Soil: More than the Dirt under your Feet!

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Abstract

People all over the world see soil, walk on soil, and grow things in soil every day, but the vast majority of people never recognize how important soil is in sustaining life on Earth. Most people likely view soil as "just dirt," something that they would usually avoid coming into contact with and normally don't think much about. In reality, soil is a highly complex, relatively thin layer of generally loose mineral and/or organic material at the Earth's surface which supports biological activity, acts as a medium for plant growth, and performs many other critical functions. Soil is essential to all life on Earth because it performs crucial functions such as water purification and nutrient cycling, providing a habitat for living organisms, and sustaining the growth of plants that are used to produce food, clothing, and energy. This article presents background information linked to teaching resources that can be used to introduce K-12 students to many of the critical functions of soils. These materials were shared with teachers during a Geophysical Information for Teachers (GIFT) workshop at the annual meeting of the American Geophysical Union (AGU) in 2018.

Soil is the foundation for all terrestrial ecosystems, and because it is always underfoot, it is almost always overlooked, and too often underappreciated.

Soil Formation

Five factors interact in the formation of a soil, abbreviated as **ClORPT**: **Cl**imate, **O**rganisms, **R**elief, **P**arent Material, and **T**ime. It only takes a little bit of loose material, a little bit of water, and a seed for a plant to grow.

All soils have depth; a vertical cross-section of a soil is called a profile. These profiles develop over hundreds or thousands of years as loose mineral materials are changed through additions of various mineral and organic compounds, transportation of minerals and organic matter through the soil profile, loss of soil particles or soluble elements and compounds from the profile (from the top or out the bottom), and transformation of minerals through chemical and biological processes. Eventually, soil particles build up in certain places to create deep soil profiles that can

Figure 1. Plants grow anywhere.
Photo Credit: Clay Robinson.

support plant growth, while mineral particles are lost from other areas, leading those places to have shallows soils or, in some cases, no soil at all. When plants grow and die, plant residue is incorporated into the soil. This plant residue is broken down by microbes and becomes soil organic matter.

The kinds of plants growing in an area can make a big difference in the soil that forms (**Figure 1**). Grasses have fibrous root systems and contribute organic matter as those roots grow and die every year, resulting in very dark soils with high organic matter contents. Trees have much larger roots that do not decompose quickly, and their leaves are deposited on the soil surface where they decompose, resulting in lighter-colored soils with less organic matter. The combination of mineral particles, decomposed organic matter, and living organisms make up soil.

Soil Properties

Students can engage in several hands-on activities to measure basic soil properties (**Figure 2**) and think more deeply about how those properties influence how soils can be used and how they can support life. Many examples of activities are available online such as on the Soil Science Society of America's (SSSA) Soils 4 Teachers website (soils4teachers.org). Here, we highlight a few activities that work well as stations for small groups of students and require only basic materials to complete, thus making them accessible for all students.

Figure 2. A soil profile showing the distinct layers within it.
Photo Credit: Clay Robinson.

Soil Physical Properties

One of the most important physical attributes of soil is the soil texture, or the proportion of sand, silt and clay-sized particles. Sand grains are large and easily visible with the naked eye and feel gritty when rubbed between your fingers. Silt grains are small and not easily seen with the naked eye but feel smooth when rubbed between your fingers. Clay particles are the smallest soil particles that often feel sticky and are especially good at holding water and clumping soil together, much like the clay you use to mold a piece of pottery.

Figure 3. Jar with water used to separate soil into clay, silt, and sand to determine percentages.
Photo Credit: Clay Robinson.

Soil texture can be easily measured by separating the different particle sizes by density; when mixed with water, larger and heavier soil particles will settle to the bottom of a jar faster than lighter smaller and lighter soil particles. When soil mixed with water is allowed to settle overnight, layers of sand, silt, and clay can then be observed, measured and the proportion of each particle size calculated as follows:

1. Fill a jar 1/3 full with <2 mm ground soil. Break apart any large clumps.
2. Add water to jar until jar is 2/3 full.
3. Shake vigorously to break up all soil clumps.
4. Let jar sit overnight to settle.
5. Find the beginnings and ends of the layers in your bottle of soil that you shook yesterday (**Figure 3**).

