The Study

Maximum soil squishiness: Assessing forest soil compaction

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Learning Objectives

Students will explore and learn about the following concepts:

- Definition of soil degradation
- Definition of soil compaction
- Definition of soil bulk density
- How to describe soil properties (texture, organic matter, water content) that affect soil bulk density
- How to assess soil compaction on your campus or schoolyard

The story behind the study

Soil degradation refers to a decline in soil quality related to physical, chemical and biological functions. In other words, it means that soil loses its ability to grow things. Since soil provides living things with food, fibre and fuel, these resources become less available at degraded sites. Soil degradation is a worldwide issue that has grown particularly serious in parts of Africa, the Americas, Europe, the Middle East and much of Asia, affecting about 22% of the total world's cropland, pastures, and forests. Soil degradation may take many forms such as erosion, desertification, compaction, or chemical contamination. (See photographs at the end of the notes for examples)

Soil compaction is a form of soil degradation. When a soil is compacted, or "squished", it loses volume as **pore spaces** between **soil particles** collapse. It may be caused by excessive cultivation of agricultural fields, heavy equipment used for logging, or overgrazing by livestock. Even activities such as mountain biking or use of dirt motorbikes can lead to soil compaction. Once soil is compacted, roots and soil organisms do not have enough space to grow and they may lack oxygen and water. Soil compaction causes changes to nutrient cycles due to altered air and water levels in the soil. Consequently, plant growth is reduced or completely eliminated. (See photographs at the end of the notes for examples)

The degree of soil compaction under the same activity (i.e., mountain biking, tillage, livestock grazing) will vary between soils. This is because soil compaction is affected by a number of different soil properties including texture, organic matter content, and water content. A certain degree of soil compaction is unavoidable and land managers need to be able to assess an acceptable level of soil compaction that does not severely limit plant growth. Once that level is surpassed, the soil is degraded and it can be difficult or impossible to repair. Determining an acceptable level of soil compaction, however, is very difficult to do. It would be very useful for land managers to have a measure (parameter) of soil compaction that is related to plant growth. Investigate the research summary to see how Dr. Maja Krzic and her research group are trying to do just that!

Research summary

Several studies have been carried out by Dr. Krzic's research group on forest soils throughout British Columbia with an aim to determine a measure (parameter) of soil compaction that could be related to tree growth. Such a parameter of soil compaction would be very helpful to foresters since it would allow them to decide if site rehabilitation is needed to restore soil productivity. **Soil rehabilitation** practices are very expensive and time consuming, and foresters have to be able to determine whether or not they are needed on a particular site.

Sandy's Notes – Maximum Soil Squishiness

Soil bulk density (BD) is a common parameter that is collected by soil scientists and it is calculated as the mass of dry soil per unit volume. Learn more about **how BD is measured** [**http://soilweb.landfood.ubc.ca/labmodules/compaction/soil-bulk-density**]. When a soil is compacted, the soil bulk density will increase. However, different soil types will have different bulk densities even if they have been compacted by the same amount. This is because of differences in soil characteristics, such as organic matter content and organic matter content. What researchers were looking for was a parameter that could be applied to all sites, even if they have different soil types.

A study began in 2003 that would take six years and more than 400 soil samples and thousands of tree measurements to complete. Soil samples were collected from forest sites where different logging practices had been used and were analyzed for numerous properties including **soil texture**, organic matter content**,** liquid and plastic limit, and iron and aluminum oxides. Those data were used to estimate soil **maximum bulk density** (MBD) and **relative bulk density** (RBD). Learn more about **how liquid & plastic limits are measured** [**http://soilweb.landfood.ubc.ca/labmodules/compaction/atterberg-limits**].

MBD is bulk density that can be achieved by a standard lab method (called Proctor compaction test), while RBD is calculated by dividing bulk density determined in the field by MBD. Learn more about **how MBD is measured** [**http://soilweb.landfood.ubc.ca/labmodules/compaction/soil-bulk-density**] The RBD determined for each soil sample was then related to growth of three tree species: Douglas-fir, lodgepole pine, and white spruce.

Photo by Trudy Naugler, UBC, Vancouver, BC.

Photo by Chuck Bulmer, MoF, Vernon, BC.

The purpose of rehabilitation is to improve degraded soil so that it can once again contribute to a productive ecosystem. For example, if a compacted forestry road is rehabilitated once it is no longer needed, vegetation will grow back more quickly. These photos so an untreated road on the left, and a treated road on the right. The treated road has been "ripped"; this means that the compacted soil has been broken up and ripped using heavy equipment.

Photo by Dr. Simon Zhao, UBC, Vancouver, BC

Photo by Dr. Simon Zhao, UBC, Vancouver, BC

Both of these photos show eight year old lodgepole pine trees growing on former logging roads in Bear Lake, BC. The road on the left was left untreated, while the road on the right was treated by deep tilling plus mulch. The treatment enabled greater tree growth by reducing the bulk density of the compacted road.

