# Soil 2125 Laboratory Manual - pdf edition

Nic Jelinski and Nora Pearson

2023-12-13

# Table of contents

**Preface** **1**
Lab Teaching Team . . . 1
Logistics and Laboratory Philosophy - Why is this lab self-paced and what does that even mean? 1

**1 Soil Texture, Color, and Structure** **3**
1.1 INVESTIGATION A: Using a Hydrometer to Determine Particle Size . . . 3
1.1.1 Preparation . . . 4
1.1.2 Measurements . . . 4
1.2 INVESTIGATION B: Using the Texture Triangle . . . 6
1.3 INVESTIGATION C: Texturing Soil with the "Feel" Method . . . 7
1.4 INVESTIGATION D: Soil Color . . . 9
1.5 INVESTIGATION E: Soil Structure . . . 9

**2 Mineralogy and Clay Minerals** **11**
2.1 INVESTIGATION A: 3-D Digitized and Model Clay Mineral Structures . . . 11
2.2 INVESTIGATION B: Clay Mineral Block Structures . . . 13
2.3 INVESTIGATION C: Clay Mineral Charges . . . 14
2.4 INVESTIGATION D: Clay Charge, Ion Charge, and Flocculation . . . 14
2.5 INVESTIGATION E: Shrink/Swell Observation . . . 15
2.6 INVESTIGATION F: Clay Soils . . . 16
2.7 INVESTIGATION G: Article . . . 16

**3 Bulk Density, Porosity, and Organic Matter** **17**
3.1 INVESTIGATION A: Bulk Density Measurements . . . 17
3.1.1 Bulk Density: Clod Method . . . 17
3.1.2 Bulk Density: Soil Core Method . . . 18
3.1.3 Bulk Density: Graduated Cylinder Method . . . 19
3.2 INVESTIGATION B: Porosity . . . 19
3.2.1 Soil Porosity: Direct Method . . . 19
3.2.2 Soil Porosity: Indirect Method . . . 20
3.3 INVESTIGATION C: Bulk Density of Mineral Soils . . . 21
3.4 INVESTIGATION D: Soil Color and Soil Organic Matter . . . 21
3.5 INVESTIGATION E: Organic Soil Types and Experiential Observation . . . 22
3.6 INVESTIGATION F: Ranges and Estimation of Bulk Soil Physical Properties . . . 22

**4 Cation Exchange Capacity, Soil pH and Salinity/Sodicity** **25**
4.1 PRE-INVESTIGATION . . . 26
4.2 INVESTIGATION A: Soil pH . . . 28
4.3 INVESTIGATION B: Calcareous Soils . . . 29
4.4 INVESTIGATION C: Cation Exchange Observation . . . 29

4.5 INVESTIGATION D: Saline Soils . . . 30
4.6 INVESTIGATION E: Calculation and Interpretation of CEC, pH and Salinity . . . 31
4.7 Soil Water Data Preparation for Next Week's Lab (THIS IS IMPORTANT!) . . . 32

**5 Soil Water** **33**
5.1 INVESTIGATION A: Constructing Water Retention Curves . . . 33
5.2 INVESTIGATION B: Determining Field Capacity . . . 36
5.3 INVESTIGATION C: Tensiometer Observation . . . 37
5.4 INVESTIGATION D: Observations of Capillary Action . . . 38
5.5 INVESTIGATION E: Determining Soil Moisture by Weight and Volume . . . 39
5.6 INVESTIGATION F: Soil Water Problems . . . 40

**6 Biological Processes (1)** **43**
6.1 INVESTIGATION A: Forms of Nitrogen . . . 44
6.2 INVESTIGATION B1: Observing Nodules . . . 45
6.3 INVESTIGATION B2: Dissecting Nodules . . . 46
6.4 INVESTIGATION C: Aggregate Stability . . . 47
6.5 INVESTIGATION D: Soil Organism Observation . . . 48
6.6 SETUP FOR NEXT WEEK'S LAB: Culturing Microorganisms from Soil Materials . . . 49

**7 Biological Processes (2)** **51**
7.1 INVESTIGATION A: Observation of Inoculated Plates . . . 52
7.2 INVESTIGATION B: Observation of Redoximorphic Features in Mini-Monoliths . . . 53
7.3 INVESTIGATION C: Observation of Redox Features in Vials . . . 54
7.4 INVESTIGATION D: Earthworm Activity . . . 55

**8 Rocks, Weathering, and Master Horizons** **57**
8.1 INVESTIGATION A: Mineral Identification . . . 57
8.2 INVESTIGATION B: Rock Identification – Rocks are Aggregates of Minerals . . . 59
8.3 INVESTIGATION C: Mineral Identification in the Sand Fraction . . . 62
8.4 INVESTIGATION D1: Physical Weathering . . . 63
8.5 INVESTIGATION D2: Chemical Weathering . . . 64
8.6 INVESTIGATION D3: Biological Weathering . . . 64
8.7 INVESTIGATION E: Weathering Examples . . . 65
8.8 INVESTIGATION F: Naming Master Horizons - Review . . . 66

**9 Five Soil Forming Factors** **67**
9.1 INVESTIGATION A: Residual Parent Materials . . . 68
9.2 INVESTIGATION B: Transported Parent Materials . . . 69
9.3 INVESTIGATION C: Climatic Factors . . . 70
9.4 INVESTIGATION D: Biotic Factors (Vegetation) . . . 71
9.5 INVESTIGATION E: Topographic Factors . . . 72
9.6 INVESTIGATION F: Time Factors . . . 73
9.7 INVESTIGATION G: Clay Eluviation/Illuviation and the Soil Forming Factors . . . 74
9.8 INVESTIGATION H: Properties from Factors and Factors from Properties . . . 75

