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Can Creating An Activity Guide On Soil Health Improve Environmental Awareness And Foster Agricultural Sustainability

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CAN CREATING AN ACTIVITY GUIDE ON SOIL HEALTH IMPROVE ENVIRONMENTAL AWARENESS AND FOSTER AGRICULTURAL SUSTAINABILITY

by

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CHAPTER ONE

Introduction

What's so important about dirt? Isn't it just the stuff that we get on us when we work or play outside? I guess dirt isn't really that important, but soil is. Soil is living, whereas dirt is often thought of as an inert medium. Soil is a complex community where the biotic and abiotic components interact in important ways. Soil is so important that the United Nations General Assembly named 2015 the International Year of Soils (A/RES/68/232), promoting awareness to citizens and decision makers across the globe. Personally, I want to dedicate more time to teaching about soil health. I also want to help other teachers have access to quality lessons on soil health that they can plug into their courses as well. The research question for my capstone project is: "Can creating an activity guide on soil health improve environmental awareness and foster agricultural sustainability?"

Rationale

One of the tools that I used as a new teacher almost twenty years ago was *Project WILD*. *Project WILD* is an interdisciplinary conservation and environmental education program that focuses on wildlife. Pat, another science teacher introduced some of the lessons in Project Wild to me. After getting his masters degree in geology, Pat was employed by the Tennessee Department of Natural Resources as a *Project WILD* educator. He taught teachers how to use *Project WILD*, and did so with me. I still use several of the wildlife lessons in my middle school life science class. For example, one lesson that I incorporate into my seventh grade life science class from *Project WILD* is "Oh Deer!". In this game, the students take the role of deer and their resources to model population dynamics. The students find the games fun and engaging. I like how I can pick and choose lessons from the curriculum and plug them into my classes to supplement existing curriculum. Research has shown that students who partook in *Project WILD l*essons showed gains in learning and developed more positive attitudes towards wildlife (Flemming, 1983). Later in my career I was exposed to *Gray Wolves, Gray Matter* curriculum at a workshop sponsored by the International Wolf Center. *Gray Wolves, Gray Matter* has a similar format to that of *Project WILD*. I was was also introduced to *Project WET* curriculum at the Rivers Institute a few years ago. Both *Gray Wolves, Gray Matter* and *Project WET*, had similar interdisciplinary activities that used active learning, similar in format to *Project WILD*. What I like about all three sets of environmental curricula is that there are many lessons to choose from. They cover many disciplines, they engage students, and they allow for flexibility in how I incorporate them into what I am doing in my classes. I adapted and used lessons from all of these, and I continue to use many of the lessons decades later. With this soil health project, I hope to create lessons similar in format to these three proven environmental curricula.

The 1960's and 1970's saw a revolution in regards to protecting air and water resources. Major legislation, including the Clean Air Act and the Clean Water Act, was passed to set standards and establish regulations to slow the depredation of our natural resources. Environmental education sprang from this movement as well, with the first Earth Day being recognized in 1970 (Carter & Simmons, 2001). 1970 also saw the Environmental Education Act become law, with President Richard Nixon stating the need for "environmental literacy" (Carter & Simmons, 2001). As a student, and later as a teacher, I found that most environmental curriculum focused on wildlife conservation, water quality, or air quality. All of those topics are obviously of importance and should be focused on extensively, but the thin layer of the earth's surface that supports life is often left out.

Just as there was no definitive moment in the 1960's and 1970's that spawned the movement that led to the transformation of how the public and government viewed our water and air resources, there is also no one point in time when the "Soil Health Revolution" started as well. The movement has gained traction in the past decade with scientists like Ray Archuleta of the National Resource Conservation Service (NRCS), spreading the word to tens of thousands of farmers and ranchers showing them how they can view their soil through a different lens. This has lead to a significant and growing group of people in the agricultural community that look at the ground that provides for them in a different way. "Water quality," and "air quality" are phrases often used to describe whether or not those natural resources meet acceptable standards. Instead of using the phrase "soil quality", the phrase "soil health" is used instead by those following this movement. The word “quality” is often used to describe a product of some sort, like carpet or a new vehicle. “Health” is used to describe something that is living. The soil health movement is one that is focusing not only on the physical and chemical part of the soil, but also the biological. The soil health movement is based on four basic principles: reduce tillage, keep the ground covered by plant residue, keep roots in the ground, as well as increase the biodiversity of organisms in the soil (Kibblewhite, Ritz & Swift, 2008) . In essence the philosophy employs a simple concept, create agricultural systems that mimic natural ecosystems.

The title of my capstone project is “Black is the New Green”. Focusing on soil health could be the next major environmental revolution. This requires a change in perspective for our agricultural systems. Instead of looking just at improving yield, the focus instead would be improving yield sustainability. Teaching about a complex topic such as this one could take one of two paths: a reductionist approach or a holistic approach. Reductionism is taking a large, complex system or concept and reducing it into smaller individual parts to better understand the larger system (Ney, n.d.). Conversely, holism is the idea that the individual parts of the system cannot explain how the system as a whole works (Mastin, 2008). Reductionism would attempt to make sense of a large system, such as agricultural and environmental sustainability, by breaking it down into simpler and simpler parts. The advantage of this would be that if one understands the smaller parts, and how they work together, one then can understand the larger system. This is typically how modern science works (Jordan, 2013). But sometimes with this approach, the bigger picture never develops. Things like effective decision making regarding environmental policy or understanding how a complex system works may also require using a holistic lens (Pullin, Knight & Watkinson, 2009). Soil health is a complex topic, so it may work the best to employ both the reductionist and holistic approach, looking both "big to small" and "small to big".

Why Soil?

Four years ago, I got a call from my brother in law, Jason, wondering if I would be interested in helping him start up a new soil health lab for his agronomy company in east central South Dakota. Previously I had no experience in agriculture, other than my science teaching background. For much of that summer, I spent many hours in a makeshift lab covered in dust and sweat, trying to figure out ways to collect data on the health of soils so that Jason could give recommendations to the farmers he worked with on short-term and long-term things that they could do to help improve the health of their soils. Since that time, Jason's company has changed from a small lab in the loft of a machine shed, to several full time employees in a new building with state of the art equipment that costs well over a million dollars. Many of the techniques and protocols that I used have been replaced by more advanced ones that give more accurate and reliable data. But the underlying goal has not changed, to help farmers improve their soil while making more money.

As I contemplated what I should do for my Natural Science and Environmental Education capstone, it really made sense for me to use what I had learned about soil health and pass it on to my students. The focus that summer was to help farmers improve the sustainability and profitability of their farms. Now I need to determine how to teach students about the benefits of healthy soils. Obviously, understanding the science of soils is important. Also, improving pro-environmental behavior should be a goal of this type of environmental curricula. Interestingly, pro-environmental behavior may best be attained by developing place attachment or sense of place, and having a pessimistic view of future conditions (Kaida & Kaida, 2016). Developing a sense of place may be more difficult in an era of less attachment to the environment as a result of an ever increasing use of electronic media. However, because I teach in a rural agricultural community, many of my students may have more personal connection to soils as a result of living on farms or directly using natural resources for recreation.

Conflicting Values

Living in rural communities my whole life, I feel that many people in my community, and communities like mine, do not fit the traditional "environmentalist" mold. Many people in rural communities may feel like "environmentalism is an alien ideology spouted by urban know-it-alls." (McBeth & Foster, 1994). Relying on natural resources as a source of income directly or indirectly, many rural residents take a utilitarian approach towards the environment. The environmental movement to many may come off as "elitist" or threatening to their way of life. Yet, when one spends time with many rural people, they often are are in fact environmentalists in many regards, but not always by name. So there may be a paradox between attitudes, as well as behaviors, in many rural Americans.

Several influences that have shaped my views of the environment may not fit the stereotypical mold. Many I would fondly refer to as "redneck environmentalists". I grew up in a very small northern Minnesota community where logging was the main industry. My father was a forester for the DNR, so from a young age I could identify most trees and understand which products were made of each. Several of my good friends' fathers were loggers. All of those people had a deep appreciation for the natural environment as it sustained them and their families. After college, I got my first teaching job and moved to a coal mining community in Utah. Again, it was a community where many people relied on the use of natural resources. There I met another science teacher, Dan, who introduced me to the canyon country. I explored many of the same places as author Edward Abbey who wrote *Desert Solitaire* and *The Monkey Wrench Gang.* Abbey's anarchist views and disdain for the industrial tourism of the National Parks was different from that of the environmental narratives of Leopold and Thoreau that I read in college. Abbey would much rather deal with the cowboys who ranged their cattle in the desert than with the bureaucrats of the National Park Service. His works showed me that environmentalists can come in many forms.