6. Measure the thickness or height of each layer.
7. Now sum the clay, silt and sand layer thickness to determine the total thickness.
8. Divide the height of each layer by the total height and multiply by 100 to find percent. The sum of all three layers should equal 100%.

Alternatively, this video describes another method to determine soil texture using a hydrometer: youtu.be/u8Pb2g8T4-8

Soil Color

Soil color can tell us a lot about the soil and the environment in which the soil has formed. What are some typical colors of soil? Red, Brown, Yellow, Black? These colors are often not the color of the minerals in the soil but are coatings of iron oxides (Fe_20_3, FeOOH, etc) or organic matter on particles. The minerals beneath are often quartz or feldspar which are grey in color. Dark black topsoil (grasslands) indicates the presence of high organic matter content as compared to light brown topsoil (deciduous forests). The presence of gray colors in the soil is used to determine how high the water comes in the soil even when the soil is dry. Looking for gray colors related to the water table is often done when assessing the site for many land uses related both to agriculture as well as urban/suburban development. Often the gray colors are referred to as wetness mottles or redoximorphic features (formed from reduction and oxidation (redox) chemical reactions in the soil). Many land use decisions are based on these colors and the fact that they do not change season to season. Thus, in summer when water tables are deep in the soil, gray colors indicate how high the water table will rise during the wettest time of the year. The color change from red (rusty) to gray in the soil is due to reduction and oxidation of Fe. This process occurs in soil but in saturated soil this occurs when Fe^{3+} is reduced to Fe^{2+} due to a microbial mediated redox reaction.

Students can demonstrate how coatings affect soil color by using red M&Ms™ following the few simple steps below:

1. Place a few M&Ms™ in a sieve. They are still red.
2. Slowly immerse them in water and gently shake them. The water will start to turn pink as the red dye is washed off.
3. Observe the color change and remove them before the underlying white coating is dissolved.
4. Dry them. They are now white to pink.

A similar process occurs in soil. For example, in saturated soil this occurs when Fe^{3+} is reduced to Fe^{2+} due to a microbial related redox reaction.

If air (O_2) is in the soil the soil is aerobic

- $4e^- + O_2 + 4H^+ \rightarrow 2H_2O$

If all O_2 is removed, soil becomes anaerobic (saturation occurs)

- Denitrification
- $10e^- + 12H^+ + 2NO_3 \rightarrow N_2 + 6H_2O$ – no color change
- Iron (Manganese) Reduction
- $2e^- + 6H^+ + Fe_2O_3 \rightarrow 2Fe(II) + 3H_2O$ – soil turns gray
- Sulfate Reduction
- $8e^- + 10H^+ + SO_4 \rightarrow H_2S + 4H_2O$ – rotten egg odor

So why is this reaction important? It helps soil scientists identify where the water table is even when the soil is not saturated. Once the gray colors have formed from Fe^{3+} reduction and removal, it is unlikely that the particles will become coated again. Since this reaction occurs in saturated and reduced or anaerobic conditions, the presence of gray colors indicates where the water table is in that soil. This helps soil scientists identify wetland or hydric soils and locate suitable soils for septic systems and related land use. This reaction only occurs if there are enough microbes and a food source (carbon) present to cause anaerobic conditions to occur.

Soil Chemical Properties

Soil pH, or the acidity or alkalinity of the soil, and soil nutrients, such as nitrogen (N), phosphorus (P), and potassium (K), are important for nourishing plants and organisms in soils, and these properties are easily measured by students using a simple garden soil test kit. Most soils range in pH from about 3.5 to 10.5, with a more neutral pH around 7 considered optimal pH for most plants and soil organisms. Soil nutrients are naturally released through the breakdown of soil minerals and organic matter, although they are sometimes added as fertilizer to boost soil nutrition.

A soil test kit to measure nutrients and pH is inexpensive and can be purchased from a garden center and usually includes plastic test wells and capsules of reagents to react with water and nutrients in the soil. The nutrient or pH level is assessed by comparing the color of the water with a standard color chart. Some kits call for dry soil to be added directly to the plastic wells before adding water and the capsule, although extracting the soil water first can make detecting color changes more straightforward for students. To extract soil water, add water and soil in a jar, shaking to suspend the soil in water. Allow the soil to settle overnight, and then carefully pour out just the water sitting on top of the soil for use in the test kit. This activity pairs well with the soil particle size activity described above since students have already allowed soil to settle in water.