**10 Soil Classification** **77**
10.1 INVESTIGATION A: Soil Classification . . . 77

10.2 SOIL 1: CROMWELL . . . 78
10.3 SOIL 2: WEBSTER . . . 79
10.4 SOIL 3: RIFLE . . . 80
10.5 SOIL 4: FARGO . . . 81
10.6 SOIL 5: KALKASKA . . . 82
10.7 SOIL 6: ZIMMERMAN . . . 83
10.8 SOIL 7: LESTER . . . 84
10.9 SOIL 8: CECIL . . . 85
10.10 INVESTIGATION B: Location of Soil Orders . . . 86
10.11 INVESTIGATION C: Nomenclature . . . 87

**11 Legal Land Descriptions and Soil Survey 89**
11.1 INVESTIGATION A: Legal Land Descriptions . . . 90
11.2 INVESTIGATION B: Using Web Soil Survey to Make Land-use Recommendations . . . 93

**12 Soil Management: Chemical 97**
12.1 PRE-LAB PREP . . . 97
12.2 INVESTIGATION A: Macronutrient Cycles . . . 98
12.3 INVESTIGATION B: Measuring Soil pH and Nitrate Levels with Test Strips . . . 99
12.4 INVESTIGATION C: Soil pH and Nutrient Availability . . . 101
12.5 INVESTIGATION D: Liming and Base Saturation . . . 103
12.6 INVESTIGATION E: Observation of Plant Nutrient Deficiencies . . . 104
12.7 INVESTIGATION F: Common Fertilizer Materials . . . 105
12.8 INVESTIGATION G: Reading and Using a Soil Test Report . . . 107

**13 Soil Management: Physical 109**
13.1 INVESTIGATION A: Soil Water Erosion: Raindrop Impact . . . 109
13.2 INVESTIGATION B: Soil Water Erosion: Residue Cover and Runoff . . . 110
13.3 INVESTIGATION C: Predicting Erosion with the Universal Soil Loss Equation . . . 111
13.4 INVESTIGATION D: Modifying Soil Loss . . . 113

# Preface

> **"Tell me and I forget, teach me and I may remember, involve me and I learn."**
>
> *- Benjamin Franklin*

**Laboratory Schedule**

Note that the laboratory portion of this course is self-paced. The lab has open hours and you can return as often as needed to complete the lab exercises (Laboratory TA's will be in the lab during all open hours to help you). **Make sure you sign in and out by using the posted QR code, reading the pre-lab instructions, and submitting the pre-lab Google Form.**
Labs take approximately 1-2 hrs to complete. You will sign up for a primary timeslot of your choice during the first week of class. Open times: W 8:30 AM - 8:30 PM Th 9:00 AM - 8:30 PM F 9:00 AM - 4:30 PM at *241 Borlaug Hall*.

## Lab Teaching Team

**Teaching Support and Lab Coordinator**

Nora Pearson

pear0747@umn.edu

Office Hours (Zoom):

F 9:35-10:25AM, and by appointment

## Logistics and Laboratory Philosophy - Why is this lab self-paced and what does that even mean?

This laboratory is self-paced to allow you to complete laboratory exercises in as much or as little time as you need for your learning style. During each weekly lab, you will work your way through a series of exercises that will be set up for you - you will use this laboratory manual to complete those exercises, which the TA will then evaluate for completeness and effort. Following evaluation of your lab manual for the week, you will take a short quiz before you leave the lab. The quiz is open book/open note, and you have two attempts on the quiz. The TA will grade your first attempt, after which you will know which questions (if any) you have gotten incorrect. You can then change or modify your answers during the second attempt. The two components (the laboratory exercises completed in the workbook + the lab quiz) make up the points you will earn for the laboratory component of this course.

# 1 Soil Texture, Color, and Structure

Objectives

- Use the Bouyoucos hydrometer to determine soil particle distribution.
- Use the textural triangle to determine the soil textural class name.
- Use the texture by "feel" method to determine soil textural classes.
- Determine soil color using Munsell notation.
- Describe different soil structure characteristics and determine the horizon where most commonly found.

Key Words & Concepts

- Texture
- Loam
- Silt
- Textural Triangle
- Hydrometer
- "Feel" method
- Munsell color
- Aggregate
- Iron Oxides
- Peds
- Granular
- Platy
- Angular Blocky
- Subangular Blocky
- Prismatic
- Single-grained

## 1.1 INVESTIGATION A: Using a Hydrometer to Determine Particle Size

Particle size distribution has become a standard means for characterizing and classifying the fine earth fraction of solid soil particles, and is used to determine the soil texture class. This experiment uses a Bouyoucos hydrometer to measure the density (grams per L) of a liquid mixture ("slurry") of soil and water.

Using the hydrometer allows us to determine soil texture by measuring the grams of the soil particles (sand, silt, and, clay) that remain suspended in the cylinder after a specific period of time. Different sized soil particles are separated by their different sedimentation rates – e.g. larger particles will settle faster in a column of water, while smaller particles remain suspended much longer in the solution (based on Stokes Law).

Watch this video before you start Investigation A

### 1.1.1 Preparation

The two cylinders in this investigation each contain **60** grams of oven-dry dispersed soil – one soil is from an E horizon and one is from a B horizon. After mixing thoroughly with a stir stick, the largest particles (sand) will quickly drop to the bottom of the cylinder. After 40 seconds, only silt and clay particles are left suspended in the water. After two hours, only clay-sized particles remain.

### 1.1.2 Measurements

**40 Second Measurement**

1. Carefully use the stirring rod (approximately 18 inches long with a disk on the end) to completely disperse the soil in the cylinder. This requires that you *slowly* lower and lift the stirring rod up and down in the cylinder until **all the sediment is removed from the bottom of the cylinder.**

2. After stirring, immediately note the time to the nearest second. *Carefully* and *slowly* insert the hydrometer (**the hydrometers are extremely fragile**) into the cylinder. Please refer to the figure on page 2. *Note*: you may need to use your finger to stop the hydrometer from bobbing.

3. After 40 seconds, read the number (at liquid level) on the hydrometer.

4. This reading must be corrected for temperature. Add 0.4 g/L for each degree above 20° Celsius or subtract 0.4 g/L for each degree below 20° Celsius.