After spending a year in Utah, I moved back to Minnesota where I continue to live and teach in a rural agricultural community. I have learned that rural students have their own unique experiences that they use as a lens to view the world. Many look at natural resources and the environment as something that is to be "used." Whether students have this "utilitarian" view of the environment or not, it is important to teach them sound ecological principles. From that foundation, students will then be able to make decisions that will lead to sustainable resource use. Rural students may even have the opportunity to make a greater impact on environmental change because of land use decisions that they have the opportunity to make (Heimlich & Anderson, 2001). Especially in a rural agricultural community, developing curricula on soil health could be an important step towards environmental sustainability.

In the next chapter I will be making a comprehensive review of the literature on soil health. I will look at the biological, physical, and chemical health indicators of soil and how all of those factors interact in complex ways. I will also be exploring effective methods and models for teaching sustainability issues. I will use this information to develop lessons that can be used by myself, as well as other teachers, to help students make connections between resource use and sustainability. Parts of this curriculum could be adapted for use in life science, earth science, physical science, chemistry, and agriculture classes in middle or high school classrooms within the rural school setting. Traditional, as well as non-traditional learning settings, could also use or adapt this curriculum to fit their needs.

CHAPTER TWO

Literature Review

Introduction

Humans have relied on soil since we evolved as a species. Early people gathered plants that grew from the soil and hunted the animals that ate those plants, until around 11,000 years ago when things changed (Harris, 2003). When our ancestors started to domesticate plants we began to alter one of our greatest resources, the soil. Use and misuse of this resource has lead to loss of soil fertility, desertification, erosion, and pollution. Focusing on soil health is a pathway to sustainability. This chapter will explore what is known about the biological, physical, and chemical health of soils. I will also explore effective methods of teaching students about soils. This will be used to answer the question "Can creating an activity guide on soil health improve environmental awareness and foster agricultural sustainability?".

Developing Sustainability Education

Teaching sustainability concepts like soil health can be complicated. Often times educators try to simplify the issues to make them understandable for the learners. This can be effective for teaching smaller concepts but often leads to gaps in understanding of the complex issue. Sund found the following:

> Simple solutions to sustainability issues can in fact threaten the very purpose of education, which is to build up students' confidence and self-esteem and to enable students to debate, evaluate, and judge for themselves the relative merits of contesting positions. Education should qualify students through knowledge and socialise them through norms and values, but at the same time support their development into autonomous, emancipated subjects. (2013)

Sund (2013) goes on to say that there are five main factors that should be the focus of environmental education. Those five factors are:

1. Developing humility and an open mind.
2. Teaching awareness in a general sense, as well as how it relates to a specific topic.
3. Helping students make a personal connection with the issues.
4. Fostering critical thinking skills such as analyzing, organizing, and reasoning.
5. Realizing that truths are negotiable and there is no single answer to complex sustainability issues.

So focusing on the scientific content cannot be the sole focus when developing environmental curricula. Learners also cannot be forced into taking a certain viewpoint. The most powerful connections are made when students develop their own ideas about sustainability. Obviously the teacher still has a very important role in this process, which I will describe in the next section.

Environmental Attitudes and Behavior

Changing attitudes towards environmental practices requires a paradigm shift. Educating farmers, students and the general public about the importance of soil health requires a major change in the fundamental approach that humans have towards environmental resources such as soil. Adopting a new, innovative environmental approach can be complicated. Priest, Greenhalgh, Neill, and Young (2015) used Rogers (2003) *Diffusion of Innovation Theory* to explain how new ideas are disseminated. Priest, et al. (2015) identified access to information, along with attitudes and value systems, as factors in environmental decision making. Toma-Simin and Jankovic (2014) use the *Diffusion of Innovation Theory* as well to explain the acceptance of organic agriculture by the general public. Rogers (2003) stated that after the innovation itself, communication was required for the idea to spread, what he referred to as “diffusion”. Time and a social system were required for the idea to gain wider acceptance. After the innovators and early adopters of the new idea, a critical mass of people are required to change attitudes and practices (Rogers, 2003). Rogers (2003) used the following groups to categorize cohorts adopting a new innovation:

1. Innovators (<2.5% adoptance of innovation in cohort)
2. Early adopters (2.5% to 15% adoptance of innovation in cohort)
3. Early majority (15% to 50% adoptance of innovation in cohort)
4. Late majority (50% to 84% adoptance of innovation in cohort)
5. Laggards (84% to 100% adoptance of innovation in cohort)

The soil health revolution is likely at the early adopter phase of Rogers (2003) diffusion process, as less than seven percent of the land used for crops is no-tilled, whereas 85 percent of those no-till acres are in North America (Huggins & Reganold, 2008). This shows that the acceptance of practices that result in healthy soils are still relatively not widely used in the larger agricultural community. The practices are used more in North America where organizations are promoting soil conservation. For the diffusion of new ideas like no-till farming to move through a population, it requires communication and human capital (Rogers, 2003). Often traditional agricultural methods that have been practiced for long periods of time are difficult for people to change. Behavioral change often lags behind scientific innovations. Having a social system in place for such change can speed up the process. Government mandates, media, and organizations can speed up the adoption of innovations. Education is obviously a part of the diffusion of the innovation of transitioning to a focus on soil health.

A difficult part of environmental education is making the connection between knowledge, beliefs and behaviors. Carmi, Arnon, and Orion (2015) found no significant correlation between pro-environmental behaviors and objective or subjective knowledge. They did find that knowledge when paired with emotion can elicit actions that benefit the environment. Social capital, which is the network of relationships between people, was identified by Kransy, Kalbacker, Stedman, and Russ (2015) as a powerful tool for developing environmental education programs. Bernstein and Puttick (2014) showed that social norm messaging can be effective in shaping environmental attitudes and behaviors.

By communicating that the environmental behaviors are the norm, the community members are more apt to adopt those behaviors.

Environmental Disconnect

One problem that exists to varying levels with people in general is a disconnect between themselves and the environment. Enhancing this connection between people and the environment is an important part of environmental education. When people have a strong "sense of place" they tend to exhibit more pro-environmental attitudes and behaviors (Efird, 2015). Sense of place can be thought of as an emotional connection and a sense of attachment with a geographic area. Developing environmental education curriculum that connects students to their community can build emotional connections with their geographic area. Efrid (2015) found that hands-on community based projects increased student knowledge, place connections, and other precursors of pro-environmental behaviors.

Zelenski, Dopko, and Capaldi (2015) demonstrated through experiments that exposure to nature can promote pro-environmental behavior with shared resources. Without connection with the environment, there is a greater chance that the shared resource will be depleted or degraded. This is called the "Tragedy of the Commons" (Lloyd, 1833), a classic environmental problem where a resource shared by all and owned by none becomes overused and deteriorated. Quimby and Angelique (2011) state that community psychology can be used to build a sense of place, and avoid the tragedy of the commons. Making connections between community members and their environment help build a deeper sense of place. Zelenski et. al (2015) show that exposure to nature and building a sense of place will enhance cooperation, which in turn addresses environmental problems which are largely collective problems.

In agriculture, sometimes farmers engage in practices that are environmentally beneficial when there is no economic benefit or even at their own cost (Ryan, Erickson, & DeYoung, 2003). Other times, even with economic incentives, farmers do not adopt environmentally friendly agricultural practices (Reimer, Thompson, & Prokopy, 2012). The decisions farmers make in regard to management practices that benefit or degrade the environment mirror those of the general public. Their values and sense of place are major influences on their land use decisions (Schoon & Grotenhuis, 2000) (Vaske & Korbin, 2001). In both farmer education, as well as education in the classroom, building a strong sense of community and a sense of place is a key component in promoting environmentally friendly attitudes and behaviors.

The literature is clear that environmental education cannot focus on knowledge alone even though it is a critical component. Even if there is clear evidence of the benefits of specific environmental practices, other strategies need to be employed to make a difference in behaviors. Communication, place-attachment, value changes, and social norming are all important in making a paradigm shift in any environmental movement including those involving soil health.

Active Learning

Another successful strategy for environmental education is the use active learning, where students engage in meaningful activities and then reflect on what they did in that process. In a meta analysis study by Freeman et. al (2013) it was reported that active learning lead to a 6% increase in test scores. As a result of that study Freeman et. al (2013) questioned the role of traditional lectures as the best way of teaching concepts. In the literature there is a general consensus that active learning is more effective than a teacher based model (Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013) (Chi & Wylie 2014) (Freeman et. al, 2013). Most studies focused on the mode of approach itself (active learning vs. traditional lecture). Cavanagh et. al (2016) did an interesting study on student "buy in" and the effectiveness of active learning. It may be assumed that students prefer active learning because they are more involved in their learning, but that may not always be the case. Cavanagh et. al (2016) found that when students did not "buy in", there was no advantage of active learning over traditional lecture based education. Keeping active learning fun, engaging and meaningful can help students welcome that type of instruction.

