United States Department of Agriculture

Soil Science Curriculum

January 2018

Rainfall Simulator

Approximately 270 minutes

"We know more about the movement of celestial bodies than about the soil underfoot."
- Leonardo Da Vinci, circa 1500's

"Essentially, all life depends upon the soil ... There can be no life without soil and no soil without life; they have evolved together."
- Charles E. Kellogg, USDA Yearbook of Agriculture, 1938

Desired Impact/Goal

Educational commitment and application of learning (Head). Students will understand how soil health, as affected by environmental conditions and human activity, influences the capacity of natural ecosystems to sustain plants, animals, and humans.

Life Skills

- Teamwork
- Record Keeping
- Critical Thinking
- Problem Solving
- Communication

Skill Level

Advanced; ages 15-19/grades 9-12

Time Needed

- Three hours prep time
- One 60-90 minute class period for lesso

Materials

- Introductory PowerPoint presentation
- Computer and projector
- Bench-top rainfall simulator and associated materials (see Directions for using the desktop expo rainfall simulator)
- Access to sites for soil sampling, including land use history information (school grounds, gardens, parks, farms)
- Copies of student Rainfall simulator demonstration and scenario worksheet

Next Generation Science Standards

- Human Impacts on Earth Systems (HS-ESS3-1): Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.
- Human Sustainability (HS-ESS3-4): Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

Key Concepts:

Soil Health

1. Soil health is defined as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans.

2. A healthy soil sustains plant, animal and human life by providing a firm foundation for plant roots and human structures, regulating water, cycling nutrients, filtering, buffering and degrading pollutants.

3. Soil health considers the integrated physical, chemical and biological components of soil ecosystems, whereas traditional soil fertility views soil as a non-living system.

4. Both environmental conditions (parent material, climate, topography) and human activities (soil disturbance, cropping, fertilization) can influence soil health.

5. In highlighting the link between functioning soil ecosystems and the productivity or resiliency of human systems, soil health represents a paradigm shift in conservation management.

Soil Minerals and Texture

1. Soil consists of four major components: mineral material (~45%), organic matter (~5%), water (~25%) and air (~25%).

2. The mineral component of soil is the remnants of weathered rocks and can be classified into three categories by particle size: sand (2.0-0.05 mm), silt (0.05-0.002 mm) and clay (<0.002mm).

3. Clay is the only chemically active texture class with the ability to adsorb plant nutrients

4. The proportion of different mineral particle sizes in a soil determines its texture, within twelve recognized classes.

5. Soil texture is important to soil health as a determinant of surface area and pore space available in a soil for holding nutrients, air and water.

6. Soil texture is primarily determined by geology and climate, and cannot be easily changed by human activity. That is except in the case of disturbed (i.e. urban) soil where large amounts of soil are imported into or removed from an area.

Soil Biology and Organic Matter

1. Soil ecosystems support a great diversity of organisms, rivaling the above-ground diversity in tropical rainforests or coral reefs.

2. Soil biota range from microscopic bacteria to vertebrates that coexist in complex food webs.
   a. Bacteria and yeast
      i. Microscopic colonies grow on root and organic matter surfaces
      ii. 100 million to 1 billion per teaspoon of soil
      iii. Biomass = 2 cows per acre
      iv. Decomposers, nutrient cyclers, pathogens
   b. Fungi and actinomycetes
      i. Grow through soil as mycelium consisting of a few hyphal cells to thousands of acres in area
      ii. Decomposers, mutualists and pathogens
      iii. Specialize in penetrating organic matter and translocating nutrients
      iv. Assist plant roots in accessing immobile nutrients like phosphorus
   c. Micro and mesofauna: Protozoans, nematodes, rotifers, tardigrades, springtails and mites
      i. Microbivores, omnivores, predators and parasites
      ii. 500 to 1 million per square meter
      iii. Help to regulate microbe populations through feeding
   d. Macrofauna: Earthworms, millipedes, isopods, mollusks and insects
      i. Size and incorporate organic matter, and also living plants as pests
      ii. Mix and aggregate soil
      iii. Create macropore spaces by burrowing, improve infiltration and create root channels
   e. Megafauna: large invertebrates, vertebrates (amphibians to mammals)
      i. Herbivores, omnivores, predators
      ii. High level consumers

3. The organic matter component of soil is the remnants of plant and animal tissue in various states of decomposition by soil organisms, a valuable source of nutrients for all members of the soil food web, plants and megafauna, as well as a reservoir for water storage in soils.