**2 Hour Measurement**

1. Due to time constraints, two hour readings will be provided in lab.

**Calculations**: correct readings before calculating sand, silt, and clay!

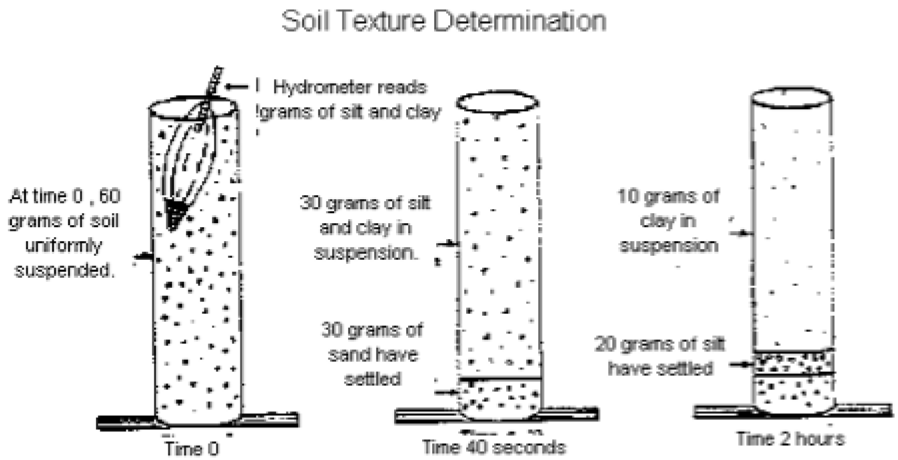



Figure 1.1: The soil in the diagram above would have: (60-30)/60 x 100= 50% Sand; 10/60 x100= 17% Clay; 100-50-17=33% Silt)

$$Sand(\%) = \frac{M_{sample,oven\ dry} - 40s\ reading}{M_{sample,oven\ dry}} x100\ ;\ Clay(\%) = \frac{2hr\ reading}{M_{sample,oven\ dry}} x100\ ;\ Silt(\%) = 100-(\%Sand+\%Clay)$$

**Results**

| **Measurements** | **Sample 1** | **Sample 2** |
|---|---|---|
| Sample mass (oven-dry) | 60 g | 60 g |
| 40s reading (uncorrected | g/L | g/L |
| Temperature (C) | °C | °C |
| 40s reading (corrected) | g/L | g/L |
| % Sand | % | % |
| 2hr reading (uncorrected) | g/L | g/L |
| Temperature @2hr (C) | °C | °C |
| 2hr reading (corrected) | g/L | g/L |
| % Clay | % | % |
| % Silt | % | % |

| **Summary** | **Sample 1** | **Sample 2** |
|---|---|---|
| % sand | | |
| % silt | | |
| % clay | | |

## 1.2 INVESTIGATION B: Using the Texture Triangle

The USDA textural triangle is used to classify the texture class of a soil. The sides of the soil textural triangle are scaled for the percentages of sand, silt, and clay (0-100%). Clay percentages are read along the lines from left to right across the triangle. Silt is read along the lines from the upper right to lower left. Sand along the lines from lower right to the upper left portion of the triangle. The intersections of the three sides on the triangle give the texture class name. For instance, if you have a soil with 20% clay, 45% silt, and 35% sand, it would fall in the "loam" textural class name.

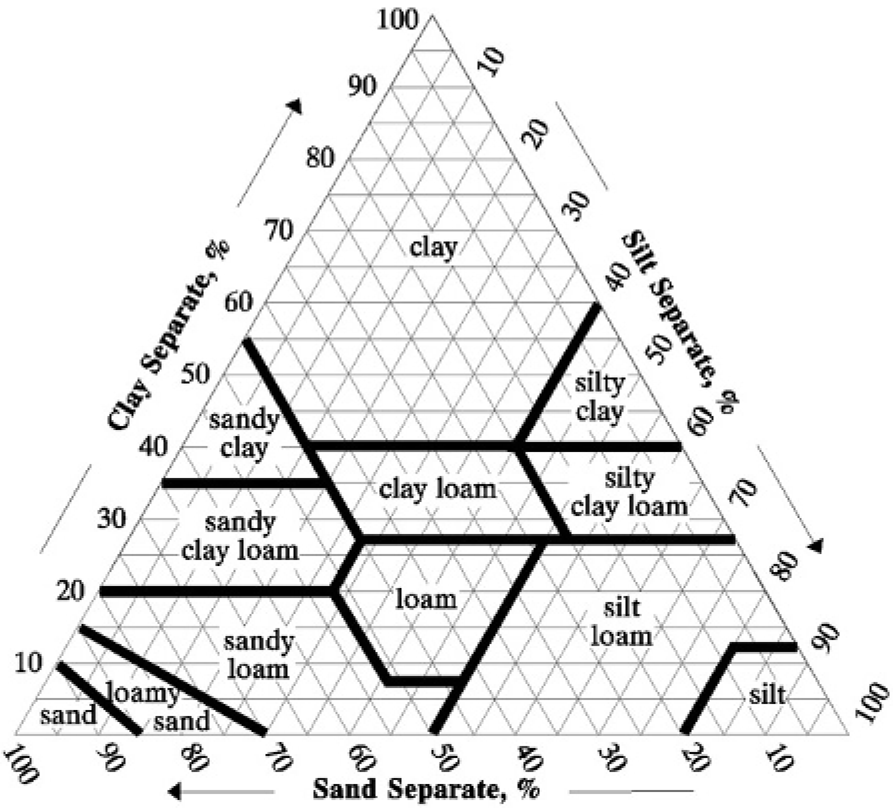



Figure 1.2: USDA Soil Texture Triangle

**Results**

Using the soil particle percent data from Investigation A, determine the texture class for the soil samples 1 and 2.

| Sample | Sand % | Silt % | Clay % | Texture Class |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |

## 1.3 INVESTIGATION C: Texturing Soil with the “Feel” Method

Determining texture by feel takes practice (professional soil scientists can texture soil by feel and determine the texture within five percent clay content!). The following table, chart provided in lab, and text will help you learn how to texture by feel.