In context of environmental education, Tal (2010) found that active learning in undergraduate college students resulted in an increase of knowledge and awareness of environmental issues. There was not an increase in behavior changes by that group, showing that knowledge and awareness are not causative to behavioral changes (Tal, 2010). Corscadden and Kevany (2017) confer that active learning is beneficial in environmental and sustainability education. They also report that the physical location of the active learning may also be a factor in learning. Active learning, described by Kolb (1984) as experiential learning, is where students "do, observe, think, and plan". Active learning needs to be at the center of any environmental curricula, as it both increases student knowledge and allows for application of that knowledge to create new insights and improve student confidence (Corscadden & Kevany, 2017) (Kolb, 1984).

Environmental Education Activity Guides

Activity guides have been a useful tool for delivering environmental and sustainability education content. *Project WILD*, first published in 1983, is the most widely used environmental education activity guide published. As of 2007, an estimated 53 million students have used lessons published in *Project WILD*, taught by over one million educators that have attended their workshops (Council for Environmental Education, 2007). *Project Learning Tree (PLT)*, an activity guide that originally focused on forest resources, is also widely used. *Project Learning Tree* has trained over 500,000 educators in all 50 states (American Forest Foundation, 2010). A third popular environmental education activity guide is *Project WET*. *Project WET* focuses on water resources and is used internationally by a large number of educators as well (Western Regional Environmental Education Council, 1995). One common theme amongst all three environmental curricula is that they are not focused on teaching students “what to think”; instead, their mission revolves around teaching students “how to think”.

A key component in all three activity guides is teacher education. Workshops lead by trained facilitators instruct attendees how to use the guides by taking them through lessons with hands-on practice (Council for Environmental Education, 2007). This experiential learning is effective in giving educators confidence in using the lessons in the activity guide. In a national field study by Marcinkowski and Iozzi (1994), it was concluded that teachers that have attended at least one PLT workshop are more likely to see gains in their students' knowledge and changes in their attitudes towards the environment. In a summary of research findings about *Project WILD*, it was reported that teachers consistently give high ratings to both the workshops and the activity guide (Pitman, 2004). Also, the teachers that are trained at workshops find the curricula effective, easy to adapt, and easy to use (Pitman, 2004). It was noted by Pitman (2004) that although trained teachers find value in *Project WILD*, administrators and colleagues may not share in that sentiment. Paul (1996) reported that teachers that attended Project WILD and *PLT* workshops that did not implement lessons expressed lack of time as their primary reason for non-use.

Several studies indicate the benefit of the use environmental activity guides (Pitman, 2004). Heimlich, Cantrell, and Duan (2001) reported students overall knowledge scores increased through *Project WILD*, while the control group had no increase or declining scores. Hua (1996) concurs that knowledge increases with *Project WILD* education, and additionally concludes that the curriculum improves students' attitudes towards the environment. Both the knowledge and attitudes declined over time, but still remained higher than students not exposed to the curriculum (Hua 1996). Findings from the study did find that pro-environmental behaviors did not wane over a longer period of time. It can be concluded that environmental activity guides are an effective tool in shaping students' knowledge, attitudes, and behaviors.

Currently there are no published activity guides focused on soil sustainability that fit the model of those mentioned earlier. United States Department of Agriculture - Natural Resources Conservation Service (USDA-NRCS) ("soil health", n.d.) does have some lessons on their website, with additional links to soil educations resources. The USDA-NRCS is mainly focused on farmer education, not necessarily focused on students. Additional organizations such as the Soil Science Society of America provide lessons for K-12 teachers on its website ("K-12 soil science teacher resources", n.d.). They also do teacher education at places such as the National Science Teachers Association National Convention. There are other websites that offer some soil sustainability resources for teachers, but nothing organized like the effective models of *Project WILD*, *PLT*, and *Project WET*. With this background information in mind, the next sections of this chapter will explore the biological, chemical and physical aspects of the soil that will be implemented into my soil health activity guide.

Soil Health

Even though soils can be degraded rather quickly, they are not a renewable resource on an anthropocentric scale (Ojas, Achouri, Maroulis, & Caon, 2016). It can take 200 to 1,000 years to build one inch of topsoil under typical agricultural conditions (Pimentel et al., 1995). Considering the world population could top nine billion by 2050 (Tilman et al., 2001), sustainability of our soils should be a high priority. Thomas Malthus (1798) predicted that the human population would grow geometrically, while food supplies would grow arithmetically. Even though the population has doubled like Malthus predicted, the green revolution during the middle of the twentieth century kept pace (Tilman et al., 2001). However, the industrialization of agriculture has consequences; most importantly, depleted soil health and degraded environments (Horrington, Lawrence, & Walker, 2002). Significant legislation has been passed that specifically protects the quality of the air and water. In comparison, little has been done to protect an equally important resource, soil.

Soil is a mixture of physical, chemical, and biological components. Aristotle's phrase, "The whole is greater than the sum of its parts," would apply well to the understanding of soils since soils are much more dynamic than those three simple ingredients. Two phrases are generally used when studying the status of soils, "soil quality" and "soil health". "Soil quality" is generally used to describe the natural qualities of the soil that are largely not influenced by human activity such as parent material, climate, topography and geologic age. In contrast, the phrase "soil health" describes the attributes of soil that are dynamic, that humans can influence either positively or negatively. These factors include the biodiversity of the flora and fauna, the fertility or nutrients in the soil, the organic matter in the soil, as well as the soil structure. For something such as soil to be "healthy", it has to be living (Schindelbeck, Ristow, Kurtz, Fennell, & van Es, 2016), as soil definitely is. Soil health has to be viewed as a dynamic living system that rests on a triad of legs: biological health, physical health, and chemical health being the three legs that supports it. In the next few sections, I will be exploring the complex relationships among those three factors of soil health, as well as how those factors can be measured and managed in a sustainable agricultural system.

Biological Health of Soils

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 (Herring, 2010). 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.

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. 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 (Datta, J. Singh, S. Singh, and J Singh 2016). 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 into the soil. This increases the capacity of the soil to store water, in turn, reducing runoff. 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. Interestly, Pathma & Sakthivel (2012) report that 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 (Ferris, Venette, & van der Meulen, 1998). In addition to the worms, arthropods are the other main type of small animals 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 (Giller, 1996). 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 (Ingham, n.d.).

Microbes. The least conspicuous, and arguably the most important soil organisms, are the fungi and bacteria. When we see a mushroom, we are seeing just a small part of the fungus. Most of the fungi is below the surface of the soil. Out of sight, possibly out of mind, but definitely doing very important jobs. Fungi are made of hyphae that form long networks of mycelia that are analogous to the roots of plants. Although a few select species of fungi can be damaging to crops, the vast majority of fungal species are beneficial. Nutrients that are essential to plants come in many forms in the soil. Many of those nutrients are held in unusable chemical forms and require enzymes to break them down so they are able to be absorbed by roots and used by the plants. Plants themselves lack many of those enzymes that fungi possess (Reynolds, Packer, Bever, &

Clay 2003). Fungi are the soil's main decomposer, being one of the few taxa of organisms containing the enzymes required to decompose lignin. These saprophytes are able to convert the carbon stored in the complex structures of lignin and cellulose into humic substances, more commonly called humus (Pettit, 2004). These humic substances remain stable in soil for hundreds of years, over time building the black, rich, topsoil found in many productive croplands.

In addition to being parasitic and saprophytic, many fungi also play an important role in plant mutualism. The majority of plants, including crop species, form mycorrhizae. Mycorrhizal fungi invaginate the plant root, getting carbon based exudates from the plant and in turn giving the plant more nutrients than it would get on its own (Bcard and Pich, 1989). These fungi make phosphorus, an often immobile nutrient when incorporated in both organic and inorganic molecules, soluble for plant uptake (Bolan, 1991). These mutualistic fungi also increase the absorptive surface area of plant roots, aiding in the uptake of water, nitrogen, phosphorus, as well as micronutrients. Because their unique enzymes have the ability to break complex carbon rings like those found in lignin, mycorrhizal fungi can even assist in the breakdown of persistent organic soil pollutants (Lenoir, Lounes-Hadj Saharaoui, & Fontaine, 2016).

