

Grade Level: 7-12
Subject : Ecology, Geology, Biology
Time:: 50 Minutes
Standards:
See Appendix for table aligning activity with state and national standards.
Summary:
In this activity students will roll dice to dictate how an atom of nitrogen moves through the biosphere. This is a fun and interactive way to introduce or review the nitrogen cycle.

Objectives

Students will:

- understand how nitrogen moves naturally between living and nonliving things.
- understand the importance of managing nitrogen in agricultural systems.
- understand the implications of humans adding nitrogen to ecosystems.

Materials

- Dice
- Printed copies of nitrogen stations
- Printed copies of student handouts

Background

Nitrogen (N) is one of the most important elements found in living things. It is needed by plants to make chlorophyll, the main pigment needed for photosynthesis. It is also found in amino acids, the building blocks of proteins as well as nucleic acids (DNA and RNA). Ironically, even though N is a main limiting factor for plant growth, the atmosphere is flush with it. Nitrogen gas (N_2) makes up 79% of the atmosphere, but is relatively inert and unavailable for plant uptake.

N_2 is fixed into ammonia (NH_3) by bacteria that are free living in the soil, or more often, found in root nodules of legumes such as clover, peas and beans. The NH_3 has to be converted to nitrites (NO_2^-), then into nitrates (NO_3^-) before it can be assimilated into plants. This process is called nitrification, and is carried out by separate bacteria than the N fixation process. Nitrates can then be absorbed by plants.

Different forms of N in the soil can be lost by runoff, leaching, volatilization, denitrification, and crop removal. Depending on the crop, significant amounts of N are lost during harvest of plant biomass. Denitrification occurs as a result of bacteria that convert usable soil NO_3^- back to N_2 gas. This occurs primarily in the A horizon (topsoil) of waterlogged soils. Volatilization loss occurs when NH_3 is changed directly into N_2 gas before it is converted into NO_2^- by soil bacteria. Leaching occurs when nitrates (NO_3^-) become mobile and move beneath the root zone.

Pollution of aquifers by the leaching of nitrates is a problem in many agricultural communities. Well water containing high levels of nitrates has been linked to "blue baby syndrome", a potentially deadly disorder where infants ability to bind oxygen by hemoglobin is reduced. Runoff of N can also lead to eutrophication of bodies of water.

Since N is lost in significant amounts in agricultural systems, it needs to be replaced to maintain soil fertility. Lost N can be replaced by adding inorganic fertilizer such as ammonia. In doing so humans have doubled the amount of available N in the biosphere with synthetic fertilizers. This also leads to more N lost through leaching and runoff leading to environmental problems.

Addressing N needs using soil biology can help make N use by plants more efficient. One method is aiding N fixation into soils by incorporating legumes into their crop rotations, and using legumes as cover crops. Adding plant residue as well as animal manure can also be a source of N for plants. As the organic biomass is decomposed by microbes, they release the N into the soil in the form of nitrates, making it available for plants. This process is called mineralization, and occurs gradually throughout the growing season.

The Activity

1. Students will start at an assigned station. If the instructor chooses, all students could start at the “atmosphere” station.
2. At each station students will roll a die to determine where in the nitrogen cycle they will go to next.
3. On the student handout sheet, they will record where they are going to next, and will describe how they are going there.
4. After a determined number of rounds or time, students will stop, then be guided in a discussion about the game.
5. Discussion topics could include:
    a. How do farmers use crop rotation to manage nitrogen?
    b. Why is nitrogen a main limiting factor for plants even though it is the most abundant gas in the atmosphere?
    c. What can be done to reduce nitrogen leaching and runoff?
    d. Why do farmers many farmers annually add nitrogen to their soils? What happened to the nitrogen that was applied the year before?

One variation of the game would be to have stamps at each station that students would use to stamp their “passport” as they travel through the cycle.

Assessment

After the discussion, students will be asked to make a drawing of the nitrogen cycle. Students will also answer questions in the student handout. A scoring rubric is provided in the materials.

Extensions

Students could read the article on nitrates in well water in Minnesota. Students shade in corn yield (by county) on a map of Minnesota. Students mark locations of wells that exceed accepted levels of nitrates on that map as well. After map is complete students explore the relationship between the two values.

Resources

Nitrates in Well Water. ***Minnesota Department of Health***
http://www.health.state.mn.us/divs/eh/wells/waterquality/nitrate.htm

Kennedy, T. (2015, May 7). Nitrate cited as ‘growing threat’ to Minnesota’s drinking water. ***Star Tribune.***
http://www.startribune.com/nitrates-from-agriculture-a-growing-threat-to-minnesota-drinking-water/302799071/

Brownwell, A. (2015, May 6). Annual drinking water report highlights nitrate pollution. ***KROC AM 1340.***
http://krocam.com/annual-drinking-water-report-highlights-nitrate-pollution/

Follett, R. (1995) Fate and transport of nutrients: nitrogen. USDA NRCS
https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/landuse/crops/?cid=nrcs143_014202

Phollowing Phosphorus

Grade Level: 7-12
Subject : Ecology, Geology, Biology
Time:: 50 Minutes
Standards:
See Appendix for table aligning activity with state and national standards.
Summary:
In this activity students will roll dice to dictate how an atom of phosphorus moves through the biosphere and lithosphere.. This is a fun and interactive way to introduce or review the nitrogen cycle.

Objectives

Students will:

- understand how phosphorus moves naturally between living and nonliving things.
- understand the importance of managing phosphorus in agricultural systems.

Materials

- Dice
- Printed copies of phosphorus stations
- Printed copies of student handouts

Background

Phosphorus (P) is an important macronutrient for plants. It is crucial for the production of the energy molecule adenosine triphosphate (ATP), as well as nucleic acids (DNA and RNA). P is highly reactive and is not found in its pure elemental form. It is usually bound into forms that are insoluble and inaccessible to plants.

All of the commercial P fertilizer sold in the United States is mined rock phosphate, that is treated with acid to make it soluble. The soluble P quickly reacts with chemicals in the soil and again becomes insoluble, binding to soil particles in a process called adsorption. Soluble P also can be immobilized into organic P forms such as in microbes or humus. Because of this, leaching of P typically is a problem only when P reaches its saturation point.

Applied P fertilizer that exceeds plant requirements is a waste of money for the producer as well an environmental problem. Runoff of soluble P after a rain event or irrigation is mostly a problem if plants don't use the available P shortly after application before binding occurs in the soil. Since P quickly binds with soil particles and chemicals, most P loading of watersheds occurs as a result of erosion of sediment that is bound with P.