> Watch this video before you start Investigation C

1. To determine the soil texture by feel, the soil must be moistened. Add a small amount of water to the soil if needed to give it a putty-like (play-doh) consistency. Not too wet - not too dry!
2. Form the soil into a ball.
3. Try to push the soil between your thumb and forefinger to make a “ribbon” ~ 2mm thick; the longer the ribbon, the more clay there is in the soil.
4. Move the soil between your thumb and forefinger to determine if the soil feels really gritty, really smooth, or somewhere in between. Sand feels gritty, silt feels smooth, clay feels sticky (allows you to form ribbons).
5. Use the provided flow chart and suggested order below to assist in calibrating yourself.

**Practicing – WASH YOUR HANDS BETWEEN EVERY SAMPLE!!!!!!!** Use the known texture samples to practice texturing soil with the “feel” method.

Here is a suggested method of practicing (Nic’s method to the madness):

1. Start with the silt loam – you should be able to make a ribbon, but < 1”.
2. Move to the silty clay loam – you should notice that you can get a longer ribbon, 1-2”.
3. Move to the silty clay – you should be able to get an even longer ribbon, > 2”.
4. In these three samples, you kept increasing clay content while decreasing sand content.
5. Now try the loam – you should notice that it feels like there is more sand in it than in the silt loam, silty clay loam and silty clay, but it doesn’t feel really gritty. The loam texture class should feel like equal proportions of sand, silt and clay. You should be able to make a ribbon, but < 1”.
6. Move to the loamy sand. This should feel much grittier and you shouldn’t be able to make a ribbon. However, the soil should form a ball without being excessively wet.

7. Finally move to the sand. This should feel extremely gritty and you shouldn't be able to make a ribbon. You need to get sands excessively wet in order make a ball out of them.

8. Lastly, try moving from the loam to the clay loam and finally the clay. You should feel a clay increase similar to the silt loam to silty clay loam to silty clay samples, but since these all have more sand, they should feel less smooth and more like a mixture of the particle size classes.

**Note**: Check one box to choose between the characteristics (gritty, smooth, or gritty/smooth). For ribbon length, choose between short (<1"), medium (1-2"), or long (>2").

| Texture | Dominated by gritty feel | Dominated by smooth feel | Equally gritty/smooth | Ribbon length |
|---|---|---|---|---|
| Silt Loam | | | | |
| Silty Clay Loam | | | | |
| Silty Clay | | | | |
| Loam | | | | |
| Loamy Sand | | | | |
| Sand | | | | |
| Clay Loam | | | | |
| Clay | | | | |

Texture the following unknown soils and complete the table.

| Texture | Dominated by gritty feel (Y/N) | Dominated by smooth feel (Y/N) | Equally gritty/smooth (Y/N) | Ribbon length | Textural Class Name |
|---|---|---|---|---|---|
| A | | | | | |
| B | | | | | |
| C | | | | | |

## 1.4 INVESTIGATION D: Soil Color

A Munsell description has three parts: hue, value, and chroma. The color 10YR 4/3 has a hue of 10YR, a value of 4, and a chroma of 3. Each page of a Munsell color book is a different hue. Colors are arranged on each page by value and chroma. Value is the relative lightness or darkness of the color. Higher values indicate lighter soil colors. Chroma is the strength or intensity (or grayness) of the color. Higher chromas indicate more intense colors.

Many soil colors in Minnesota are found on the 10YR page. Soils from the eastern and northeastern parts of Minnesota are redder and probably will be found on the 7.5YR pages. (Note: Pure red = 5R; Pure “orange” (Yellow-Red) = 5YR; Pure yellow = 5Y.)

**Practicing**- Determining soil color

We have provided eight soils for you to color. Answers are given for soils 1 to 4; practice with these. Soils A - D are unknowns; check your skills with these soil samples.

1. Moisten a soil sample (if already moist, do not apply more water). Apply just enough water to moisten the soil, but not so much that it glistens.
2. Look for the matching hue (page) in the Munsell book, starting with the 10YR page. Be sure to check the same chip on the pages before and after to make sure you have the right hue (page).

i.e., if you think that the 10YR 4/3 chip best matches the soil sample, also check the 7.5YR 4/3 (one page redder) and 2.5Y 4/3 (one page yellower) chips to make sure you have the right hue.

| Sample | Color: Munsell notation | Color: color name from book |
|---|---|---|
| A | | |
| B | | |
| C | | |
| D | | |

## 1.5 INVESTIGATION E: Soil Structure

You know about soil *texture* (the proportion of sand, silt, and clay particles). Now you will look at soil *structure*, or the ways in which soil particles (sand, silt, and clay) are held together. Soil particles are bound together into aggregates (or peds) by cementing agents (things that hold the individual sand, silt and clay particles together into larger aggregates) such as microbial gums and other kinds of organic matter, iron oxides, and clay. Additionally, some structures can result from compaction or water movement (i.e., horizontal movement or freeze-thaw).

In some cases, the soil is classified as having no structure (i.e. the individual grains are not cemented together in any natural way).

Complete the charts below using lecture notes and the structural examples provided.

| Structure | Common Master Horizon | Characteristics | Possible cementing agent or process |
|---|---|---|---|
| Granular | A | | |
| Platy | E | | |
| Angular Blocky | B | | |
| Subangular Blocky | B | | |
| Prismatic | B | | |

| Structureless | Common Horizon | Characteristics |
|---|---|---|
| Single-grained (coarse particles) | C | |
| Massive (fine particles) | C | |

Identify 3 unknown structures and the Master Horizon that they most likely came from.

| Sample | Structure | Probable Master Horizon |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |

# 2 Mineralogy and Clay Minerals

Objectives

- Draw the structure of clay minerals.
- Understand why the structure of the clay determines the soils physical and chemical properties.
- Describe differences between 1:1 and 2:1 clay minerals.