Similar to fungi, few bacteria are parasitic or pathogenic, while the majority of the species interact in ways that benefit the plant communities that healthy soils support. Bacteria numbers in soils are astounding as population estimates go up to 10 billion bacteria per gram and two tons of biomass per acre (Clark, 1967). By feeding on organic matter in the soil bacteria, like fungi they are vital decomposers, helping to produce stable soil humus as well as storing and releasing nutrients making them available to the plant community. For example, saprophytic bacteria break down amino acids from the proteins found in dead plants and animals into ammonia (Galloway et al., 2004), the first step in the freeing up of the nitrogen and making it available for plants. Chemoautotrophic bacteria, those that use inorganic compounds as a food source, also have crucial roles in the movement of nitrogen. A few select taxa of nitrifying bacteria are involved with the conversion of ammonia to nitrites, while separate taxa of nitrifying bacteria convert nitrites into nitrates which can then be used by plants (Verstraete and Focht, 1977). Probably the most important role of bacteria in the nitrogen cycle is the fixing of inert atmospheric nitrogen into ammonia, that can be acted upon by other types of bacteria as previously mentioned. These crucial bacteria that fix atmospheric nitrogen can either live freely in soil, or can found in symbiotic root nodules of the legume family (Peoples, Herridge, & Ladha, 1995). Because of this mutualistic relationship with nitrogen fixing microbes, legumes such as peas, beans, clover, and alfalfa are crucial components of crop rotations.

Plants. Lastly, the plants themselves play important roles in a healthy soil. Even though plants are not motile like animals, they do have unique trophic responses to environmental stimuli, as well as engaging in complex relationships with other members of their community. McNear (2013) described the unique interface between plant roots and their immediate surroundings called the “rhizosphere”. Growing root tips must exude a tremendous amount of force upon the soil to allow for growth. Additionally, Lopez-Bucio, Cruz-Ramirez, & Herrera-Estrella (2003) report that plant roots are able to detect various levels of nitrates, phosphates, sulphates and iron in the soil. These nutrients act as ligands that signal the growth of root architecture that responds to the soil environment to allow the plant to "forage". Plants not only respond to stimuli by altering their root morphology, they also can do so chemically. Root exudates, substances secreted by the roots, can help to free up otherwise bound nutrients (McNear, 2013). In addition, they also can release specific exudates to attract specific mutualists that can be employed to serve them.

Balance. Healthy soils have a diverse collection of organisms. That biodiversity ensures a balance of populations, as well as movement of nutrients that are not only beneficial to plants, but also to the larger environment. The diverse soil fauna fixes, converts, stores, and releases nutrients in a steady, sustainable manner. Understanding their roles and learning how to enhance these populations are crucial to a sustainable agriculture . In the following section, I will discuss physical characteristics of soil health.

Physical Health of Soils

Structure. Physical properties of soils play a crucial role in determining if the soil is suitable for specific uses. Many of the physical properties of soils are not influenced by humans. Factors such as the climate, geography, geology, glacial history, and age greatly influence its qualities. Generally speaking most desirable agricultural soils have a ratio of approximately 45% mineral component, 25% water, 25% air, and around 5% organic material (Buckman, 1969). Those numbers can differ greatly from region to region as well as seasonally and daily. The mineral components of soil are made up of three particle size categories. Sand has a size range between 0.05-2 mm, silt

0.002-0.05 mm, and clay less than 0.002 mm (Buckman, 1969). The percentages of each particle determine the soil texture, which can be used to place the soil into different classification groups. The soil texture determines many soil properties such as capacity for water storage, water infiltration, aeration, as well as how well the soil retains nutrients. As particle size gets smaller, their surface area increases exponentially. For example, clay may have up to 1,000 times more surface area than an equal volume of sand. As a result, they adhere more water molecules and provide surface area for chemical reactions. Humans have little or no effect on the soil composition and texture, but can still influence other physical properties.

The physical profile of the soil can be categorized into three basic layers, often categorized as A,B, and C horizons (Gerasimova, Lebedeva, & Kitrov, 2013). The A layer is the surface soil that contains minerals mixed with humus. This layer tends to be thick in grasslands and productive agricultural land. The B layer, or the subsoil, contains materials that have leached down from the A layer. Below the B layer, the C layer contains loose parent material where soil is formed in the process of pedogenesis (Breemen, 1998). In addition to those three basic layers, the R layer is the original source of parent material for the soil. The R layer is found below the C layer. An O layer, or loose organic material, may be found on the surface of the soil as well. 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 as well.

Compaction. Soil compaction is a major concern when considering the health of the soil. Soil bulk density is a phrase used to describe the amount of soil in a specified volume. Soil parent material (rock) has an average density of 2.55 g/cm^3. Since non-compacted soil generally has 50% pore space filled with water and air, typical bulk density rates of dried soils would be in the neighborhood of 1.33 g/cm^3 (USDA-NRCS, 2008). Soil bulk densities vary naturally by soil type, but generally densities above 1.6 g/cm^3 restrict the growth of roots (McKenzie, Coughlan, & Cresswell, 2002), soil aeration, and water infiltration.

There are several factors that can lead to soil compaction and an increase in bulk density. At the surface, compaction can result from raindrop impact. The resulting crust may possibly impede seed germination. Having plant litter on the surface of the soil can help alleviate this. The majority of compaction is a result from animal foot traffic and traffic from farm machinery. Compaction has been compounded by the increase of agricultural equipment. According to the University of Minnesota Extension (Dejong-Hughes, Moncrief, Voorhees, & Swan, n.d.) tire traffic that is less than five tons per axle on dry soil typically compacts the soil less than twelve inches, whereas axle weight that exceeds ten tons per axle in wet soil can result in compaction that exceeds two feet in depth. Compaction of surface horizons can be addressed by various means of tillage, which loosens and aerates the soil. Ironically, tillage also can cause compaction itself. Below the zone where the tillage implement penetrates, a “tillage pan” or “plow pan” can form, especially when tillage depths are not varied. This subsoil pan has higher bulk density and lower porosity than the area above or below. These deep compaction zones are often difficult to fix. Biological countermeasures to tillage pans and deep soil compaction include introducing deep rooting plants in crop rotations, along with strategies for enhancing earthworm populations (Yvan et al., 2012).

Aggregates. An additional physical soil property is aggregate formation. 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 (Lynch & Bragg, 1985). Aggregates also can form from the casts of earthworms (Bossuyt, Six, & Hedrix, 2005). 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 (Six, Elliot, & Paustian, 2000). 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. Ding and Zhang (2016) determined that soils of various types with high percentages of aggregates were 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 physical and chemical forces. Slaking can occur, where upon rapid wetting, the aggregates cannot withstand the forces of sudden water uptake causing the soil aggregate to fall apart (Arias, Gonzlez-Prez, Gonzlez-Vila, & Ball, 2005). This can result in erosion of soils, or the sealing of the soil surface. 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 (Kemper & Rosenau, 1986).

Healthy soils need to have physical health. They need to have pore space allowing for infiltration and storage of water and air. They also need to resist the physical forces of wind and water, as well as having a stable physical structure (tilth) that allows for plant growth. In the following section I will discuss the chemical health of soils

Chemical Health of Soils

All living things are made of the same basic elements. I teach the CHNOPS acronym in my sophomore biology classes to teach the students the basic elements that make up most biological molecules through covalent bonding. Carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur are the main players, with other micronutrients being biologically important, but are found in much smaller quantities in living things. Most of the matter we eat, along with other consumers in terrestrial environments, can be traced back to plants. With the exception of carbon and oxygen (found in CO_2), the majority of the elements that plants use for catabolic reactions comes from the soil. Understanding how soil chemicals interact and how they are used by plants is essential when considering the health of the soil.

pH. Acid and bases are usually introduced to science students at a fairly young age. Acids have a pH below 7 while bases have a pH above 7. The pH scale measures from 0 to 14 the amount of hydrogen ions (H+) in solution in a logarithmic scale. Most plants grow best in soils with a pH between 6 and 7 (USDA NRCS Soil Quality Information Sheet, 2008). The reason that plants grow best is the availability of nutrients changes as the pH of the soil changes. Some nutrients like nitrogen (N), sulfur (S), and potassium (K) are available in fairly wide pH range and are not affected as much as nutrients such as P. At high pH values, hydrogen phosphate ions (HPO_4^{2-}) react with magnesium (Mg^{2+}) and calcium (Ca^{2+}) ions making P less soluble for plant uptake (Jensen, 2010) . In a similar fashion, P is also becomes less soluble when soils are acidic. Under these conditions, dihydrogen phosphate ions ($H_2PO_4^-$) react with iron (Fe) or aluminium (Al), (Jensen, 2010). Other micronutrients tend to become more available in the slightly acidic range as well. When soils become acidic, Al, the most abundant metal in Earth's crust becomes soluble as an ion. In this form, Al^{3+} is toxic to plants impeding root development, along with many other adverse effects to plants (Yang et al., 2015).