The study found that the height of Douglas-fir trees was limited when RBD was > 0.72. For lodgepole pine and hybrid white spruce, maximum tree height was achieved when RBD was 0.60 - 0.68 and tree height appeared to be limited when RBD was 0.78 - 0.87.

Our results showed that RBD can be used to assess compaction of forest soils. By using RBD, we could look at the relationship of compaction and tree growth even at sites that had different soil properties. To obtain good seedling establishment, soil rehabilitation should be considered on disturbed forest sites where soil RBD is > 0.80.

Are you curious about how scientists exchange their research ideas? This article was written by the people involved in this project to share their findings with other scientists:

Zhao, Y., M. Krzic, C.E. Bulmer, M.G. Schmidt, and S.W. Simard. (2010) Relative bulk density as a measure of compaction and its influence on tree height. Canadian J. of Forest Research 40: 1724-1735.

Definitions

Bulk density: The mass of dry soil per unit bulk (or total) volume. The "actual" or "field" soil bulk density is determined by collecting and weighing an undisturbed sample of known volume.

Maximum bulk density (MBD): The maximum mass per unit volume a soil can obtain by applying a standardized pressure during the lab method known as the Proctor compaction test. The method is rigorously defined and utilizes standard testing equipment.

Pore space: The portion of soil bulk volume occupied by soil pores.

Relative bulk density (RBD): A calculated value that can be used to compare the bulk density of soils that have different characteristics. It is calculated by dividing the actual (field) bulk density by the maximum bulk density (MBD). Relative bulk density has been shown to be a useful index to assess soil compaction on agricultural and forest soils.

Sandy's Notes – Maximum Soil Squishiness

Soil compaction: The process by which soil grains (particles) are rearranged to decrease pore space and bring grains in closer contact with one another, thereby increasing the soil bulk density.

Soil degradation: Human-induced change or disturbance to a soil that reduces soil quality.

Soil particles: Also known as soil separates, these are the individual mineral components of the soil. Particles range from very small clay particles (< 0.002 mm), silt (0.002-0.05 mm), and sand (0.05-2 mm), to gravel (2-75 mm), cobbles (75-250 mm), stones (250-600 mm), and boulders (>600 mm).

Soil rehabilitation: Planned action to improve soil following degradation or disturbance. Rehabilitation improves soil quality and/or productivity.

Soil texture: Soil texture refers to the relative proportion of sand, silt and clay in a soil.

Student Activities

This section provides links to additional resources with background information, instructional videos and possible exercises. Use these resources to help students further explore the concepts addressed in the research summary above.

1) Determining soil bulk density

Bulk density refers to the weight of the solid particles in a standard volume of field soil (i.e. solids plus pore space occupied by air and water). It is an important soil parameter because it is used to make inferences about soil. Use these links to find exercises that will teach students how bulk density samples are collected and how to calculate bulk density from the results. Have students collect their own soil sample and calculate the bulk density.

- **Virtual Soil Lab Modules (UBC)** http://soilweb.landfood.ubc.ca/labmodules/compaction/soil-bulk-density
  This site provides photographs on collecting soil samples using the core method. Students can review the many techniques to determine soil bulk density.
- **SoilWeb (UBC)** http://www.landfood.ubc.ca/soil200/components/mineral.htm#114
  This site provides an introduction to particle and soil bulk density. An animation illustrates the relationships among the weight and volume of soil air, water, and solids.
- **The Cooperative Soil Survey** http://soils.missouri.edu/tutorial/page10.asp#c
  This site will show you how to collect an undisturbed soil sample with simple tools, how to prepare the sample, and how to use the results to calculate soil bulk density. Students can use the instructions to collect their own soil sample and calculate soil bulk density.

2) Determining maximum bulk density (MBD) by the Proctor compaction test

As illustrated in the research summary, maximum bulk density (MBD) is used to calculate relative bulk density (RBD). RBD can be an important tool for assessing whether a site requires rehabilitation.

- **Virtual Soil Lab Modules (UBC)** http://soilweb.landfood.ubc.ca/labmodules/compaction/soil-bulk-density
  Students should read the description and watch a video clip on how MBD is determined.

3) Determining soil texture

Soil texture refers to the relative proportions of sand, silt, and clay in a soil. It is often the first and most important property to be determined when describing a soil, since many conclusions can be drawn from this

information. These links can be used as a review of texture principals as well as provide simple exercises that can be completed in class.