Just like in plants, P is one of the main limiting nutrients of algae and cyanobacteria. Consequently, external P loading from agriculture is one of the main causes of eutrophication of freshwater ecosystems. Along with testing of soils to only apply needed P and controlling erosion, soil health measures to improve the biological activity of the soil can also help manage P. Healthy soils with significant microbial activity and organic matter release fixed P slowly throughout the growing season as needed by plants. This reduces P loss through erosion and leaching.

The Activity

1. Students will start at an assigned station. If the instructor chooses, all students could start at the "Soluble Inorganic Phosphate" station.
2. At each station students will roll a die to determine where in the phosphorus cycle they will go to next.
3. On the student handout sheet, they will record where they are going to next, and will describe how they are going there.
4. After a determined number of rounds or time, students will stop, then be guided in a discussion about the game.
5. Discussion topics could include:
    a. Why is phosphorus a bigger concern for scientists addressing eutrophication of freshwater?
    b. Since phosphorus sources have to be mined, is it possible that we may run out of that resource in the future?
    c. Is it possible that there is adequate phosphorus in the soils for plants, but the phosphorus just isn't available?

One variation of the game would be to have stamps at each station that students would use to stamp their "passport" as they travel through the cycle.

Assessment

After the discussion, students will be asked to make a drawing of the phosphorus cycle. Students will also answer questions in the student handout. A scoring rubric is provided in the materials.

Extensions

Students could be assigned into pairs to read a section of a Pollution Control Agency document on a nutrient management such as plan shared in the resources. Groups could then share a summary of that part of the document in a way that is understandable. By doing so, students

Resources

Osakis Lake Area Excess Nutrient TDML Implementation Plan
https://www.pca.state.mn.us/sites/default/files/wq-iw8-39c.pdf

USDA NRCS Fate and Transport of Nutrients: Phosphorus
https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/rca/?cid=nrcs143_014203

Slaking Sleuths

Grade Level: 7-12
Subject : Ecology, Biology, Agriculture
Time: 50 minutes for data collection, 30 minutes for data analysis
Standards:
See Appendix for table aligning activity with state and national standards.
Summary:
In this activity students will test soil aggregate stability to withstand slaking.

Objectives

Students will:

- Understand the importance of stable soil aggregates.
- Understand how organic "glues" help keep aggregates stable.
- Understand how stable aggregates reduce slaking and erosion.

Materials

- Distilled water
- Slaking kit (See NRCS Slake Test in Resources)
  - 1" PVC cut into sampling sieve baskets
  - 1.5 mm screen
  - Hot glue
  - Plastic tray made into 8 compartments, or an ice cube tray
- Stopwatch / timer
- Air dried soil samples

Background

When you crumble a handful of soil in your hands the pieces of soils that remain together are the soil aggregates. Aggregates form by organic residues excreted by various microorganisms, plant roots, and mycorrhizae. Aggregates also can form from the casts of earthworms. When the small individual soil particles bind to form an aggregate, carbon in the form of soil organic matter (SOM) resists decomposition and becomes stabilized allowing it to be stored for extended periods of time. There is a positive correlation between the formation of soil aggregates and SOM, each factor enhancing the other.

Aggregates benefit the soil in several ways. As mentioned before, they help stabilize SOM, one of the main indicators used when assessing soil health. The aggregates, because of their varied sizes and shapes, increase porosity and decrease soil bulk density. Aggregate stability is also important in stabilizing soils and helping prevent erosion. Soils of various types with high percentages of aggregates are resistant to interrill erosion, erosion from raindrops that detach soil particles making them mobile for transport, while soil low in aggregates, experienced more interrill erosion. Aggregate stability is the ability of the the soil aggregates to resist external physical and chemical forces.

When large dry soil aggregates are suddenly immersed in water, they sometimes break apart into smaller aggregates. This is called slaking. Slaking often occurs when dry soil is rapidly wetted after rainfall. As opposed to aggregate stability, which is the ability of soil aggregates to withstand external forces, slaking involves internal forces. When water enters the pore space of the soil, the uneven expansion of clay particles as well as other forces cause the soil to lose its structure.

When soils have high organic matter the large aggregates are more stable and resist slaking. The organic "glues" produced by living things keep the smaller clay, silt, and sand particles stuck together in larger aggregates. Tillage and other disturbances to the soil break down the stable aggregates decreasing the quality of the soil.

Slaking can result in erosion of soils, or the sealing of the soil surface by small soil particles making hardpans. Stable aggregates, in addition to resisting slaking and water erosion, can also resist erosion from wind. Wind itself usually only dislodges particles that are very loosely held together, but those particles themselves can become missiles with more kinetic energy causing more erosion.

The Activity

1. Activity modified from NRCS Slaking Test (See Resources)
2. Students or instructor collect two samples that have contrasting management practices. Such as perennial grasses vs. conventional tillage, or conservation tillage vs. conventional tillage. From each site collect at least four separate large aggregates approximately 1 cm in diameter being careful not to destroy the fragments.
3. Students develop a hypothesis as to which management practices will lead to better aggregate stability.
4. Air dry soil samples for 48 hours.
5. Remove sieves from tray, fill tray with distilled water deep enough to cover soil particles in sieve. Water temperature should be about the same as the soil.
6. Place aggregates about 1 cm in diameter into the sieves. Lower one sieve into the box with water for five minutes. Observe the soil fragment, referring to the stability class table in the student handout.
7. After five minutes in the water, raise the basket out of the water then lower it to the bottom. It should take one second for the basket to clear the surface and one second to return to the bottom.
8. Repeat immersion four times (total of five immersions). Refer to the stability class table in student handout and record in data table.
9. Soil stability is rated according to the time required to disintegrate during the five minute immersion and the proportion of the soil fragment remaining on the mesh after the five extraction-immersion cycles.
10. Repeat process for other three fragments from the first location, then repeat all steps for four aggregates from a second location with different management practices.

Assessment

After collecting soil from two different management practices, students will develop a hypothesis to the following question, “Which soil sample will resist slaking better?” Students use data to determine whether hypothesis was supported by the experiment. Students then answer analysis questions to better understand how different management practices lead to better aggregate stability.

Extensions

Students could also test smaller aggregate stability by completing the Volumetric Aggregate Stability Test (VAST) developed by SOLVITA ® . The VAST test is a commercially developed standardized test used by soil testing labs to evaluate aggregate stability. A link to the SOLVITA ® website is in the resources.