Soil pH is a natural characteristic based on the parent material, climate, as well as dominant plant types. Soils that have more clay and organic matter tend to buffer against pH changes by absorbing and releasing H+. Application of ammonia (NH_3) based fertilizers, removal of crops and crop residues from fields as well as leaching can remove bases from fields, in turn acidifying soils (Sawyer, 2002). Other than managing for more organic matter to better buffer the soils, farmers have other ways to address pH problems. One would be reduce ammonia (NH_3) based fertilizer applications. When NH_3 is converted to nitrites (NO_2^-) by soil microbes, hydrogen ions are released, in turn making the soil more acidic with successive applications (Zhao, Cai & Xu, 2007). Another common practice that can neutralize acidic soil conditions in a relatively short period of time is "liming". Liming is adding materials high in calcium (Ca) or magnesium (Mg) to the soil (Tumusiime, Brorsen, Biermacher & Mosali, 2010).

Cation exchange. The reason that some soils can buffer their pH better than other is their cation exchange capacity (CEC). Cations are positively charged atoms or molecules. The CEC is the capacity of the soil's negatively charged particles (anions) to bind and exchange the cations (Hazelton & Murphy, 2016). Typically soils high in clay and/or soil organic matter (SOM) have a higher CEC. Soil with high CEC accept H+, buffering them against acidification. Ca^{2+}, Mg^{2+}, and K^+ are three of the most common cations found in soil, and are important nutrients from plants. Cations from the soil can replace those lost by leaching and root uptake (Mengel, n.d.). So soils with high CEC are typically fertile, allowing nutrients to be stored in the soil efficiently for plant uptake. Anthropomorphic acidification results in the decrease in soil CEC because of the interference of H^+ (Hazelton & Murphy, 2016).

A buildup of ions in the soil can cause salinization. Salts, which are combinations of cations and anions, are naturally found in groundwater and in parent material in varying amounts. Levels of salts in the soil can increase for many reasons (Rengasamy, 2006). One cause can be decreased drainage, resulting in less leaching of salts, allowing them to build up. Seasonal wet periods or changes in the landscape that bring up the water table may allow salts to be drawn into the A and B horizons by capillary action.

Also, irrigation can bring salts from groundwater up to the surface leading to salinization (Rengsamy, 2006). The soluble salts in the soil can result in osmotic imbalances, interfering with water uptake of plants (Seelig, 2000). This can lead to reduced plant growth, lower yields and even total crop failure (Crescimanno & Marcum, 2009). Secondary salinization (salinization caused by human activity) has lead to 25 million hectares of land to become desertified (Pla, 1996), greatly reducing the amount of arable land worldwide available to feed the world's growing population. Salinized soils can often be seen as a white crust when dry. Specifically, if the salt ion in the soil is sodium (Na^+), the soils can become sodic. Sodic soils are where over 15% of the attachment sites on clay particles are occupied by Na^+ (Seelig, 2000). When this occurs, the clay particles fail to stick together to form stable aggregates, resulting in poor soil structure. In sodic soils impermeable surface crusts and upper horizon claypans can form from the dispersed clay particles (Dongli et al., 2015). These layers impede root penetration, seed germination, water absorption, and aeration (Wang et al., 2002).

Carbon. 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 (Hamkalo & Bedernichek, 2014). Soils store approximately 2500 billion metric tons of carbon (Ontl & Schulte, 2012). With atmospheric carbon dioxide being one of the major greenhouse gases, sequestering carbon from the atmosphere obviously has important implications in regards to the Earth's climate. According to Lal (2004), changes in land use practices have accounted for one third of the post industrial revolution anthropogenic increase in atmospheric carbon dioxide. 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 (Yiqi, 2010). 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 (Ontl & Schulte, 2012). 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 (Ontl & Schulte, 2012).

Nutrients. Three of the most important elements in the soil that are the main limiting factors for plant growth are potassium (K), phosphorus (P), and nitrogen (N). As plant biomass is harvested in cropping systems, these nutrients can become depleted in the soil limiting plant growth and crop yield. As a result K, P, and N are the main nutrients added by fertilization. Correlating with the green revolution and the industrialization of agriculture, came the application of artificial fertilizers to increase crop yields. The role of K in indirect, meaning that is is not used to make any plant tissue. Instead, K is used to make a wide range of enzymes that are used for metabolic functions including ATP production, cellular membrane transport proteins, osmotic balance, stomatal regulation, among many others (Busman et al., 2002). As a result, K is an essential element that plants need to get from the soil. The source of artificial K is usually potash. K from potash application does not have significant negative environmental consequences (Busman et al., 2002). Therefore, excess K is mainly of concern to farmers losing money from over-fertilizing, not the environment.

Phosphorus. 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 (Shulte & Kelling, 1996). The soluble P quickly reacts with chemicals in the soil and again becomes insoluble, binding to soil particles. Because of this, leaching of P typically is only a problem when P reaches its saturation point (Hyland et al., 2005). 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 (Busman et al., 2002). 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 (Zarageta & Acebes, 2017). 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 (Hyland et al., 2005). This reduces P loss through erosion and leaching.

Nitrogen. The most widely used fertilizer is nitrogen (N). N 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 (Lamb, Fernandez & Kaiser, 2014). As described before, 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 (Jennings, n.d.). The NH_3 has to be converted to nitrites (NO_2^-), then into nitrates (NO_3^-) before it can be assimilated into plants (Brown & Johnson, 2015). This process is called nitrification, and is carried out by separate bacteria than the N fixation process. Nitrates can then be absorbed by plants. Forms of N in the soil can be lost by runoff, leaching, volatilization, denitrification, and crop removal (Lamb, Fernandez & Kaiser, 2014). 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 of waterlogged soils (Brown & Johnson, 2015). 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 (Geng, Girard & Ledoux, 1996). 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 (Knobeloch, Salna, Hogan, Postle & Anderson, 2000). Runoff of N can lead to eutrophication of bodies of water, although P is usually the nutrient that limits algal growth.

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 (Space Daily, 2013). This also leads to more N lost through leaching and runoff leading to environmental problems. Addressing N requirements 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 (Lamb, Fernandez & Kaiser, 2014). 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.

Balance. One element that is essential for plant growth but does not come directly from the soil is carbon (C). Carbon is fixed into organic material during the process of photosynthesis. Surprisingly C in the soil is very important for plants, just not directly. C in organic matter feeds soil microbes, while nitrogen (N) is an essential element for protein production. Healthy soil should have a ratio of C:N of about 20:1 (Haney et al., 2012). Microbes need about 20 atoms of C for every 1 atom of N. At that ratio, the microbes have the proper amount of fuel, and molecular building materials. When the C:N ratio exceeds 20:1, N is immobilized by the microbes and not made available for plant use (Lewandowski, 2002). For example wheat straw (C:N ratio 80:1) and corn stalks (C:N ratio 60:1) make good ground cover to prevent erosion in reduced tillage or no till systems (Lewandowski, 2002). Microbes can use their abundant C as a fuel source, but must scavenge N from the soil, tying it up in the microbes themselves. Conversely legumes, hairy vetch, and animal manure are biomasses with C:N ratios lower than 20:1 (Lewandowski, 2002). They typically decompose quickly, providing little ground cover, but quickly free up N for plant use. One drawback is that low C:N ratios can result in rapid mineralization of N, leading to leaching of nitrates when N deposition is high (Dise, Matzner & Forsius, 1998). For that reason, C:N ratios should be considered when assessing soil health and soil fertility.

Both N and P can cause environmental harm when in excess. They are also one of the most significant expenses farmers have as a result of fertilization. By evaluating soil health, both N and P inputs can be significantly reduced. Rick Haney, soil scientist for the USDA and leading expert on soil health, explains how (R. Haney, personal communication, September 19, 2017). First, total P is measured in the soil, from that amount the inorganic P is subtracted to estimate the amount of organic P. The same is done with N. If the microbial activity is high enough relative to the organic C, then the N & P are expected to be plant available. This ties back into the biological health that was mentioned earlier in the chapter. The microbial activity can be determined by a standardized procedure that measures the CO_2 released after a soil sample is dried and then rewetted (Haney, Brinton & Evans, 2008). If the CO_2 levels are higher, there is more microbial activity, which leads to more potential mineralization of N and P. So managing soil for more biological diversity not only is important ecologically, but is also important economically.

Putting it all Together.