Key Words & Concepts

- Kaolinite
- Illite
- 1:1
- Octahedral
- Smectite
- Expanding clay
- Tetrahedral
- Vermiculite
- 2:1

## 2.1 INVESTIGATION A: 3-D Digitized and Model Clay Mineral Structures

Using the iPads provided, choose the iBook named SOIL 2125 Mineral Structures- Lab 2. Start on the first page, and flip through the iBook. Be sure to read the captions. Turn pages by swiping right or left on the top or bottom. The figures are fully-rotatable 3-D diagrams. You can use your finger on the screen to manipulate them. If you need assistance, ask the TA. **Please navigate with the bookmark or flip back to the very first page (Interactive 1.1) for the next person when you are done.**

Answer the following questions from your observation and reading of the models in the iBook:

1. What other elements are present in the mineral structure of Feldspars that are not present in Quartz?

2. Based on what you know about the stability of the cation-oxygen bonds in the BIG 8 (Lecture 1.5), do you think Feldspars are more or less stable (or resistant to weathering) than Quartz?

3. In the phyllosilicates, how are the Si-tetrahedral sheets and Al-octahedral sheets linked?

4. Why is kaolinite called a 1:1 clay mineral?

5. Why are Micas called 2:1 clay minerals?

6. What occupies the space between layers in Mica or Illite?

7. Are there any other atoms besides Si in the tetrahedral sheets of a Mica or Illite? If so, what element?

Note how water (WAT) and other cations (in this case Na) occupy the interlayer of the Vermiculites and Smectites. Unlike Kaolinite and Micas/Illites, Vermiculite/Smectites are shrinking and swelling (or expanding) clays because they have a weak enough negative charge that hydrated ions and water can enter the interlayer space. Smectites can expand even more than vermiculites because they have a lower negative charge so the positively charged cations that hold the layers together are few and the layers can disperse far apart.

## 2.2 INVESTIGATION B: Clay Mineral Block Structures

Draw the mineral structure of the two clay minerals listed below using your lecture notes. Your drawing should include: tetrahedral sheets, octahedral sheets and labeled interlayers.

| Clay | Drawing |
|---|---|
| Kaolinite (1:1) | |
| Smectite (2:1) | |

Explain why Kaolinite does not expand and Smectite does expand.

Draw a picture to aid your explanation.

## 2.3 INVESTIGATION C: Clay Mineral Charges

1. Insert the electrodes (which are connected to the battery) into the clay slurry.
2. Wait ~ 1-2 minutes.
3. Pull the electrodes out and determine the charge (positive or negative) of the clay mineral in the beaker. Wires are attached to the electrodes of the battery – black is positive and white is negative. The clay will be attracted to the opposite charge of the battery electrode (positive attracted to negative).
4. Clean the wires off once you are done with this investigation.

**Observations**

What battery electrode positive (+) or negative (-) were the clays in the slurry attracted to?

What does this tell you about the charge on those clay particles?

## 2.4 INVESTIGATION D: Clay Charge, Ion Charge, and Flocculation

1. Shake up each of the 3 pre-made tubes containing a slurry of a clay-enriched B horizon in eastern MN with 20ml of either deionized H2O, NaCl, or AlCl3. The deionized H2O contains no cations, the NaCl solution contains Na+ ions, and the AlCl3 solution contains Al3+ ions.
2. Wait 5 minutes and watch each tube for the formation of colloids (clay particles held together by electrical attraction to an ion) – when they form, you should be able to see them with your naked eye. The clay colloids will start to settle to the bottom, whereas in the absence of colloid formation the clays will stay in suspension.

Record your observations in the table below. PAY ATTENTION TO THE CLARITY OF THE LIQUID AT THE TOP OF EACH TUBE OF SLURRYS AFTER 5 MINUTES. High clarity indicates the absence of suspended clay particles, while cloudy liquid indicates that clay particles are still floating around in suspension and have not settled out.

| **Solution** | **Ion** | **Water Clarity** |
|---|---|---|
| DI-H20 | None | |
| NaCl | Na+ | |
| AlCl3 | Al3+ | |

**Interpret the results of Investigation D based on what you know about the charge on clays and the ionic potential of cations. What accounts for the differences observed?** Hint: Look at the lecture slides on clay mineralogy. The answer has to do with the charge on clay particles and the strength of the charge on the cation in solution.

## 2.5 INVESTIGATION E: Shrink/Swell Observation

1. Take two Dixie cups. Label one “Kaolinite” and the other “Smectite”.
2. Place a teaspoon of Wyoming bentonite in the “Smectite” cup (WY Bentonite is a type of smectite often used in engineering applications) and a teaspoon of Kaolinite in the “Kaolinite” cup.
3. Using the graduated cylinder, add 20 ml of distilled H2O to each cup and stir with the pencil provided. (If the clay is not saturated, continue to add water in 10 ml increments and stir until you see excess water on the bottom).

Describe what happens to each of the clays. How much water (ml) could you add to each before there was excess water?

Explain this below using what you know about the properties of the major clay mineral groups and the difference between Kaolinites and Smectites.

## 2.6 INVESTIGATION F: Clay Soils

Two soils have been set out for you to look at. One is dominated by Kaolinite clays and one by Smectite clays. Both soils have a clay percentage greater than 35%. Unlike the Kaolinite and Smectite clays in Investigation E, which are from mined geological deposits, these are real soil materials (dominated by each of these different clay types) and so they have color associated with them which is not due to the clay minerals alone.

Note the wetted and dried samples of each and describe what you see in terms of its behavior. Describe the characteristics of each.

| **Dominant Clay Mineral in Soil** | **Moist Characteristics** | **Dry Characteristics** | **General Locations of Soil in US** |
|---|---|---|---|
| | | | |
| | | | |

## 2.7 INVESTIGATION G: Article

Read the short article provided. What was one of the clay minerals that solved the double murder mystery?