Students could also watch a video of USDA NRCS soil scientist Ray Archuleta demonstrating slaking. Students could replicate Archuleta’s experiment with local soils. Video link is in resources.

Resources

Slake Test - NRCS
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_051287.pdf

Soil Quality for Environmental Health - Slaking
http://soilquality.org/indicators/slaking.html

Volumetric Aggregate Stability Test (VAST) developed by SOLVITA ®
https://solvita.com/soil/vast/

Demonstration of slaking test by Ray Archuleta
https://www.youtube.com/watch?v=5UfnbiBo-Ds

Soil Snack!

Grade Level: 5-8
Subject : Ecology, Biology, Geology, Art
Time: 50 Minutes
Standards:
See Appendix for table aligning activity with state and national standards.
Summary:
In this activity, students will be constructing an edible model of the horizons of a soil profile.

Objectives

Students will:

- understand the components of a soil profile.
- make a model to show a scientific phenomenon.

Materials

- 10 oz. plastic cups
- Oreo cookies
- Chocolate chips
- Chocolate pudding
- Vanilla pudding
- Gummie worms
- Shredded coconut dyed green
- Plastic spoons
- Masking tape
- Marker

Background

When you thrust a shovel into the ground or view a new roadside cut, you can see the different layers of soil beneath your feet. That physical profile of the soil can be categorized into three basic layers. These layers, called horizons, usually have similar color, mineral composition, structure, texture, and chemical characteristics. These layers are often categorized as A,B, and C horizons.

The **A layer** is also called the topsoil. It contains minerals mixed with humus. Humus is partially decomposed organic matter (living things). This layer has approximately 45% minerals, 25% water, 25% air, and 5% organic matter. The A layer is teaming with many types of organisms such as earthworms, insects, nematodes, bacteria, fungi, and plant roots. This horizon tends to be thick in grasslands, and productive agricultural land. Grasses have extensive root systems that die off every year that decompose to make the humus. Oppositely, in forest ecosystems, most of the living matter is above ground held in living trees. Tree roots typically do not die each year, resulting in less decomposition in the A horizon. As a result this layer is usually thinner in forests than grasslands. A horizons are noted by darker in color resulting from the accumulation of humus.

The **B layer,** also called the subsoil, contains materials that have leached down from the A layer. The leached material often are the smaller particles such as clays as well as other minerals. The B horizon has little organic material and is usually lighter in color.

The **C layer** contains the parent material. Parent material are the particles that the upper horizons are made from in a process called pedogenesis (soil formation). The parent material can be weathered bedrock from below or it could have been transported to the location by wind, water, ice, or gravity. For example, most of the parent material in Western Minnesota was moved here by glaciers, and is called glacial till.

In addition to those three basic layers, the **R layer**, or bedrock is found below the C layer and is the original source of parent material for the soil. The R layer may be a few inches to several hundred feet below the surface.

An **O layer,** or loose organic material, may be found on the surface of the soil as well. This layer is composed of things such as leaf litter and is usually less than a few inches thick. As the O layer decomposes, it contributes to the A layer.

Even though all soils do not have all of these horizons, or differ greatly in their depth and qualities, it does allow for common language when describing the soil's properties not only in agriculture, but also in other fields of science as well.

The Activity

Prior to this activity, students should be taught the basic layers of the soil profile (horizons). In the activity, students work individually or in pairs to make a edible soil profile model using common dessert items.

Steps:

1. Review the three basic layers of the soil profile.
    - O Horizon - Organic matter on top of the soil.
    - A Horizon - Topsoil that is rich with humus and nutrients.
    - B Horizon - Subsoil that contains minerals and clay that has moved downward from the A horizon.
    - C Horizon - Parent material that is formed from weathered bedrock.
    - R Horizon - Bedrock.
2. Tell the students that they will be making a model of the soil profile using Oreo cookies, chocolate chips, chocolate pudding, vanilla pudding, gummy worms and shredded coconut. The model will be constructed inside of a 10 oz. plastic cup.
3. Give students approximately 10 minutes to come up with a plan for making their model. They will draw their model on page 1 of the activity sheet. Before the model can be constructed, students will need to have their model plan approved.
4. Students construct their cup according to their plan. Following the guidelines from the Soil Snack rubric. If available, students take a picture of their model and submit via digital learning management system (DLMS) such as Schoology, Moodle, Google Classroom, or D2L.
5. Students fill in table 1 of the activity sheet and answer the assessment questions.
6. If approved by the instructor, students may eat their model!

Assessment

Students can be assessed after completing the edible soil profile model and Soil Snack Student Handout by using the Soil Snack Scoring Rubric.

Extensions

Students can visit the Soil Profile Gallery from the USDA NRCS to view soil profiles from across the country. (See Resources)

Have students use USDA NRCS National Cooperative Soil Survey to locate the type of soil found where they live or where a friend or relative lives. (See Resources)

Resources

USDA NRCS Soil Profile Gallary
https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/office/ssr7/profile/?cid=nrcs142p2_047970

USDA NRCS National Cooperative Soil Survey
https://websoilsurvey.sc.egov.usda.gov

	Berlese Biodiversity	Buffer Blitz	Carbon Crusade	Cover Crop Capture	Food Fight	Microbe Mania	Nitrogen Knock Around	Phollowing Phosphorus	Slaking Sleuths	Soil Snack
Minnesota Science Standard										
Interdependence Among Living Systems 7.4.2.1.1	X				X					
Interdependence Among Living Systems 7.4.2.1.2	X				X					
Interdependence Among Living Systems 7.4.2.1.3	X					X				
Interdependence Among Living Systems 7.4.2.2.1			X		X					
Interdependence Among Living Systems 7.4.2.2.2										
Interdependence Among Living Systems 7.4.2.2.3			X		X	X	X	X		
Human Interactions with Living Systems 9.4.4.1.1										
Human Interactions with Living Systems 9.4.4.1.2		X		X					X	
Human Interactions with Living Systems 9.4.4.2.4		X		X					X	
NGSS Scientific and engineering practices										
Asking questions and defining problems	X			X		X			X	
Developing and using models		X		X					X	X
Planning and carrying out investigations	X			X		X			X	
Analyzing and interpreting data	X			X		X			X	
Using mathematics, information ...				X		X			X	
Constructing explanations and designing solutions				X		X			X	
Engaging in argument from evidence				X		X			X	
Obtaining, Evaluating, and communicating information	X			X		X			X	
NGSS Cross-cutting concepts										
Patterns						X			X	X
Cause and effect: mechanism and explanation	X	X		X		X			X	
Scale, proportion, and quantity										X
Systems, and system models		X		X	X	X	X	X		X
Energy and matter: flows, cycles, and conservation	X		X		X		X	X		
Structure and function										X
Stability and change	X	X				X			X	
NGSS Disciplinary core ideas										
ESS2.A Earth materials and systems			X				X	X	X	X
ESS3.A Natural resources		X		X		X			X	X
ESS3.C Human impacts on Earth systems		X	X	X		X	X	X	X	
ESS3.D Global climate change						X				
LS1.C Organization for matter and energy flow in organisms			X		X		X	X		
LS2.A Interdependent relationships in ecosystems	X	X	X	X	X	X	X	X	X	
LS2.B Cycles of matter and energy transfer in ecosystems			X		X		X	X		
LS2.C Ecosystem dynamics, functioning, and resilience	X	X	X	X	X	X	X	X	X	
LS4.D Biodiversity and humans	X				X	X				