Improving soil health really comes down to a few things: Disturbing the soil less, keeping the soil covered, keeping the nutrients in balance, and feeding the organisms of the soil. Disturbing the soil typically happens with tillage or with compaction from heavy equipment. Tillage is typically done to control weeds, aerate and warm the soil, and prepare a seedbed. As mentioned earlier in the chapter, tillage pans, erosion, and soil aggregate loss happen as a result of tillage. In addition to those effects, tillage also supplies oxygen to the soil quickly which can cause a spike in microbial activity. This spike results in the consumption of soil organic matter by the microbes. Organic matter is one of the most important indicators of healthy, fertile soil. Ann Lewandowski, a University of Minnesota Extension agent, uses an interesting analogy when discussing organic matter and tillage:

> Another way to think of soil is like a giant wood stove. You continually add organic matter (wood), and it burns to release energy and nutrients that will be used by plants and microorganisms. Ideally, you want a slow, steady burn that releases nutrients to plants as needed. Intensive tillage aerates the soil and is like

> opening the flue or fanning the flames. Decomposition is desirable because it releases nutrients and feeds soil organisms. But if decomposition is faster than the rate at which organic matter is added, soil organic matter levels will decrease. (2002)

In addition to reduced tillage, using a diverse crop rotation and/or the use of cover crops help keep the soil protected from wind and water erosion, keeps nutrients in balance, and feeds the organisms in the soil. Cover crops are crops that are planted to provide soil cover after the primary crop is harvested. Often the cover crop is planted after harvest, or sometimes it can be interseeded into the growing primary crop (Noland, Little, and Wells, 2016). Jason Schley, soil health agronomist, explains that specific cover crop species can address specific soil health concerns. Grains such as cereal rye are relatively inexpensive and provide protection against wind and water erosion. Legumes such as hairy vetch fix atmospheric nitrogen that can be mineralized when the plant decomposes. Brassica species such as turnips and radishes can be used for tillage to break up pans and allow for better water penetration (J. Schley, personal communication, September 26, 2017). Additionally, cover crop “cocktails” can be formulated to address multiple soil issues. Baggs, Watson & Rees (2000) explain that cover crops act as “green manure” taking in N from the soil in the winter (non-growing season) and releasing during the next growing season as the cover crop decomposes. This limits N loss through leaching, denitrification, and volatilization.

The use of cover crops has increased in popularity. Cover Crop Survey Analysis done by Sustainable Agriculture Research & Education (2016) found a doubling of acreage of land protected by cover crops in the last five years alone. 33.7% of survey respondents reported that cover crops increased profitability of their farms, whereas only 5.7% saw a decrease. Even though no-till farming and cover crop usage have been increasing, the majority of farmers have not yet adopted their use. Snapp and colleagues (2005) suggest that tax credits and/or reduction in federal crop insurance premiums could help persuade more farmers to employ the practices that help protect soils. Since the benefits of adopting these practices extend well beyond the farm, there is a strong argument for significant support for them from the government including financial incentives. Because adopting practices that focus on soil health often require fundamental shift in how farms are managed, education is essential to environmental and agricultural sustainability.

The United States Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS) is the federal government agency that is responsible for soil education. In addition to the NRCS, agricultural extension services also play important roles in soil education. Most education programs focus on farmers. Doran and Safley (1997) of the NRCS suggest that sustainability and soil health education should focus on two things: 1. Developing soil health standards with cooperation between national agencies, local agencies, and farming interest groups. 2. Development of tools and standardized practices for on-site assessment of soil health by farmers, extension services, agronomists, conservationists, and environmental monitoring agencies. The NRCS, extension services, as well as other organizations such as the Soil Science Society of America have soil curricula that is directed towards school age children. These lessons can be useful in teaching basic soil concepts to middle school and high school students. Of equal importance to the scientific concepts being taught are how the lessons are framed. Pool and O'Connor (2000) state that emotions and beliefs are more important than knowledge in shaping environmental attitudes. So incorporating emotions and beliefs into the curriculum should be a focus of environmental sustainability educational programs.

Summary

Sustainability of plant, animal, and human life relies on the capacity of soil to function as a living ecosystem. Understanding the complex interactions between the abiotic chemical and physical components of the soil with the biotic components will help maintain and restore this vital resource for future generations. Changing the attitudes farmers, students, and the general public have towards soil will be key to changing land use practices that have lead to significant losses to soil health since the industrial revolution. Developing and implementing soil health curricula in middle and high schools is an important part in making a shift in attitudes towards soil. In the next chapter I will present a description of the project that I developed to help address this issue of sustainability in the rural school district where I teach.

CHAPTER THREE

Project Description

Introduction and Project Overview

"Can creating an activity guide on soil health improve environmental awareness and foster agricultural sustainability"? In this chapter I will give an overview of how I will be putting soil health curriculum together to address this question. I will identify the standards that soil health lessons best fit. The intended audience and setting will be identified. Lastly, the project will be described, giving a timeline to be implemented.

Setting and Audience

The intended audience of this curriculum is middle and high school science students in Osakis Public Schools in west central Minnesota. Class sizes range between 20-26 students. Parts of the curriculum would be incorporated into the classes I teach (sophomore biology & seventh grade life science). The curriculum will be shared with an earth science teacher who has been in education for 12 years. The lessons will be also be shared with a first year agriculture teacher, who teaches a horticulture class during the spring semester. This teacher has expressed interest in adding lessons on soil and soil health to her curriculum. This may be an opportunity to influence her in a positive way, like I was influenced at the beginning of my career by more experienced teachers. Additionally, this activity guide may be made available to teachers in other school districts, as well as educators in non-traditional settings.

This soil health curriculum is not intended to be used as a “stand-alone” unit in any one class in Osakis Public Schools. It would be refreshing to be able to teach a course on soils, or agricultural sustainability. Instead, most of our science courses focus on covering standards that will be tested by the Minnesota Comprehensive Assessment. In accordance with Minnesota statutes, “State tests must be constructed and aligned with state academic standards” (Minnesota Statutes, section 120B.030). Pressure from the administration, teachers themselves, as well as from the community to have students perform well on these tests has lead to a narrowing of the curriculum in order to follow state standards. The Minnesota standards do have areas for partial implementation of these lessons, but may not allow for full implementation of them into a unit because of time constraints. Full implementation would require an elective course offering.

Frameworks - Connection to Standards

I do see opportunities for lessons on soil health as a part of individual units that already exist in my classes. The Minnesota Academic Standards (MN Department of Education, 2009) provides a framework for what benchmarks are met at each grade level across the state. Grade 7 strand is Life Science, one of the classes I teach. The substrand in which soil health lessons would fit best is *Substrand 2. Interdependence Among Living Systems*. Within that substrand, there are two standards, as well as different benchmarks within those standards, that soil health lessons would fit into for the seventh grade life science and sophomore biology classes that I teach.

Grad e	Strand	Substrand	Standard "Understand that ...	Code	Benchmark
7	4. Life Science	2. Interdependence Among Living Systems	1. Natural systems include a variety of organisms that interact with one another in several ways.	7.4.2.1.1	Identify a variety of populations and communities in an ecosystem and describe the relationships among the populations and communities in a stable ecosystem.
7	4. Life Science	2. Interdependence Among Living Systems	1. Natural systems include a variety of organisms that interact with one another in several ways.	7.4.2.1.2	Compare and contrast the roles of organisms within the following relationships: predator/prey, parasite/host, and producer/consumer/decomposer.
7	4. Life Science	2. Interdependence Among Living Systems	1. Natural systems include a variety of organisms that interact with one another in several ways.	7.4.2.1.3	Explain how the number of populations an ecosystem can support depends on the biotic resources available as well as abiotic factors such as amount of light and water, temperature range and soil composition.
7	4. Life Science	2. Interdependence Among Living Systems	2. The flow of energy and the recycling of matter are essential to a stable ecosystem.	7.4.2.2.1	Recognize that producers use the energy from sunlight to make sugars from carbon dioxide and water through a process called photosynthesis. This food can be used immediately, stored for later use, or used by other organisms.
7	4. Life Science	2. Interdependence Among Living Systems	2. The flow of energy and the recycling of matter are essential to a stable ecosystem.	7.4.2.2.2	Describe the roles and relationships among producers, consumers, and decomposers in changing energy from one form to another in a food web within an ecosystem.

7	4. Life Science	2. Interdependence Among Living Systems	2. The flow of energy and the recycling of matter are essential to a stable ecosystem.	7.4.2.2.3	Explain that the total amount of matter in an ecosystem remains the same as it is transferred between organisms and their physical environment, even though its form and location change. For example:Construct a food web to trace the flow of matter in an ecosystem.
9-12	4. Life Science	4. Human Interactions with Living Systems	1. Human activity has consequences on living organisms and ecosystems.	9.4.4.1.1	Describe the social, economic, and ecological risks and benefits of biotechnology in agriculture and medicine. For example:Selective breeding, genetic engineering, and antibiotic development and use.
9-12	4. Life Science	4. Human Interactions with Living Systems	1. Human activity has consequences on living organisms and ecosystems.	9.4.4.1.2	Describe the social, economic and ecological risks and benefits of changing a natural ecosystem as a result of human activity. For example:Changing the temperature or composition of water, air or soil; altering the populations and communities, developing artificial ecosystems; or changing the use of land or water.
9-12	4. Life Science	4. Human Interactions with Living Systems	2. Personal and community health can be affected by the environment, body functions and human behavior.	9.4.4.2.4	Explain how environmental factors and personal decisions, such as water quality, air quality and smoking affect personal and community health.