Soil Biological Properties

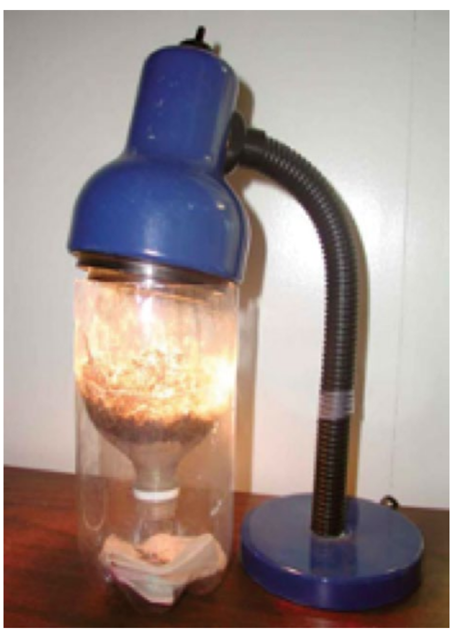

Figure 4. Berlese funnel made with a plastic soda bottle, rubbing alcohol, and a desk lamp.

Photo Credit: Natural Resources Conservation Services.

Soil is full of life and is one of the most diverse ecosystems on earth. In fact, a tablespoon of topsoil may contain well over one million organisms! Soil biota include plants, animals, and microorganisms that help break down soil minerals and decompose organic material to return nutrients to the soil. Plants play an important role in soils by growing roots that help break up compacted soil and allow water and air to enter soil when the roots decompose. Earthworms are one of the easiest soil organisms to identify, and also help air and water move into the soil through their burrowing activity. Microorganisms, such as bacteria, protozoa, algae, and fungi, are important for breaking down organic and mineral material, but are too small to see with the naked eye.

An excellent teacher resource about the soil food web and soil creatures can be found on the Natural Resources and Conservation Service nrcs.usda.gov website. Teachers can download The Soil Biology Primer for free or they can order a hard copy from nrcs.usda.gov/wps/portal/nrcs/main/soils/health/biology/.

Students can explore life in the soil by constructing Burlese funnels, which are funnels that help to extract organisms from a soil so they can be examined, ideally under a microscope. The funnel can be made from a plastic soda bottle cut in half with the top inverted into the bottom half of the bottle (**Figure 4**). Soil is placed in the newly created funnel, and rubbing alcohol is added to the bottom of the bottle to "trap" organisms. A desk lamp is placed over the top of the bottle, and because the organisms move away from the heat and dryness created by the lamp, they will move to the bottom of the funnel and get trapped in the rubbing alcohol after several days. The organisms can then be examined with a hand lens or microscope, and some nematodes, arthropods, and earthworms can be identified. Students can count, identify and compare organisms in different soils and consider how these organisms fit into the larger food web of soils.

Connecting Soil Science to Science Learning Standards

Soils are the great core idea connecting physical, life, and Earth and space sciences, and they lend themselves well to three-dimensional (3-D) teaching and learning as prescribed by the Next Generation Science Standards (NGSS). Soils can be investigated for their geologic origin, their organic matter and life, their chemistry, and the physics that explains how fluids migrate in soils. In 3-D teaching and learning, students employ science and engineering practices and crosscutting concepts to build understanding of disciplinary core ideas embedded in student-friendly phenomena such as a case study related to soil erosion or plant growth.

As states and districts are developing innovative ways to ensure all students engage in all science standards, soil science is a thread that unites many disciplinary core ideas. Using middle school science as an example, soil science is found in the following Earth and Space Science disciplinary core ideas: Earth Materials and Systems (ESS2.A), The Role of Water in Earth's Surface Processes (ESS2.C), Weather and Climate (ESS2.D), Natural Resources (ESS3.A), Natural Hazards (EES3.B), and Human Impacts of Earth Systems (ESS3.D). In the case of middle school life science disciplinary core ideas, soil science is naturally connected to: Interdependent Relationships in Ecosystems (LS2.A), Cycles of Matter and Energy Transfer in Ecosystems (LS2.B), and Ecosystem Dynamics, Functioning, and Resilience (LS2.C). In the case of middle school physical science disciplinary core ideas, soil science is naturally connected to: Structure and Properties of Matter (PS1.A), Chemical Reactions (PS1.B), and Energy in Chemical Processes and Everyday Life (PS3.D).