# 3 Bulk Density, Porosity, and Organic Matter

Objectives

- Understand bulk density, particle density, and porosity and make appropriate calculations for each.
- Understand the relationship between soil color and organic matter.
- Understand the relationship between bulk density, texture, and organic matter.

Key Words & Concepts

- Bulk density
- Porosity
- Particle density
- WFPS
- Sapric
- Hemic
- Fibric

## 3.1 INVESTIGATION A: Bulk Density Measurements

Bulk density can be determined in three ways: the clod method, the graduated cylinder method, and the soil core method. The **soil core method** is the most commonly utilized method and the one you should be the most familiar with, given appropriate information on a test. The clod method and graduated cylinder method are done in this lab purely to demonstrate other ways to determine the bulk density of soil materials.

### 3.1.1 Bulk Density: Clod Method

$$D_{b,clod} = \frac{(weight\ of\ clod\ in\ air)\ g}{(weight\ of\ clod\ in\ air\ -\ weight\ of\ clod\ in\ water)\ g * 1cm^3/1g}$$

Bulk density is defined as mass (oven dry weight) divided by total volume. Measuring the mass of the clod is straightforward; measuring the volume is not. We can use Archimedes' Principle to measure the volume of any solid, regardless of its shape. Simply stated, if a 50g clod weighs 20g when immersed in water, it must have displaced 30g of water. Since 1 $cm^3$ of water weighs 1 gram, the 30g of water is equivalent to 30 $cm^3$ of water. The volume of the clod, therefore, is 30 $cm^3$. A general mathematical expression for the above statement is:

Volume of clod (in $cm^3$) = [(weight of clod in air) − (weight of clod in water)] g × 1 $cm^3$/1 g

This formula represents the denominator in the $Db_{clod}$ formula above, giving the result of your calculation in units of g/$cm^3$ (also written as g cm-3), which is bulk density.

> **Watch brief video on the clod method. If you have any questions, please ask the TA for assistance.**

1. Take one clod from the counter; a small tag will be attached indicating the clod ID (take note of this when filling out the chart below).
2. Measure the weight of the clod **in air** by attaching the paperclip to the hook hanging from the bottom of the scale. Slide the weights along the scale from left to right, starting with the largest weights first. Ask a TA for help if you need any assistance.
3. Place the water bucket beneath the clod, allowing it to be submerged in the water while hanging from the paper clip and take the weight a second time. This will be the weight of the clod when **submerged in water**.
4. Determine the volume (recall the formula provided above).
5. Place the clod back on the counter, and set the scale back to 0 for the next student.

| | **Clod __** | **Clod __** |
|---|---|---|
| Weight of clod in air | grams | grams |
| Weight of clod submerged in water | grams | grams |
| Volume of water displaced by clod | cm3 | cm3 |
| Volume of clod | cm3 | cm3 |
| Bulk density | grams/cm3 | grams/cm3 |

### 3.1.2 Bulk Density: Soil Core Method

$$D_{b,core} = \frac{(weight\ of\ core\ and\ soil\ -\ weight\ of\ core)\ g}{(volume\ of\ soil)\ cm^3}$$

Volume of a cylinder (the soil core) = *($\pi \times r^2 \times h$)* For r (radius), measure the *inside* diameter of the core in centimeters (not inches).

| | **Measurements** |
|---|---|
| Soil core # | |
| Core weight (empty core provided) | grams |
| Weight of core and soil | grams |
| Weight of soil | grams |
| Core volume | cm3 |
| Bulk density of soil | grams/cm3 |

### 3.1.3 Bulk Density: Graduated Cylinder Method

$$D_{b,cyl} = \frac{(mass\ of\ cylinder\ and\ soil\ -\ mass\ of\ cylinder)\ g}{(volume\ of\ soil)\ cm^3}$$

| | **Measurements** |
|---|---|
| Weight of clean, dry 100 mL graduated cylinder | grams |
| Weight of clean, dry 100 ml graduated cylinder filled with 100 ml of fine sand | grams |
| Weight of soil | grams |
| Volume of soil (1 ml in cylinder = 1 cm3) | cm3 |
| Bulk density of soil | grams/cm3 |

NOTE: Pour the sand into a small beaker and save for Investigation B, Method 1.

## 3.2 INVESTIGATION B: Porosity

Soil porosity is the amount of pore space in a soil. Pore spaces are found between soil particles and are filled with either air or water. Soil porosity can be measured directly and indirectly.

### 3.2.1 Soil Porosity: Direct Method

This method measures the amount of water it takes to fill the soil pores (percent porosity). This method only works for sands where the pores are large so we can fill them up just by pouring water in. For finer-textured soils this does not work very well because air gets trapped in very small pores.

$$Porosity(P)_{direct} = \frac{(volume\ of\ all\ pores)\ cm^3}{(total\ volume\ of\ soil)\ cm^3} * 100$$

1. Fill a 100 mL graduated cylinder to the 100 mL mark with tap water. Tilt the beaker with the fine sandy soil (from Investigation A, Method 2) to a 15° angle. Pour the water very slowly into the soil-filled beaker until the water is **just at** the surface of the soil. The soil surface should glisten. Be very careful not to stir or shake the soil in the beaker.
2. Let the soil stand for several minutes until all of the water soaks into the very small pores. After the water soaks in, add a little more water. Repeat this step as necessary.
3. Determine the amount of water used to fill the pore space in the 100 cm$^3$ of soil by subtracting the volume of water in the graduated cylinder from the original 100 mL volume. Note: We are assuming that the water poured into the soil exactly filled the pore space and thus equals the total pore volume.
4. Dispose of wet soil in the bucket labeled "For Wet Soil Only."
5. Record your results in the table below and make the necessary calculations.
6. Rinse the beaker in the bucket provided and wipe it out with a towel.

| | **Measurements** |
|---|---|
| Initial volume of water | 100 mL |
| Volume of water remaining in cylinder after all soil pores are filled | mL |
| Volume of water filling soil pores (initial – remaining) | mL |
| Total volume of soil (1 cm3 = 1 ml) | 100 mL |
| Porosity = (volume of water filling pores / total volume) × 100% | % |

### 3.2.2 Soil Porosity: Indirect Method

This method uses bulk density and particle density to determine porosity (percent pore space). Most mineral soils have a particle density of about 2.6 to 2.7 grams/cm$^3$. *For this exercise, assume a particle density of 2.65 g/cm$^3$* (the same density as quartz, a major constituent of mineral soils).

$$Porosity(P)_{indirect} = [1 - (\frac{(D_b\ by\ graduated\ cylinder\ method)\ \frac{g}{cm^3}}{(2.65\ \frac{g}{cm^3})})] * 100$$

Depending on accuracy in collecting your porosity data, your calculations of porosity by the direct method and the indirect method should be similar. Record and compare your results.