Berlese Biodiversity

Name:______________________________

Location of sample	
Description of location (shade, plants, tillage, compaction, etc)	
Phylum Class Order (Identifying characteristics)	Tally of organisms in each taxa (n)
Nematoda (unsegmented worms, pointed at both ends)	
Mollusca (snails and slugs)	
Arthropoda (jointed appendages) *Arachnida* (spiders, ticks, & mites) (four pairs of legs)	
Arthropoda (jointed appendages) *Insecta* (three pairs of legs)	
Arthropoda (jointed appendages) *Chilopoda* (centipedes - one pair of legs per segment)	
Arthropoda (jointed appendages) *Diplopoda* (milipedes - two pairs of legs per segment)	
Arthropoda (jointed appendages) *Crustacea* (sow bugs, pill bugs)	
Unidentified	
Total of all individuals in all taxa (N)	

Determine the population density of soil invertebrates per square meter.

Equation for estimating population density: Number of individuals in sample (N) / size of sample area

Number of individuals in sample (N)	:	Estimated number of individuals
Size of sample area (.01 m^2)		m^2

Estimated population density: _______________

Pick two other groups to share data with. Discuss in the space below the differences between the sample location and biodiversity in the different soil communities. In the discussion propose possible explanations for the difference in biodiversity in the sites.

Carbon Crusades - Student Handout

Name: ___________________________

Roll a die to determine where you (an atom of carbon) are going in the carbon cycle. Record in the table below where you are going and describe the process that is transforming you.

Round	Where are you going?	Describe the process that is taking you there?
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
`16		
17		
18		
19		
20		

Making Models: In the space below, draw the carbon cycle based on what you experienced in the game. If necessary, you can look up carbon cycle diagrams to help you. Include the words from the list below in your diagram.

Include the following sinks and sources in your diagram: Soil, Atmosphere, Plants, Animals, Rock, Fossil Fuels, Oceans

Include the following processes in your diagram: Photosynthesis, Cellular Respiration, Burning, Decomposition

Assessment Questions:

1. What is the difference between a sink and a source in the carbon cycle?

2. Name two ways that humans can alter the carbon cycle.

3. How can tilling soil result in more carbon in the atmosphere?

4. How can the carbon in fossil fuels be traced back to the process of photosynthesis?

Carbon Crusades - Scoring Rubric

4	3	2	1
Carbon cycle diagram clearly shows correct connections between all required sinks and sources.	Carbon cycle diagram shows correct connections between various sinks and sources.	Carbon cycle diagram shows connections between some sinks and sources. Most connections are correct	Carbon cycle diagram does not show correct connections between various sinks and sources.
All required processes that involve carbon movement are effectively used to show connections between sinks and sources.	All required processes that involve carbon movement are used to show connections between sinks and sources.	Some required processes that involve carbon movement are used to show connections between sinks and sources.	Processes that involve carbon movement are not effectively used to show connections between sinks and sources.
Assessment questions are answered and show a deep understanding of the carbon cycle.	Assessment questions are answered and show an adequate understanding of the carbon cycle.	Assessment questions are answered and show a limited understanding of the carbon cycle.	Assessment questions are not answered or show a no understanding of the carbon cycle.

Cover Crop Capture

Name:___________________________

	Soil With Cover Crop	Soil Without Cover Crop
Volume of leachate moved through soil after 5 minutes. (mL)		
Amount of glucose leached through soil after 5 minutes (mg/dL) (Glucose models nitrogen)		

Analysis Questions:

1. Which sample prevented the most leaching (less water moving through)?

2. Which sample had less glucose in in the leachate?

3. Determine the total amount of glucose from each sample. Multiply the mg/L by the total volume (L) of leachate from each sample.

Soil With Cover Crop ____________

Soil Without Cover Crop ____________

4. What conclusions can you make from the experiment? (Summarize your data in words)

5. What agricultural and environmental implications can you make about cover crops when reflecting upon the results of this experience?

Food Fight

(Soil Food Web)

Name:____________________________

There is a tremendous diversity of different organisms in the soil. The organisms interact in relationships that can be shown in a food web. In a food web, all organisms are connected either directly or indirectly. Too many or too few of one organism can have a cascade effect through the rest of the ecosystem leaving the community out of balance. The organisms in the soil community help clean water, recycle nutrients, prevent erosion, and help agricultural crops grow.

Below are specific niches or roles that various soil organisms play in different trophic levels:

Trophic Level - Producers

Plants - fix carbon dioxide into organic matter through photosynthesis. Produce residue, root exudates, and metabolites that support the soil community.

Trophic Level - Primary consumers

Bacteria - feed off of organic matter in the soil.

Saprophytic fungi- feed off of organic matter in the soil.

Mycorrhizal fungi - get energy from plants that they engage in mutualistic relationships with.

Root eating nematodes - eat plant roots.

Trophic Level - Secondary consumers

Millipedes - feed off of bacteria and fungi. Act as shredders as they chew up the dead plants that the fungi and bacteria feed off of.

Sowbugs - feed off of bacteria and fungi. Act as shredders as they chew up the dead plants that the fungi and bacteria feed off of.

Mites - feed off of bacteria and fungi. Act as shredders as they chew up the dead plants that the fungi and bacteria feed off of.

Grazing nematodes - roundworms that eat bacteria and fungi.

Protozoans - graze on bacteria.

Trophic Level - Higher level consumers

Predatory nematodes - eat other nematodes and protozoans.