The Minnesota science standards were revised in 2009 and implemented in 2010-2011. The standards are scheduled for another revision in 2018-2019. Even though Minnesota hasn't adopted Next Generation Science Standards (NGSS), it is likely that

Minnesota will implement standards that incorporate STEM (science, technology, engineering, and mathematics) that may resemble NGSS. NGSS has three dimensions (Pratt, 2013): 1. Scientific and engineering practices. 2. Cross-cutting concepts. 3. Disciplinary core ideas. The following scientific and engineering practices as identified by *A Framework for K-12 Science Education* (Pratt, 2013) will be incorporated in the soil health activity guide:

- Asking questions and defining problems
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics, information and computer technology, and computational thinking
- Constructing explanations and designing solutions
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

Cross-cutting as presented by *Frameworks* is when different domains of science are linked together. The cross-cutting concepts are similar to unifying concepts, or concepts that extend beyond one specific discipline or topic. Soil health curricula, by its nature, draws together differing themes in science. Listed below are the different cross-cutting themes (Pratt, 2013) that will be incorporated into the soil health activity guide:

- Patterns
- Cause and effect: mechanism and explanation

- Scale, proportion, and quantity
- Systems, and system models
- Energy and matter: flows, cycles, and conservation
- Structure and function
- Stability and change

The specific disciplinary core ideas from the *Frameworks* that will be addressed in the soil health activity guide are the following:

- ESS2.A Earth materials and systems
- ESS3.A Natural resources
- ESS3.C Human impacts on Earth systems
- ESS3.D Global climate change
- LS1.C Organization for matter and energy flow in organisms
- LS2.A Interdependent relationships in ecosystems
- LS2.B Cycles of matter and energy transfer in ecosystems
- LS2.C Ecosystem dynamics, functioning, and resilience
- LS4.D Biodiversity and humans

Project Description

For this project, I will be creating ten lessons on soil health that will be put together in an activity guide. The activity guide will be titled "Soil Health - Black is the New Green". Three of the lessons will be focused on the biological health of soils, three on chemical health, and four on physical health. Many of the activities will cross-cut concepts and link together the biological, chemical, and physical components of the soil. The activity guide will help students understand the connection between healthy soils and environmental and agricultural sustainability. The activities will be engaging and include games, models, and laboratory experiments. Using the literature review as evidence, this format will be effective, as it uses active learning to allow students to develop their own conclusions about complex sustainability issues.

The three activities focusing on biological health are called “Berlese Biodiversity”, “Food Fight”, and “Microbe Mania”. “Berlese Biodiversity” will focus on the biodiversity of invertebrate life in healthy soils. In the activity, students will sample soils, identify soil invertebrates in the samples, and compare the number of types of organisms in different soil samples. In “Food Fight” students will take the roles of various soil organisms of various niches. Students then make a class soil food web by passing around balls of yarn. During the activity “Microbe Mania”, students determine the biological activity of soil microbes by measuring the carbon dioxide released during a 24 hour period.

The soil chemical health lessons will focus on the cycling of the nutrients through the ecosystem between living and nonliving things. “Carbon Crusade” is a lesson that follows carbon as through the ecosystem, “Nitrogen Knock Around” follows nitrogen, while the lesson “Phollowing Phosphorus” shows how phosphorus is used and transferred within the environment. These lessons all have a similar format. They use dice to show the many ways in which elements cycle, and the importance of soils in those cycles.

The other four lessons will focus on the living soils' physical properties. "Soil Snack" is an activity where the students will use food to make a model of a soil profile to learn about the structure of the soil. In the activity "Slaking Sleuths", students measure the stability of soil aggregates and learn about the relationship between the biota of the soil and its physical properties. In "Cover Crop Capture", students simulate how cover crops reduce nutrient leaching and runoff. Lastly, in the activity "Buffer Blitz", students play tag to simulate how riparian buffer strips reduce runoff of nutrients into water bodies.

Implementation

The finished activity guide will be available in both print and electronic forms. The guide will be shared with upper elementary, middle school, and high school science teachers as well as agriculture teachers in our school districts. They will have the opportunity to incorporate the lessons "a la carte" into their curriculum to supplement what they are already teaching. Over time I hope to add new lessons to the activity guide and expand the reach beyond our school.

Summary

The soil health activity guide that I have created will be implemented as described above with myself and other teachers in our school. Aligning the lessons with standards will better help teachers place lessons into their curriculum appropriately. In the next chapter, I will describe how I also plan on expanding the reach of the activity guide beyond my school. I will also reflect on how I have been inspired by and what I have learned from the capstone project process.

CHAPTER FOUR

Conclusion

Introduction

In this chapter I will discuss what I have learned in the journey of completing my capstone project. I will reflect upon what brought me to this point. I will then discuss what has influenced me during the process. There will be a description of what I have learned by developing the soil health activity guide, and by reviewing literature on soil science and environmental education activity guides. I will also describe what I plan on doing going forward with my capstone project and how I could potentially expand the reach of those impacted by the soil health activity guide. Lastly, I will wrap things up by discussing conclusions about my capstone question "Can creating an activity guide on soil health improve environmental awareness and foster agricultural sustainability?"

Getting Here

When I first started the Master of Arts in Education: Natural Science and Environmental Education program almost ten years ago, I didn't picture my path taking me to this point. I enjoyed the required and elective coursework as I progressed through the program. As I neared the end of the program, my focus on finishing it started to wane. My wife and I were having our second child and coaching two sports along with teaching left me with little time to commit to starting the capstone process. I also did not have one topic that I felt passionate enough about that I could justify giving up the time that I knew would be necessary to complete the capstone.

Fast forward almost seven years, and I finally had the two things that I didn't have almost a decade prior: time and passion. My three children were now old enough to entertain themselves and each other. This allowed me to not feel guilty about spending hours at the computer researching and writing for the capstone project. More importantly, I found a new passion about a topic that I felt needed to be addressed in formal and informal educational venues. That topic is soil health. As I mentioned in Chapter 1, my interest in soil health started with an opportunity to help my brother-in-law start a unique soil testing lab.

The soil lab I helped him create was focused on expanding upon the conventional soil tests that are traditionally offered to producers. Traditional soil tests focus primarily on measuring soil nutrients, and then using that analysis to determine inputs required to meet yield goals. The main focus was on inputs, yield, and short-term profitability. All of those things are important, but one crucial component was missing, the health of the soil. Without healthy soil, the traditional agricultural model is not sustainable. Maintaining the profitability of agriculture and the well-being of the environment requires equal focus on the health of the soil in addition to the inputs and outputs from it. The soil health lab, now called Next Level Ag, is committed to helping growers measure, analyze, and make recommendations in regards to the health of soils. Being a part of this upstart company helped me see the scale of the potential benefit to the agricultural community as well as all the environmental benefits that could result from healthy soils. Education of farmers and agronomists is obviously very important in making systemic change in agricultural practices. It follows that teaching primary and secondary students about the importance of healthy soils sets a good foundation for the future.

For some time, I contemplated doing a capstone thesis that focused on testing the soil itself, trying to expand the knowledge base on soil health. I then pondered developing a capstone project directed towards educating farmers about soil health. That idea would be useful if I would decide to leave secondary education, which has been a consideration since working at the soil lab. My decision was to develop an activity guide to use in formal and informal middle and high school settings that enabled me to find a confluence of my many passions. Those passions include environmental education, active learning, and soil science. In the next section, I will describe what I have learned as a researcher, learner, and teacher in developing my capstone project.

What I Have Learned

I learned in the process of this capstone project is that it's not about reaching the summit, it's the climb up the mountain that really matters. What I mean by that is that the process of developing the capstone project is going to be more valuable to me than the completed project itself. In this section I will highlight what I learned when I reviewed literature for the capstone project.

The most valuable part of reviewing the literature was expanding on my own personal knowledge of soils. Soil science is relatively new to me. Most of what I knew was a result of being a self-taught learner when asked to aide in the starting of Next Level Ag a few years ago. I had enough knowledge of soils from my undergraduate education to be able to work my way through scientific scholarly journals to deepen my understanding of narrowed topics that focused on detailed aspects of soil health. Not only did I increase my depth of understanding of soil science, I also increased the breadth of my knowledge of the biological, chemical, and physical aspects of soil science as well. I have always enjoyed learning, especially about scientific topics that I feel are important. Even though I may not use everything that I learned in my classroom, I feel I now am more knowledgeable in many aspects of soil science.