4. Soil life is often concentrated in areas with more organic matter including near plant roots (rhizosphere exudates), close to surface litter and in sites with incorporated organic matter like crop residue, cover crops, or manure.

Soil Aggregation and Aggregate Stability

1. The four components of soil often stick together in units called aggregates that include both solid (mineral and organic) materials and pore space (air and water) held together by physical and chemical forces.

2. Several natural processes contribute to soil aggregation through the physical movement and adhesion of soil particles including:
   a. wetting and drying
   b. freezing and thawing
   c. microbial activity that aids in the decay of organic matter (glomalin produced by fungi)
   d. activity of roots and soil animals (root sugar exudates)
   e. soil chemical charges (adsorbed cations)

3. Aggregates vary in their size, shape and stability. Patterns of soil aggregation determine soil structure within nine categories (i.e. crumb, blocky, single grain), that along with texture, is used to describe a particular soil type.

4. Soil aggregation is important to soil health as a determinant of pore space available in a soil for holding air, water and nutrients, as well as the growth of soil biology. Aggregates include micropore spaces within their structure, but also form macropores between aggregate units.

5. Soil aggregation is sensitive to environmental conditions and human activities. The impact of raindrops, tillage and wheel traffic destroy aggregates. Aggregation is encouraged by practices such as reduced tillage, and organic matter additions from crop residue, cover crops or manure.

Soil Bulk Density

1. To maximize plant root growth, a soil should ideally consist of 50% solid (mineral and organic) materials and 50% pore space (air and water).

2. Soil bulk density is a measure of soil porosity/compaction expressed as soil weight per unit volume (g/cm3).

3. In general, low bulk density (< 1.50 g/cm3) is associated with a loose, porous soil with plenty of room for air, water and biology, while a higher bulk density (>1.50 g/cm3) can limit movement of air and water through soil and restrict root growth.

4. Practices that destroy soil aggregates, like tillage and wheel traffic, increase bulk density over time. This is somewhat counterintuitive since tillage is designed to temporarily loosen soil for planting and crop establishment. However, fractured aggregates settle and compact over time. Practices that increase aggregation, such as reduced tillage, controlled wheel traffic and organic matter additions from crop residue, cover crops or manure tend to decrease soil bulk density.

Life Skill Objectives:

- Teamwork
  Teams of students will share responsibility for observations before and during the rainfall simulator demonstration, development and testing of hypotheses and communication of results.

- Keeping Records
  Students will accurately record observations relevant to soil properties, land use/management, and their effect on the movement of water over and through soils during the demonstration.

- Critical Thinking
  Students will reflect on their observations to hypothesize about the inherent soil properties and land use/management differences that may have contributed to their findings.

- Problem Solving
  Teams of students will develop a plan to change land use/management on the site(s) of interest in an effort to reduce runoff/erosion and improve infiltration.

- Communication
  Teams of students will present their proposed changes in land use/management to the class and test their hypotheses against those of another team using the rainfall simulator, observe and record the outcome.

Instructional Plan:

1. Background

a. Through an introductory PowerPoint or video presented by the instructor:

i. Students will be introduced to the concept of soil health, its integrative definition and importance to agriculture.

ii. Four major components of soil and their relative abundance.

iii. Understand that the organic matter component of soil is the remnants of plant and animal tissue in various states of decomposition by soil microorganisms, and the mineral component of soil is the remnants of weathered rocks.

iv. Learn that the mineral component of soil can be classified into three categories by particle size, which determines soil texture.

v. Realize that the four components of soil tend to stick together in units called aggregates that include both solid (mineral and organic) materials and pore space (air and water) held together by physical and chemical forces.

vi. Discover that to maximize plant growth, a soil should ideally consist of 50% solid (mineral and organic) materials and 50% pore space (air and water), and become familiar with soil bulk density as a measure of soil porosity/compaction expressed as soil weight per unit volume (g/cm3).