Predatory arthropods - arthropods such as **centipedes**, **ants**, **spiders** and **ground beetles**.

Mammals - mammals such as **moles** eat arthropods and earthworms.

Birds - birds such as **robins** eat arthropods and earthworms.

Trophic Level - Generalists

Earthworms - eat many smaller organisms including soil organic matter from plants, bacteria, fungi, and protozoans.

Assessment: In the space below, draw a food web of a soil community. Use the organisms listed on the previous page. If necessary, research the organisms using the internet.

Keystone species are organisms who are vital to the entire ecological community. Their impact often is not proportional to their population size. Keystone species can be producers that supply energy for many species, they can be top predators that keep populations in check resulting in increased biodiversity, or they can change their environment. Pick three organisms from the food web that you made that are keystone species, and predict how the loss of those organisms would have a cascade effect on other species.

Keystone species #1:

Describe how losing that species would affect the community.

Keystone species #2:

Describe how losing that species would affect the community.

Microbe Mania

Soil Microbe Lab - CO2 Burst Method

Name: ___________________________

Method:

1. Collect soil samples from two or more different areas that have different land management practices.
2. Air dry soil samples in an aluminum pan for at least 48 hours until dry to the touch.
3. Grind soils by using rolling pin.
4. Sieve the soil through a coarse sieve to remove rocks and debris.
5. Add 40 g of sieved, dry soil from each sample to small plastic beaker with holes in the bottom.
6. Place small beaker containing soil inside jar.
7. Pipet 20 ml of distilled water to the bottom of the beaker (the water will re-wet the soil by capillary action allowing the bacteria in the soil to begin to metabolize the organic material in the soil).
8. Place Solvita® paddle into jars that contain soils.
9. Allow soils to incubate for 24 hours.
10. After 24 hours remove paddles from jars and use color chart to determine CO_2 released. Record in data table.
11. Analyze data and answer questions.

Data Table

	Soil Sample:	Soil Sample
Solvita ® paddle color after 24 hr incubation		
CO_2 Respiration (mg CO_2/kg soil/wk)		
Biological Soil Quality (microbial activity)		
Approx nitrogen (N) mineralization per year (lbs/acre)		

Soil Quality Curve

Color 0 - 1 Blue-Gray	1 - 2.5 Gray-Green	2.5 - 3.5 Green	3.5 - 4 Green-Yellow	4 - 5 Yellow
VERY LOW SOIL ACTIVITY Associated with dry sandy soils, and little or no organic matter	MODERATELY LOW SOIL ACTIVITY Soil is marginal in terms of biological activity and organic matter	MEDIUM SOIL ACTIVITY Soil is in a moderately balanced condition and has been receiving organic matter additions	IDEAL SOIL ACTIVITY Soil is well supplied with organic matter and has an active population of microorganisms	UNUSUALLY HIGH SOIL ACTIVITY High/excessive organic matter additions
APPROXIMATE LEVEL OF CO_2- RESPIRATION[a]				
< 300 mg CO_2/kg soil/wk	400 (300 - 500)	750 (500 - 1,000)	1,500 (1,000 - 2,000)	> 2,000 mg CO_2/kg soil/wk
Approximate quantity of nitrogen (N) release per year (average climate)				
< 5 lbs/acre	10-20 lbs/acre	20-30 lbs/acre	30-50 lbs/acre	75-100 lbs/acre

Questions

1. What roles do microbes have in healthy soils?

2. How does the CO2 burst method estimate soil microbial activity?

3. How can increased microbial activity reduce the amount of fertilizer applied to farmers fields?

4. What farming practices can help to improve soil microbial populations?

5. Which soil sample had higher microbial activity?

6. What variables may have lead to the higher activity in the soil identified in question #5.

Nitrogen Knock Around - Student Handout

Name: ________________________

Roll a die to determine where you (an atom of nitrogen) are going in the carbon cycle. Record in the table below where you are going and describe the process that is transforming you.

Round	Where are you going?	Describe the process that is taking you there?
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
`16		
17		
18		
19		
20		

Making Models: In the space below, draw the nitrogen cycle based on what you experienced in the game. If necessary, you can look up nitrogen cycle diagrams to help you. Include the words from the list below in your diagram.

Include the following sinks and sources in your diagram: Soil, Atmosphere, Plants, Animals, Rock, Water

Include the following processes in your diagram: Nitrogen Fixation, Nitrification, Denitrification, Decomposition.

Assessment Questions:

1. What type of organisms are involved with nitrogen fixation?

2. Name two ways that humans can alter the nitrogen cycle.

3. What farming practices add nitrogen to the soil? (At least two)

4. How can nitrogen result in pollution of water?

Nitrogen Knock Around - Scoring Rubric

4	3	2	1
Nitrogen cycle diagram clearly shows correct connections between all required sinks and sources.	Nitrogen cycle diagram shows correct connections between various sinks and sources.	Nitrogen cycle diagram shows connections between some sinks and sources. Most connections are correct	Nitrogen cycle diagram does not show correct connections between various sinks and sources.
All required processes that involve nitrogen movement are effectively used to show connections between sinks and sources.	All required processes that involve nitrogen movement are used to show connections between sinks and sources.	Some required processes that involve nitrogen movement are used to show connections between sinks and sources.	Processes that involve nitrogen movement are not effectively used to show connections between sinks and sources.
Assessment questions are answered and show a deep understanding of the nitrogen cycle.	Assessment questions are answered and show an adequate understanding of the nitrogen cycle.	Assessment questions are answered and show a limited understanding of the nitrogen cycle.	Assessment questions are not answered or show a no understanding of the nitrogen cycle.

Nitrogen Knock Around - Student Handout

Name: ________________________

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Nitrogen Knock Around - Scoring Rubric

4	3	2	1
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All required processes that involve nitrogen movement are effectively used to show connections between sinks and sources.	All required processes that involve nitrogen movement are used to show connections between sinks and sources.	Some required processes that involve nitrogen movement are used to show connections between sinks and sources.	Processes that involve nitrogen movement are not effectively used to show connections between sinks and sources.

Assessment questions are answered and show a deep understanding of the nitrogen cycle.	Assessment questions are answered and show an adequate understanding of the nitrogen cycle.	Assessment questions are answered and show a limited understanding of the nitrogen cycle.	Assessment questions are not answered or show a no understanding of the nitrogen cycle.

Slaking Sleuths

Name:____________________________

Which soil sample will resist slaking better?

Hypothesis: In the space below state the hypothesis to the question above.