- **Soil Web (UBC)** http://www.landfood.ubc.ca/soil200/components/mineral.htm#121
  This site provides a review of general soil texture concepts
- **Soil Texture Video (Field)** http://www.youtube.com/watch?v=knrmCbctGEA
  This YouTube video reviews the concept of sand, silt and clay and provides a simple experiment for a rough determination of soil texture
- **Soil Texture Video (Lab)** http://www.youtube.com/watch?v=GWZwbVJCNec
  This YouTube video takes you through determining soil texture by the hand-texturing method. Print out this flow diagram http://www.ndhealth.gov/wq/sw/z1_nps/pdf_files/soil_texture_feel_test.pdf to follow along.

4) Determining soil water and organic matter content

Along with minerals and air, organic matter and water are important component in all soil. These can be calculated using simple techniques.

- **Virtual Soil Lab Modules (UBC)** http://soilweb.landfood.ubc.ca/labmodules/water
  This site reviews two methods for determining soil water content and includes a video clip.
- **Water Content Video** http://www.youtube.com/watch?v=XmprDMqu4zc
  This video provides a synopsis of how to calculate gravimetric water content and organic matter content.

5) Evaluation of soil compaction of soils on your campus or schoolyard

Here's an activity you can adapt to any school ground. Identify an area of campus or schoolyard that students will be able to use for this assessment. Students should work in teams of 2-3 to accomplish following tasks:

a) Draw a map of the campus.

b) Walk around the campus and identify areas of no compaction as well as those with mild, moderate, and extreme soil compaction. Enter these 4 categories of soil compaction into the map.

c) Photograph examples of no, mild, moderate, and extreme soil compaction.

d) Explain the criteria that you have used to group areas into one of the 4 categories (no, mild, moderate, and extreme) of soil compaction.

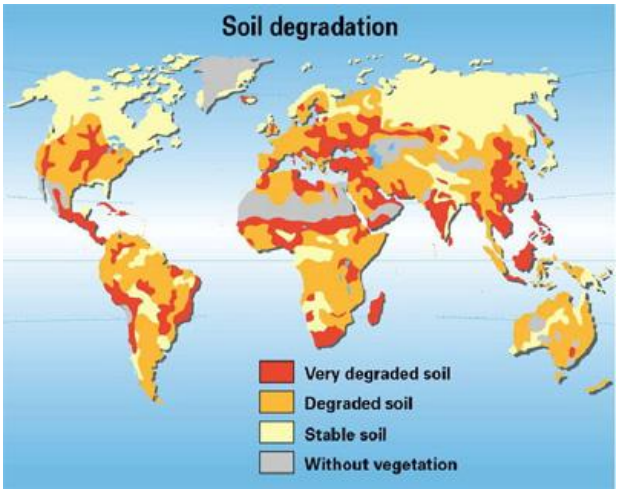
Headlines

National Geographic: Our Good Earth
http://ngm.nationalgeographic.com/2008/09/soil/mann-text
A detailed article that investigates soil loss and soil management around the world. It includes a photo journal, a special article on soil in Haiti, and a soil quiz.

Science Daily: Thirty-Eight Percent of World's Surface in Danger of Desertification
http://www.sciencedaily.com/releases/2010/02/100209183133.htm
This article provides shows how soil parameters are being incorporated into evaluations of environmental impacts.

FAO: National Soil Degradation Maps
http://www.fao.org/landandwater/agll/glasod/glasodmaps.jsp?country=CAN&search=Display+map+%21
Explore interactive soil degradation assessments by country.

Photographs – Soil Degradation



This map was developed by the Food and Agriculture Organization (FAO) of the United Nations to illustrate where soil degradation can be found throughout the world.

At the FAO website http://www.fao.org/landandwater/agll/glasod/glasodmaps.jsp?country=CAN&search=Display+map+%21 you can find an interactive map to view soil degradation assessments.

A classic example of soil degradation is the Dust Bowl of the 1930's. Severe drought coupled with agricultural practices that did not prevent erosion made the soil susceptible to erosion by wind. This photo shows soil particles being blown around.

Photo courtesy of USDA Natural Resources Conservation Service.

Desertification occurs in dry landscapes. This photograph shows plant roots retaining the underlying soil while the surrounding soil has been removed by wind erosion.

Photo courtesy of USDA Natural Resources Conservation Service.

Construction practices can lead to degradation.

Photo by Margaret Schmidt, SFU.

Sediment from sheet and rill erosion in an agricultural field covers crops at the base of a hill.

Photo by Lynn Betts, USDA Natural Resources Conservation Service.

Soil compaction can restrict and even prevent plant growth. No-till and conservation tillage farming methods are one way to reduce the impact of heavy equipment on agricultural fields by limiting the number of passes required.

Photos by Lynn Betts, USDA Natural Resources Conservation Service

A forest fire recently moved through this site. Because the fire burns much of the organic matter on the soil surface and kills the trees, slopes like this one become very susceptible to erosion following fire.

Photo by Chuck Bulmer, MoF, Vernon, BC.