2. Experience – Getting Started

a. The instructor will assign teams of students a geographic area of interest (AOI) for the lesson, from which soil samples will be collected for analysis, plus a site description with background information on site location and land use and blank space for field observations.

b. The instructor will introduce soil survey resources and teams of students will use Web Soil Survey or soil survey books to identify different soil types present in a given area of interest and select areas of different types/textures for sampling (or observe area where samples were collected by instructor beforehand), making predictions about soil characteristics on-site.

c. The instructor and students will travel to a field site and use FarmLogs to locate their desired sampling area, make general site and management observations to add to their site scenario (plant cover, color, structure, moisture, slope, land use, disturbance), conduct an in-field earthworm count and collect soil samples for lab analysis of soil texture, aggregate stability, bulk density, respiration and soil (optional additional 90-minute class period).

3. Experience – Going Further

a. In the lab, teams of students will use the hand test to estimate a soil's proportion of different mineral particle sizes by feel and identify soil texture within twelve recognized classes, indicating this on a soil texture triangle located on a lab worksheet.

b. Teams will conduct a slake test on their unique soil as a qualitative measure of aggregate stability and record their results on a lab worksheet.

c. Teams will measure the bulk density of their unique soil sample collected using the core method and record their results on a lab worksheet.

4. Think and Discuss

a. Teams will research and orally report on ways that parent geology, climate, topography, biology and time may have influenced the soil types/textures found at their AOI.

b. Students will inspect and manipulate several aggregates collected by other teams to see how they vary in their size, shape, stability and density based on texture and field histories (i.e. tilled vs. no-till).

c. The instructor will lead the entire class in a comparison of their bulk density results by constructing a graph(s)and discussing how tillage and compaction can degrade soil aggregation and increase bulk density.

d. Students will build on their knowledge of soil components, texture and field history to develop a brief essay/video/oral presentation theorizing about the natural and human processes that contribute to or degrade soil aggregation and bulk density including:

- soil texture
- wetting and drying
- freezing and thawing
- microbial activity that aids in the decay of organic matter (glomalin produced by fungi)
- activity of roots and soil animals (root sugar exudates)
- soil chemical charges (adsorbed cations)
- mechanical disturbance (tillage)
- mechanical compaction

Measurable Indicators:

Benchtop Rainfall Simulator Demonstration
Student Worksheet

Before the demonstration begins…

1. What do you know about the soil samples that will be used in the rainfall simulator demonstration? Describe each one including information about use/management of the site(s) they were collected from and any known chemical, physical, or biological properties.

2. How do expect the physical properties of each soil sample (texture, aggregation, structure, pore space) to affect how water runs-off or infiltrates through the soil? Do you think that use/ management of the site(s) each sample was collected from has affected the soil's physical condition? In what ways?

3. How do expect the biological properties of each soil sample (organic matter, cover type, biota) to affect how water runs-off or infiltrates through the soil? Do you think that use/ management of the site(s) each sample was collected from has affected the soil's biological condition? In what ways?

During the demonstration…

4. Observe how water runs-off and/or infiltrates through the soil sample(s). Which sample(s) had the greatest volume of water run-off the soil surface? What color was the water in the run-off catch pan(s)? What does the color of the run-off water tell you about the movement of soil and nutrients with rain water?

5. Which sample(s) had the greatest volume of water infiltrate through the soil? How quickly did infiltration water accumulate in the lower catch pans compared to run-off water? Why might greater infiltration be desirable for water quality/quantity, crop production, etc.

After the demonstration…

6. Did the demonstration support your hypotheses about how water would run-off vs. infiltrate through each soil sample? If so, which physical and biological soil properties or site use/management factors seemed to have the greatest effect on the movement of water? If not, what do think led to the unexpected result?

7. Considering the sample with the greatest volume of run-off water caught in the front pan, how could use/management of the site be changed to decrease run-off and increase infiltration? Be sure to discuss use/management changes that could affect chemical, physical and biological soil properties.