Instructions:

1. Students or instructor collect two samples that have contrasting management practices. Such as perennial grasses vs. conventional tillage, or conservation tillage vs. conventional tillage. From each site collect at least four separate large aggregates approximately 1 cm in diameter being careful not to destroy the fragments.
2. Students develop a hypothesis as to which management practices will lead to better aggregate stability.
3. Air dry soil samples for 48 hours.
4. Remove sieves from tray, fill tray with distilled water deep enough to cover soil particles in sieve. Water temperature should be about the same as the soil.
5. Place aggregates about 1 cm in diameter into the sieves. Lower one sieve into the box with water for five minutes. Observe the soil fragment, referring to the stability class table in the student handout.
6. After five minutes in the water, raise the basket out of the water then lower it to the bottom. It should take one second for the basket to clear the surface and one second to return to the bottom.
7. Repeat immersion four times (total of five immersions). Refer to the stability class table in student handout and record in data table.
8. Soil stability is rated according to the time required to disintegrate during the five minute immersion and the proportion of the soil fragment remaining on the mesh after the five extraction-immersion cycles.
9. Repeat process for other three fragments from the first location, then repeat all steps for four aggregates from a second location with different management practices.

Use the following scale to determine aggregate stability.

Stability Class	Criteria for assignment to stability class
0	Soil to unstable to sample (falls through sieve).
1	50% of structural integrity lost within 5 seconds of insertion in water.
2	50% of structural integrity lost after 5-30 seconds in water.
3	50% of structural integrity lost after 30-300 seconds in water. Or less than 10% of soil remains on the sieve after 5 dipping cycles.
4	10-25% of soil remains on the sieve after 5 dipping cycles.

5	25-75% of soil remains on the sieve after 5 dipping cycles.
6	75-100% of soil remains on the sieve after 5 dipping cycles.

Data: In the table below record the data collected from each during the slaking activity for each soil sample

	Soil sample location: Soil management practices:	Soil sample location: Soil management practices:
Stability class of aggregate #1		
Stability class of aggregate #2		
Stability class of aggregate #3		
Stability class of aggregate #4		
Average stability of aggregates from sample		

Analysis:

1. Was your hypothesis supported by the experiment? Explain.

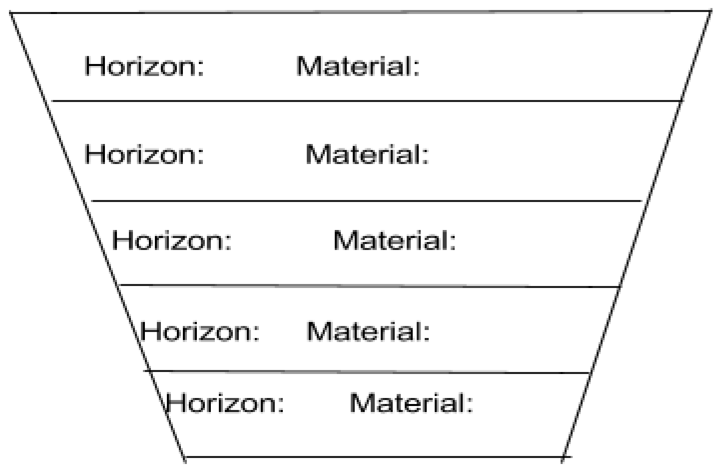
2. Was there a significant difference in the stability class of the aggregates in the soils for the contrasting management practices? Explain the possible reasons for the difference or similarity in the two samples.

3. What are two things that farmers can do to improve aggregate stability?

4. Give two reasons that having soil with stable aggregates is important.

Soil Snack - Student Handout

Name: ____________________



Draw your proposed edible soil profile model above. Label the horizon and the material that you will be using to represent that horizon.

Fill in the table below:

Soil Horizon	Characteristics of horizon	Material chosen to represent horizon	Why did you chose that material to represent that horizon?

Soil Snack - Scoring Rubric

4	3	2	1
Model clearly and accurately represents the layers of the soil profile. Model is clearly labeled.	Model represents the layers of the soil profile. Model is mostly clear. Model labels are partially clear.	Model represents the layers of the soil profile. Model is not clear. Model labels are not clear.	Model does not represent the layers of the soil profile. Model is not clear. Model is not labeled.
Characteristics of each horizon are described with detail. Material chosen to represent horizon is logical. Description of why you chose the materials of the model is explained in detail.	Characteristics of each horizon are described. Material chosen to represent horizon is logical. Description of why you chose the materials of the model is explained with some detail.	Characteristics of each horizon are partially described. Material chosen to represent horizons is not logical. Description of why you chose the materials of the model is explained with little detail.	Characteristics of each horizon are not described. Material chosen to represent horizon is not logical. Description of why you chose the materials of the model is explained without detail.
Model is shared with teacher electronically by the due date. Model is neat and attractive.	Model is shared with teacher electronically by the due date. Model is adequately neat and attractive.	Model is shared with teacher electronically by the due date. Model is adequately neat and attractive.	Model is not shared with the teacher on time. Model is not neat or attractive.

Carbon Cycle

Soil

You roll a...	This is what happens
1	You stay in the **soil** as soil organic matter (humus).
2	You stay in the **soil** as soil organic matter (humus).
3	You stay in the **soil** as soil organic matter (humus).
4	Humus is broken down by microbes, you are released into the **atmosphere** as CO_2.
5	Soil is disturbed by tilling, microbes use the oxygen to break down soil organic matter. You are released into the **atmosphere** as CO_2.
6	The soil you are a part of becomes sedimentary rock. Enter the **Long-Term Carbon-Cycle**.

Carbon Cycle

Atmosphere

You roll a...	This is what happens
1	You **stay in the atmosphere as CO_2.**
2	You **stay in the atmosphere as CO_2.**
3	You **stay in the atmosphere as CO_2.**
4	You are fixed into glucose ($C_6H_{12}O_6$) during photosynthesis in a **plant**.
5	You are fixed into glucose ($C_6H_{12}O_6$) during photosynthesis in a **plant**.
6	You dissolve into water, to the **ocean**.

Carbon Cycle

Plants

You roll a...	This is what happens
1	You **stay in the plant.**
2	You are released as CO_2 into the **atmosphere** during cellular respiration.
3	You are eaten, and become part of **animal** tissue.
4	You die and are decomposed by microbes, and are released as CO_2 in the **atmosphere**.
5	You die and become organic matter (humus) in the **soil**.
6	You die and become organic matter (humus) in the **soil**.