Direct method:

Indirect method:

## 3.3 INVESTIGATION C: Bulk Density of Mineral Soils

Soil bulk density is the mass of oven dry soil (grams) divided by the total volume of soil (cm3). Soil bulk density may be highly variable over small distances and may even change within the same horizon. Bulk density is also highly correlated with soil texture. Compare and rank the bulk densities for the soil materials within each box from low to high bulk density:

| **Rank** | **Box Number** |
|---|---|
| Lowest | |
| \| | |
| \| | |
| \| | |
| \| | |
| \| | |
| Highest | |

Give a general description of why the soil materials are ranked that way. Using your lecture notes, recall what factors influence bulk density.

## 3.4 INVESTIGATION D: Soil Color and Soil Organic Matter

You can use soil color to estimate the amount of organic matter within a soil. Use the Munsell color charts and the estimation cards to determine soil color and the subsequent amount of soil organic matter.

| **Soil Name** | **Soil Color** | **Organic Matter (%)** |
|---|---|---|
| A | | |
| B | | |
| C | | |

## 3.5 INVESTIGATION E: Organic Soil Types and Experiential Observation

Examine the three different examples of organic soils and classify the three unknowns as sapric, hemic, or fibric.

| Dish | Classification |
|---|---|
| 1 | |
| 2 | |
| 3 | |

Pick up a chunk of the moist organic soil in the bucket. This soil is a decomposed peat from northern Minnesota. Rub the material between your fingers and notice how most of it rubs away or disappears. In a mineral soil, you would feel the mineral grains (sand, silt or clay).

What is the definition of soil texture?

Does this soil fit into any of our textural classes?

## 3.6 INVESTIGATION F: Ranges and Estimation of Bulk Soil Physical Properties

*There is no lab station*; find a spot near the lab and answer the following questions. Use your lecture notes (in particular, **Lecture 1.4**)!

1. What is the common Db range (g/cm3) for typical cultivated topsoils?

2. What is the Db range (g/cm3) for typical uncultivated topsoils?

3. I have two soils. Soil 1 is a clay with a Db of 1.4 g/cm3. Soil 2 is a loamy sand with a Db of 1.4 g/cm3. Will root penetration likely be inhibited in either of these soils? Why or why not?

4. Someone tells you they calculated a Db of 2.7 g/cm3 from a soil core they took. Should you believe them? Why or why not?

5. In general, what is a reasonable value to guess for WFPS (i.e., if you don't know anything else about a soil)? Think about our pie chart from lecture 1-1.

6. Soil A has a porosity of 52% and a WFPS of 92%. Soil B has a porosity of 23% and a WFPS of 92%. Which one contains more water?

7. Without doing any calculations, which soil in the previous question (A or B) has the higher bulk density? Why?

# 4 Cation Exchange Capacity, Soil pH and Salinity/Sodicity

Objectives

- Determine pH of soil slurries using a pH meter.
- Test for carbonates using HCl.
- Understand the source of negative sites for CEC and why cations exchange from the soil solution to the exchange sites.
- Test for salinity using a conductivity meter.

Key Words & Concepts

- pH
- Calcareous
- Hydrochloric acid
- Saline
- CEC
- Sodic

## 4.1 PRE-INVESTIGATION

In this laboratory exercise, you will be working with a set of 8 soils that vary in their CEC, base saturation, pH, and salinity. Material from lectures 1.8 and 2.2 will help you. To predict CEC, focus on the mineralogy, texture and OM% (soils with high OM, more clay, and 2:1 minerals will have higher CEC). To predict pH, calcareous status, and salinity, think about the climate that these soils come from (soils in wetter climates typically have lower pH, and are not calcareous – only soils in the driest climates are usually saline because water dissolves salts). Fill out the table on the next page before you begin; **you are strongly encouraged to work in groups!** When you have completed the pre-exercise, have the TA check it over and proceed with the lab exercises.

| Sample | Climate | Location of Origin | Dominant Mineralogy | Texture | OM% |
|---|---|---|---|---|---|
| 1 | Cold/Humid | Northern Minnesota | N/A | N/A | 95% |
| 2 | Temperate/ Humid | Anoka County, MN | Quartz | Loamy Sand | < 1% |
| 3 | Temperate/ Humid | Anoka County, MN | Quartz | Loamy Sand | 4% |
| 4 | Tropical/Wet | Puerto Rico | Fe/Al Oxides | Clay | 1% |
| 5 | Temperate/ Humid | East Central Minnesota | Mixed 2:1 and 1:1, Fe Oxides | Sandy Clay Loam | 2% |
| 6 | Temperate/ Humid | West Central Minnesota | Predominantely 2:1, some 1:1 | Clay Loam | 2% |
| 7 | Temperate/ Dry | Far Western Minnesota | Predominantely 2:1, some 1:1 | Clay Loam | 2% |
| 8 | Temperate/ Very Dry | South Dakota | Predominantely 2:1 | Clay Loam | 2% |

Fill in the table on the next page with predictions based on your lecture notes.

| Sample | CEC | pH | Calcareous | Salinity |
| --- | --- | --- | --- | --- |
| | (cmolc/kg, pH=7); Low < 10, Medium 10-100, High > 100 | Acidic < 6, Near-neutral 6-8, or Alkaline > 8 | Contains CaCO3 AND/OR Na2CO3; Mark Yes/No | Saline/Non-saline |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |

## 4.2 INVESTIGATION A: Soil pH

You are encouraged to work in groups for this portion of the lab.