This close-up shows that soil has been eroded around the trees (can you see the exposed roots?).

Photo by Chuck Bulmer, MoF, Vernon, BC.

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Heavy rains at this site which also experienced a forest fire show the effects of erosion.

Photo by Chuck Bulmer, MoF, Vernon, BC.

To help prevent erosion at this fire-affected site, logs have been placed across the slope. The logs trap sediment that moves downslope during a rainstorm. This helps preserve the soil and provides stable sites for vegetation to grow.

Photo by Chuck Bulmer, MoF, Vernon, BC.

Animals can cause soil degradation too. At this site, heavy use by cows at a landing has removed the vegetation and caused soil compaction.

Photo by Chuck Bulmer, MoF, Vernon, BC.

The area around the water tank has been compacted because cows congregate in this area. However, the placement of the water tank as well as some fencing keeps the cows out of critical riparian (stream) habitat nearby.

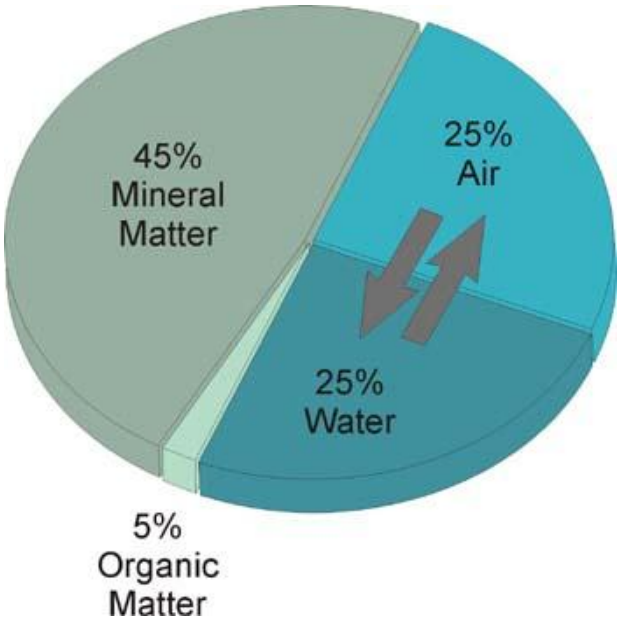
Photo by Jeff Vanuga, USDA Natural Resources Conservation Service.

Sandy's Notes – Maximum Soil Squishiness

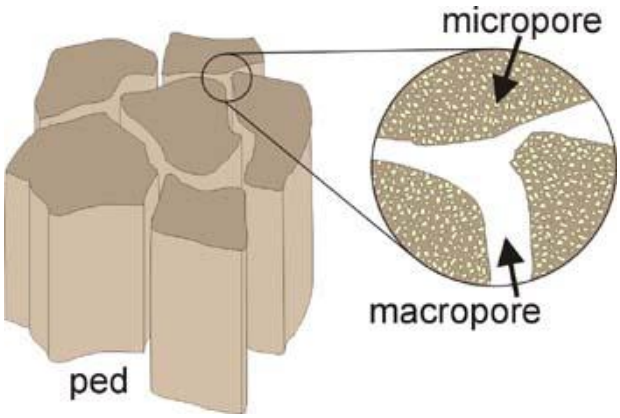
Goats graze on a steep hillside in Nepal. Plant roots help stabilize steep slopes. When vegetative cover is reduced on slopes, they become more susceptible to erosion.

Photo by Margaret Schmidt, SFU.

Photographs – Soil Compaction



Soil is made up of particles (mineral and organic) and pores. Pores can be filled either with air or water. This image shows the typical proportion of mineral and organic particles as well as soil air and water in an uncompacted soil. When soil is compacted, the pore spaces collapse and the soil becomes denser.



Pores can either be big (macropore) or small (micropore). Macropores are easy to see with the eye.

Sandy's Notes – Maximum Soil Squishiness

Can you see the macropores in the close up of this soil? Can you tell the difference between the mineral and organic particles?

Photo by Chuck Bulmer, MoF, Vernon, BC.

Soil compaction often occurs along heavily used areas such as forest roads and landings (areas where logs are loaded onto trucks). The heavy machinery and trucks used in forestry management practices put a lot of pressure on the soil.

Photo by Trudy Naugler, UBC, Vancouver, BC.

Oil well sites, like this one in Northern British Columbia, are also disturbed and require soil rehabilitation in order to promote plant growth once the site is no longer being used.

Photo by Chuck Bulmer, MoF, Vernon, BC.

You can see the impact of heavy machinery on forest soils in this photo; the soil on the left hand side has been compacted by heavy machinery, whereas the soil on the right hand side is a native forest soil. Notice that the native forest soil has a thicker mat of organic matter (the dark brown near the top) and appears "fluffier".

Photo by Chuck Bulmer, MoF, Vernon, BC.