Carbon Cycle

Animals

You roll a...	This is what happens
1	You are eaten by another **animal**.
2	You are released as CO_2 into the **atmosphere** during cellular respiration.
3	You are released as CO_2 into the **atmosphere** during cellular respiration.
4	You die and are decomposed by microbes, and are released as CO_2 in the **atmosphere**.
5	You die and become organic matter (humus) in the **soil**.
6	You die and become organic matter (humus) in the **soil**.

Carbon Cycle

Ocean

You roll a...	This is what happens
1	You go to the deep **ocean**.
2	You go to the deep **ocean**.
3	You go to the deep **ocean**.
4	You are at the ocean surface (Roll an odd number to be used during photosynthesis by **plants** or cyanobacteria). (Roll an even and stay in **ocean**)
5	You are at the ocean surface (Roll an odd number to diffuse into the **atmosphere**). (Roll an even and stay in **ocean**)
6	You are in the deep ocean. (Roll an odd number to become sedimentary rock, and go to the **Long-Term Carbon-Cycle**.) (Roll an even and stay in **ocean**)

Long-Term Carbon Cycle

You roll a...	This is what happens
1	Stay as sedimentary rock in **Long-Term Carbon Cycle**
2	Stay as sedimentary rock in **Long-Term Carbon Cycle**
3	Stay as sedimentary rock in **Long-Term Carbon Cycle**
4	Sedimentary rock is exposed by human activity, roll boxcars (two sixes) with colored dice to be released by chemical weathering into the **atmosphere**. If you do not roll boxcars, stay in **Long-Term Carbon Cycle.**
5	You are a fossil fuel trapped in sedimentary rock, roll any pair with the colored dice to be mined, burned as fuel, and released to the **atmosphere** as CO_2. If you do not roll any pair stay in **Long-Term Carbon Cycle.**
6	Roll snake eyes (two ones) on the colored dice to be released to the **atmosphere** by volcanic activity.

Nitrogen Cycle

Atmosphere

(N_2 gas)

You roll a...	This is what happens
1	Stay in **atmosphere**
2	Stay in **atmosphere**
3	Nitrogen fixation occurs in the production of commercial fertilizers. Go to **ammonium** NH_4
4	Nitrogen fixation occurs in soil bacteria. Go to **ammonium** NH_4
5	Nitrogen fixation occurs in bacteria that reside in the root nodules of legumes. Go to **ammonium** NH_4
6	Nitrogen fixation occurs by lighting. N_2 gas is split with oxygen (O_2) to become **nitrates** (NO_3-) that enter soil through precipitation.

Nitrogen Cycle

Ammonium (NH_4+) In Soil

You roll a...	This is what happens
1	Ammonium (NH_4+) in soil binds with cation exchange sites on clay particles. Stay as **ammonia** in soil.
2	Nitrification occurs. Nitrifying bacteria turn ammonium (NH_4+) into **nitrites** (NO_2-).
3	Nitrification occurs. Nitrifying bacteria turn ammonium (NH_4+) into **nitrites** (NO_2-).
4	Volitalization occurs. Ammonium (NH_4+) is oxidized into ammonia (NH_3) and evaporates into the **atmosphere**.
5	Immobilization occurs. Nitrogen is taken up by soil microbes when the carbon to nitrogen ratio is above 25:1. Go to **soil organic matter**.
6	Leaching or runoff occur. Go to **water**.

Nitrogen Cycle

Plants

You roll a...	This is what happens
1	Plant grows. Nitrogen stays in **plant** tissue.
2	Plant grows. Nitrogen stays in **plant** tissue.
3	Plant is eaten by an **animal**. Nitrogen is used to build amino acids that make up proteins, as well as build nucleic acids including DNA and RNA.
4	Plant is eaten by an **animal**. Nitrogen is used to build amino acids that make up proteins, as well as build nucleic acids including DNA and RNA.
5	Plant dies and become **soil organic matter**.
6	Plant dies and become **soil organic matter**.

Nitrogen Cycle

Animals

You roll a...	This is what happens
1	Animal grows, nitrogen stays in **animal** tissue.
2	Animal is eaten by another **animal**.
3	Animal urinates. Urea is converted to **ammonium**.
4	Animal deficates. Feces becomes **soil organic matter**.
5	Animal dies. Becomes **soil organic matter**.
6	Animal dies. Becomes **soil organic matter**.

Nitrogen Cycle

Nitrites (NO_2-)

You roll a...	This is what happens
1	Nitrification occurs. Bacteria oxidize nitrites (NO_2-) into **nitrates** (NO_3-).
2	Nitrification occurs. Bacteria oxidize nitrites (NO_2-) into **nitrates** (NO_3-).
3	Nitrification occurs. Bacteria oxidize nitrites (NO_2-) into **nitrates** (NO_3-).
4	Nitrification occurs. Bacteria oxidize nitrites (NO_2-) into **nitrates** (NO_3-).
5	Nitrification occurs. Bacteria oxidize nitrites (NO_2-) into **nitrates** (NO_3-).
6	Leaching or runoff occur. Go to **water**.

Nitrogen Cycle

Nitrates (NO_3-)

You roll a...	This is what happens
1	Assimilation occurs. Plants readily take up nitrates into their roots and use them to chlorophyll used in photosynthesis, as well as amino acids which make up proteins. Go to **plants**.
2	Assimilation occurs. Plants readily take up nitrates into their roots and use them to chlorophyll used in photosynthesis, as well as amino acids which make up proteins. Go to **plants**.
3	Assimilation occurs. Plants readily take up nitrates into their roots and use them to chlorophyll used in photosynthesis, as well as amino acids which make up proteins. Go to **plants**.
4	Assimilation occurs. Plants readily take up nitrates into their roots

	and use them to chlorophyll used in photosynthesis, as well as amino acids which make up proteins. Go to **plants**.
5	Denitrification occurs. Nitrates (NO_3-) in water saturated soils are turned into nitrogen gas (N_2) by denitrifying bacteria. Go to the **atmosphere**.
6	Leaching or runoff occur. Go to **water**.

Nitrogen Cycle

Soil Organic Matter

You roll a...	**This is what happens**
1	Nitrogen remains in **soil organic matter** (humus).
2	Nitrogen remains in **soil organic matter** (humus).
3	Nitrogen remains in **soil organic matter** (humus).
4	Mineralization occurs. If the carbon to nitrogen ratio is below 25:1, nitrogen from soil organic matter is released as **ammonium** (NH_4+) in the soil.