As an example of how to integrate the NGSS disciplinary core ideas with science and engineering practices, and crosscutting concepts, the K12 Committee of SSSA developed a middle school soil science unit that integrates these three dimensions centered on the following essential questions:

- How do soils sustain life and influence life as abiotic and biotic factors in an ecosystem? (Part 1)
- What are the five soil formation factors (ClORPT) and how do they contribute to the formation of soil? (Part 2)
- What are the characteristics that differentiate a soil from other soils (i.e. particle size/texture, structure, color, profile) and how do these characteristics contribute to soil quality and function? (Part 3)
- What are the challenges of ensuring soils are sustained into the future, and how can we address those challenges? (Parts 4)
- How do soils contribute to society: the products we use, places we live? (interdisciplinary) (Part 5)

The unit with links to the activities can be found at the Soil Science Society of America's (SSSA) Soils 4 Teachers website (soils4teachers.org) (**Figure 5**). The SSSA is a professional scientific society, made up of soil scientists, educators, and consultants focused on promoting soil science, including enhancing soils topics in schools. The Soils 4 Teachers website provides resources for teachers on multiple soil topics. There are lesson plans and activities for different grade levels and topics. Topics range from general soils lessons (composition, color, texture, formation) to soil chemistry (soil pH, nutrients, chemical reactions) to soil biology (soil organisms, decomposition, composting) to soil forensics and more. Resources include State Soil Booklets that detail what a state soil is, what makes the state soil unique and important for each state. Coming soon to the Soils 4 Teachers

Figure 5. K-12 Soil Science Teacher Resources from the Soil Science Society of America.
Photo Credit: Public domain screenshot.

website is a searchable database of vetted resources to support K12 teaching of soil science. Users will be able to search by topic, grade-band, NGSS disciplinary core idea, and type of resource.

In addition to the soil science resources found on the SSSA Soils 4 Teachers Website, the GLOBE Program also includes soil science protocols. The Global Learning and Observations to Benefit the Environment (GLOBE) Program's mission is "to promote the teaching and learning of science, enhance environmental literacy and stewardship, and promote scientific discovery". Educators and students can dive into the scientific process and collect data in their local environment and be a part of real, hands-on science that contributes to how we understand our global environment. Students and educators can connect with other students, educators, and scientists around the world through the GLOBE collaborations and regional offices.

Looking for grade level-appropriate, interdisciplinary activities developed by the scientific community and validated by teachers? GLOBE has you covered for investigating the soil/pedosphere through the GLOBE Teachers Guide at globe.gov/do-globe/globe-teachers-guide/soil-pedosphere. In the Data Game activity, students learn how data can be distorted and learn to think critically about data being presented. Other activities explore how soil moisture and temperature can vary across a landscape, how water moves through soils, and how organic materials are decomposed in soil.

To connect students to the soil in their backyard without going outside, the Web Soil Survey (websoilsurvey.sc.egov.usda.gov/App/HomePage.htm) from the Natural Resource Conservation Service provides teachers the opportunity to explore the soils of the US without having to leave the classroom. Students can explore the various soil types and soil classifications of specific areas that they select. Would the site they selected be a good place to grow a crop, build a house or road? Information includes what limitations may exist for supporting plant growth, such as shallow soil depth or frequent flooding and limitations for housing, such as septic tank absorption field suitability.

Conclusion

Soil is not dirt! These lessons and references should help students understand the complexity of soils. In a science curriculum soils can be used to teach about: physics – particle size, gravity and settling; chemistry – color, reduction/oxidation, pH, nutrients; biology – Burlese funnel and microbial mediated color changes; GIS and Technology – Web Soil Survey; and so much more. Resources abound (GLOBE, NRCS, Soils4Teachers, etc.) to help educators find lesson plans and materials that can be adapted to any classroom and any age. Furthermore, adoption of soils into lesson plans fits well within the NGSS in many ways. Best of all, soils represent the real world. They allow students to apply fundamental principles to something they can touch and that affects their lives in so many ways. Soils are fundamental to all life so if you know soils you know life and with no soils there is no life. So, go out and get dirty.

About the Authors

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