I also learned a lot about teaching sustainability. The literature is clear on effective methods of teaching students environmental and sustainability topics. As an instructor, one cannot oversimplify sustainability issues (Sund, 2013). Instead, teachers have to enable students to develop their own conclusions based on experiential learning. Active learning (experiential learning) is also a prefered method over traditional lectures for increasing students knowledge, instilling pro-environmental attitudes and behaviors (Chi & Wylie 2014) (Corscadden & Kevany, 2017) (Dunlosky et. al, 2013) (Freeman et. al, 2013) (Kolb, 1984). Curriculum delivery needs to be student focused instead of teacher focused. Additionally, fostering place attachment (sense of place) in students also needs to be implemented in sustainability education (Efird, 2015) (Zelenski et. al, 2015). The activity guides (*Project WILD*, *Project Learning Tree* & *Project WET*) that I modeled mine after meet those criteria. They build a student's sense of place, address complex sustainability issues, and do so using experiential learning.

After reflecting on what I have learned, I am more confident now than I was before I started the project that my soil health activity guide will be effective in teaching students about agricultural and environmental sustainability. In the next section, I will describe who and what inspired me along during the capstone process.

Inspiration

I am also inspired by learning from the leading soil health scientists that are very active in the soil science and agronomy communities. Four of these scientists really stick out to me as being part of my “Mount Rushmore” of soil health scientists. They are Rick Haney, Ray Archuleta, Will Brinton, and Jason Schley. These people have not only taught me and others much about the science of healthy soils, they have inspired change in traditional approaches to soils and agriculture. Unlike many scientist that are content to work in their labs, they use their expertise to proselytize what they think could revolutionize agriculture. Rick Haney and Ray Archuleta both work for the United States Department of Agriculture (USDA). Archuleta, also known as “Ray the Soil Guy”, is known for his slake test demonstration that shows the benefits of reducing tillage to keep the soil healthy and intact. Haney, with many published articles, emphasizes the importance of mimicking nature when testing and managing soils. He believes by doing so farmers can save money as well as reduce fertilizer lost to the environment that causes ecological damage. Haney was even kind enough to respond to my emails to answer questions about carbon to nitrogen ratios in the soil. Will Brinton of Woods End

Laboratories and the University of Maine developed a method for determining the soil health by determining the microbial activity, hidden nutrients, and the aggregate stability of soils. These methods are the standard tests done in soil health labs that go beyond the traditional chemistry tests. Lastly, Jason Schley, owner of Next Level Ag, has been a big influence on me. Schley had the courage to take a risk to start up a commercial soil health lab that is a paradigm shift from traditional soil testing labs. His commitment and passion for soil health has been inspiring. From these four scientists, the research I did branched out like spokes on a wheel from their knowledge base.

I have been familiar with environmental education activity guides for almost twenty years. After I started to use *Project WILD* lessons in my Life Science classroom as a new teacher, I was drawn to the lessons' ease of use and accessibility. That is something that I wanted to incorporate into my soil health activity guide. While doing research, I was able to compare the lessons and lesson format from different eras of *Project WILD* publications. *Project WILD* evolved in both the format and content of the lessons. Along with *Project WILD*, the lesson format and content of other environmental education activity guides like *Project Learning Tree*, *Project WET*, and *Gray Wolves*, *Gray Matter,* also were major influences in developing my soil health activity guide.

A person cannot attain goals without having inspiration. The work of people before me is invaluable to what I have learned and how I have been inspired. Like Isaac Newton said, "If I have seen further than others, it is by standing upon the shoulders of giants." In the following section, I will describe how I will use the knowledge and inspiration I have gained going forward.

Going Forward

So far I have used two of the lessons in my classroom that I have developed with the soil health activity guide. The two activities were on the cycling of nutrients in ecosystems. They were used to supplement a seventh grade Life Science Ecology unit on energy flow and matter cycles. The activities were titled "Carbon Crusade" and "Nitrogen Knock Around". Both lessons involved students rolling dice to follow how carbon and nitrogen cycle through ecosystems. Students enjoyed being able to move around the classroom and experiencing first hand how the cycles work. The students seemed to better understand abstract concepts such as nitrogen fixation, mineralization, and immobilization. They were also able to understand that elements cycling through ecosystems can take different forms, can have different properties, can be available for plant and animal use, and can have the potential to cause environmental harm. Those two activities successfully enhanced my teaching and the students' learning. Going forward I plan on continuing to incorporate activities into my own curriculum, as well as share the activity guide with other science and agriculture teachers in our school district.

As I worked on the activity guide, I began to think about the reach that I potentially could have with this activity guide. Inspired by how many people have been impacted by the soil scientists I mentioned earlier, I realize there is a need for a similar outreach to the students across the country. Additionally inspiring is the number of students and teachers that have used environmental education activity guides and the impact they have had in shaping knowledge and attitudes. Project WILD has reached over an estimated 53 million students (Council for Environmental Education, 2007). If only a fraction of that number were reached by this type of soil education through active learning, it would be monumental.

Once I step back from this capstone project upon completion, there are two things that I would like to eventually do. One is to expand upon the soil health lessons that I have compiled so far. In expanding the lessons, I think it would be important to expand the disciplines covered in the lessons beyond science and agriculture to include political science, civics, history, art, and reading as well as possibly others. The cross-linking of disciplines could make connections that go far beyond understanding scientific concepts. The second thing I'd like to do is get the expanded soil health activity guide into the hands of as many teachers and students across the country as possible. There are a few possible ways of achieving those goals. One possibility is promoting a non-profit organization to take the lead in promoting the activity guide. *Project Learning Tree* was supported by the American Forest Foundation (American Forest Foundation, 2010), and *Project WILD* originated from the Western Regional Environmental Education Council (Council for Environmental Education, 2007). Both of those organizations used writing workshops that included hundreds of educators and scientists to create, critique, and pilot the lessons. Partnering with a larger organization may allow for funding of things like teacher outreach. *Project WILD* has reached over 1,000,000 educators through workshops (Council for Environmental Education, 2007), while *Project Learning Tree* has had 500,000 (American Forest Foundation, 2010). Both organizations believe in educating teachers at workshops instead of simply supplying them with the activity guides without being taught how to use them effectively.

One possible partner would be the Soil Science Society of America. They already have a limited number number of lessons on their website and are involved in teacher education. They have partnered with the USDA-NRCS for some lesson development. Other potential partners may include student groups such as the Future Farmers of America, farmer organizations such as National Farm Union, or environmental education organizations like North American Association for Environmental Education. Partnering with an organization may possibly provide the necessary funds and expertise to get this type of activity guide published and distributed, and become a network for teacher education.

Summary

Upon completion of the capstone project, I conclude that a soil health activity guide can be an effective way of improving environmental awareness and fostering agricultural sustainability. The evidence is clear that active learning is an effective way of motivating students, comprehending concepts, and making connections with other ideas. Environmental education activity guides have been a proven method of delivering material to teachers in a format that is easy to use with their students. Lastly, there is ample evidence that healthy soils are crucial for the long term stability of agricultural systems, as well as a vital part of healthy ecosystems. I hope the soil health activity guide that I have developed will be a tool for myself as well as others for teaching students about the importance of soils.

APPENDIX A

Soil Health Activity Guide

Soil Health Activity Guide

BLACK Is The New GREEN

Developed By:
Lee VanNyhuis

Developed for a Capstone Project

Masters of Arts in Education

Natural Science and Environmental Education

Hamline University

December, 2017

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

APPENDIX B

Standards Alignment

	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				

APPENDIX C

Student Handouts

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		
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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.

Food Fight

(Soil Food Web)

Name:___________________________

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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.

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)		

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

Soil Quality Curve

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		
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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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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

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Assessment Questions:

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

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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.

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.

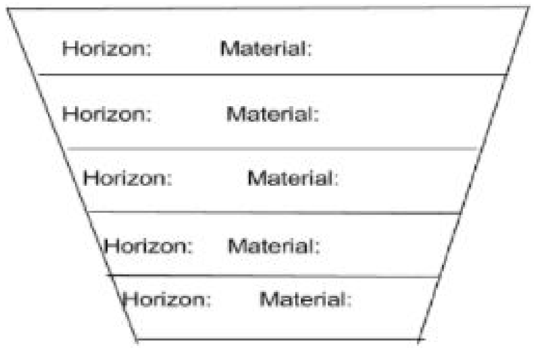
2. Was there a significant difference in the stability class of the aggregates in the soils for the contrasting management practices? Explain the possible reasons for the difference or similarity in the two samples.

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.

APPENDIX D

Soil Nutrient Cycle Teacher Printables

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**)

Carbon Cycle

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	Volatilization 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 defecates. 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.

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**.

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