5	Mineralization occurs. If the carbon to nitrogen ratio is below 25:1, nitrogen from soil organic matter is released as **ammonium** (NH_4+) in the soil.
6	Mineralization occurs. If the carbon to nitrogen ratio is below 25:1, nitrogen from soil organic matter is released as **ammonium** (NH_4+) in the soil.

Nitrogen Cycle

Water

You roll a...	This is what happens
1	Eutrophication occurs. Nitrogen runoff gets in surface water. Algae, cyanobacteria, and plants populations boom, resulting in poor water quality. Go to **plants.**
2	Eutrophication occurs. Nitrogen runoff gets in surface water. Algae, cyanobacteria, and plants populations boom, resulting in poor water quality. Go to **plants.**
3	Eutrophication occurs. Nitrogen runoff gets in surface water. Algae, cyanobacteria, and plants populations boom, resulting in poor water quality. Go to **plants.**
4	Leaching occurs. Nitrogen leaches into groundwater. If a human baby ingests the water, the baby can get "Blue Baby Syndrome". This is where nitrogen competes for oxygen binding sites in the

	red blood cells. Go to **animal**.
5	Leaching occurs. Nitrogen leaches into groundwater. If a human baby ingests the water, the baby can get "Blue Baby Syndrome". This is where nitrogen competes for oxygen binding sites in the red blood cells. Go to **animal**.
6	Nitrogen runoff causes an anoxic dead zone in the coastal ocean. Little to no life can survive in the oxygen depleted environment. GAME OVER. Talk to your teacher to get back in the game.

Phosphorus Cycle

Soluble Inorganic Phosphate In Soil

You roll a...	This is what happens
1	Assimilation occurs. Soluble phosphates are taken in by plant roots and are used by plants in ATP and nucleotide (DNA & RNA) production. Go to **plants**.

2	Assimilation occurs. Soluble phosphates are taken in by plant roots and are used by plants in ATP and nucleotide (DNA & RNA) production. Go to **plants**.
3	Immobilization occurs. Phosphorus is taken in by soil microbes. Go to **soil organic phosphate**.
4	Adsorption occurs. Phosphates bind with clay, iron, or aluminum in soil. Go to **soil minerals**.
5	Precipitation occurs. Phosphates come out of solution and react with other chemicals. Go to **sedimentary rock.**
6	Leaching occurs. Soluble phosphates go to surface or groundwater**.**

Phosphorus Cycle

Organic Phosphate In Soil

You roll a...	**This is what happens**
1	Humus in the soil does not break down. Stay as **organic phosphate in soil**.
2	Humus in the soil does not break down. Stay as **organic phosphate in soil**.

3	Mineralization occurs. Phosphates are released as organic matter is broken down. Go to **soil inorganic phosphate**.
4	Mineralization occurs. Phosphates are released as organic matter is broken down. Go to **soil inorganic phosphate**.
5	Mineralization occurs. Phosphates are released as organic matter is broken down. Go to **soil inorganic phosphate**.
6	Erosion occurs. Go to **water**.

Phosphorus Cycle

Animals

You roll a...	**This is what happens**
1	Animal grows, phosphorus stays in **animal** tissue.
2	Animal is eaten by another **animal**. Animal uses phosphorus for ATP and nucleotide (DNA & RNA) production.
3	Animal urinates, go to **soil organic phosphate**.
4	Animal defecates. Feces becomes **soil organic phosphate**.
5	Animal dies. Becomes **soil organic phosphate.**
6	Animal dies. Becomes **soil organic phosphate.**

Phosphorus Cycle

Plants

You roll a...	This is what happens
1	Plants grow, phosphorus remains in **plants** and is used for ATP production and building of nucleotides (DNA and RNA).
2	Plants grow, phosphorus remains in **plants** and is used for ATP production and building of nucleotides (DNA and RNA).
3	Plants are eaten by **animals**. Animals use phosphorus or ATP production and building of nucleotides (DNA and RNA).
4	Plants are eaten by **animals**. Animals use phosphorus or ATP production and building of nucleotides (DNA and RNA).
5	Plant dies and becomes soil organic matter. Go to **soil organic phosphorus**.

6	Plant dies and becomes soil organic matter. Go to **soil organic phosphorus**.

Phosphorus Cycle

Water

You roll a...	This is what happens
1	Eutrophication occurs. Phosphate runoff gets in surface water. Algae, cyanobacteria, and plants populations boom, resulting in poor water quality. Go to **plants.**
2	Eutrophication occurs. Phosphate runoff gets in surface water. Algae, cyanobacteria, and plants populations boom, resulting in poor water quality. Go to **plants.**
3	Eutrophication occurs. Phosphate runoff gets in surface water. Algae, cyanobacteria, and plants populations boom, resulting in poor water quality. Go to **plants.**

4	Eutrophication occurs. Phosphate runoff gets in surface water. Algae, cyanobacteria, and plants populations boom, resulting in poor water quality. Go to **plants.**
5	Eutrophication occurs. Phosphate runoff gets in surface water. Algae, cyanobacteria, and plants populations boom, resulting in poor water quality. Go to **plants.**
6	Eutrophication occurs. Phosphate runoff gets in surface water. Algae, cyanobacteria, and plants populations boom, resulting in poor water quality. Go to **plants.**

Phosphorus Cycle

Sedimentary Rock

You roll a...	This is what happens
1	Stay in **sedimentary rock**.
2	Stay in **sedimentary rock**.
3	Stay in **sedimentary rock**.
4	Stay in **sedimentary rock**.
5	Geological uplifting occurs, bringing you close to the surface. If you roll a 6 you are mined and become fertilizer and are applied to

	agricultural field as **inorganic phosphates in the soil**. If you do not roll a 6 you stay as sedimentary rock.
6	Geological uplifting occurs, bringing you close to the surface. If you roll a 6 you are weathered chemically or physically and become **inorganic phosphates in the soil**. If you do not roll a 6 you stay as sedimentary rock.

Phosphorus Cycle

Soil Minerals

You roll a...	**This is what happens**
1	Remain attached to clay particles. Stay in **soil minerals**.
2	Remain attached to iron (Fe) particles. Stay in **soil minerals**.
3	Remain attached to aluminum (Al) particles. Stay in **soil minerals**.
4	Desorption occurs. Go to **inorganic phosphates in the soil.**
5	Desorption occurs. Go to **inorganic phosphates in the soil.**
6	Minerals get buried in the sediments. Become **sedimentary rock**.