**Watch brief video on how to use pH meter. If you have any questions, please ask the TA for assistance.**

1. Use the pH meter to determine the pH of each soil provided slurry.
2. Measure the slurries in order. Measure the pH first to check the pH meter is calibrated.
3. Wash the electrode thoroughly with deionized water between every sample into the rinse bottle.
4. If the pH value has not stabilized after 2 minutes, record the value to one decimal place and move on to the next sample.
5. When you are finished, place the electrode in the de-ionized water.

| Soil Number | Soil pH |
|---|---|
| pH 4 Buffer | |
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |

Very generally, compare these values to your pH predictions in the pre-investigation exercise:

## 4.3 INVESTIGATION B: Calcareous Soils

1. Place a small quantity of each soil on a spot plate.
2. Add two drops of 10% HCl.
3. Check for effervescence. "*Effervescence*," or bubbling, indicates the evolution of $CO_2$ from neutralization reactions between carbonate salts – $CaCO_3$ and $Na_2CO_3$ – and the HCl. Calcareous soils contain carbonate salts that react with acid (HCl in this case).

| Soil Number | Is the Soil Calcareous (Yes/No)? |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |

## 4.4 INVESTIGATION C: Cation Exchange Observation

Solutions of two dyes (Eosin red: negatively charged (-); and Methylene blue: positively charged (+)) were added to the soil in the filter and the leachate was collected in the flask.

Explain the predominant color observed in the leachate after the solution filtered through the soil into the flask. What color do you see? What is the reason for this?

| Slurry pH in Distilled Water | Slurry pH in MgCl2 |
|---|---|
| | |

Explain why adding a concentrated salt (which contains no H+ ions) would decrease the pH (increase the number of H+ ions in solution). HINT: Cation exchange plays a huge role!

## 4.5 INVESTIGATION D: Saline Soils

Determine the electrical conductivity of each soil slurry provided using the conductivity meter. You will have to convert the reading on the meter to the units of dS/m to determine if the soil would classify as a saline soil or not. **READ CAREFULLY: The meter will output two different salinity units depending on the concentration of salts in the solution or slurry.** If the conductivity meter is reading a number in microsiemens (uS), *divide* the number by 1000 to obtain the salinity in dS/m. If the conductivity meter is reading a number in millisiemens (mS), the number on the display is equivalent to dS/m.

**Watch brief video on how to use electrical conductivity meter. If you have any questions, please ask the TA for assistance.**

1. Use the meter to determine the electrical conductivity of each soil provided slurry. MAKE SURE THE CAP IS OFF THE PROBE.
2. Measure the slurries in order.
3. WASH THE ELECTRODE THOROUGHLY WITH DEIONIZED WATER BETWEEN EVERY SAMPLE INTO THE RINSE BOTTLE.
4. If the value has not stabilized after 2 minutes, record the value and move on to the next sample.
5. When you are finished, place the electrode in the deionized water.

| Soil Number | Salinity | Salinity |
|---|---|---|
| | EC (dS/m) | Saline Soil (Yes/No); recall that soil is saline if the EC is $>$ 4 dS/m |
| Deionized Water | | |
| Tap Water | | |
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |

6. Very generally, compare these values to your predictions in the pre-investigation exercise:

## 4.6 INVESTIGATION E: Calculation and Interpretation of CEC, pH and Salinity

The same 8 soils that you have working with in this laboratory were also tested by the University of Minnesota Soil Testing Laboratory, which provides analytical testing to clients who need to know detailed information about the properties of their soils. There is no lab station for this investigation; find a spot near the lab and answer the following questions. *Use your findings in investigations A-D and soil testing results to answer the following questions; ask a TA for a data sheet.*

1. First **focus on soils 4, 5, 7, and 8,** which have specific exchange phase ion composition data reported on the data sheet. Calculate the CEC from the sum of exchange phase cations given for each soil. Do these numbers match the whole soil CEC reported in the table?

2. Calculate the Base Saturation percentage (BS%) for soils 4, 5, 7 and 8.

3. Look at the pH and exchange phase composition of Soil 4. What major problems might you expect with plant growth on this soil?

4. Which of the 8 soils would be classified as Saline soils based on the analytical data reported on the sheet? (Saline soils are soils that have EC > 4 dS/m).

5. Calculate the Exchangable Sodium Percentage (ESP%) for the soils you identified as saline in Question 4.

6. Which of these soils would be classified as Sodic soils? (Sodic soils have an ESP% > 15%).

7. What major problems for plant growth would you expect to encounter in Sodic soils?

Now, consider the geographic location and climate of all 8 soil samples you investigated (from the table on the first page of this lab):

8. Soils 5 and 6 both occur in a temperate/humid climate and in relatively close proximity (Soil 5 is from East-Central MN and Soil 6 is from West-Central MN). They were both formed in parent material that dropped out of glacial ice (termed glacial till). However, their CECs, mineralogies, calcareous status, and pHs are very different. What "tale" did we talk about in class (see the end of lecture 1.8 – soil pH) that would account for these differences?

9. Sodium carbonate salts (Na2CO3) are more soluble than calcium carbonate salts (CaCO3). This means that when sodium carbonates are dissolved, more OH- is released. Sodium carbonates also increase Na+ concentrations. Both soil 7 and 8 are saline, but differ in their sodicity status and pH. Briefly explain how the different solubilities of Na and Ca carbonate salts mean that sodic soils would be (1) found in drier climates and (2) have higher pHs than other non-sodic (but still saline) soils.

## 4.7 Soil Water Data Preparation for Next Week's Lab (THIS IS IMPORTANT!)

Follow these steps to prepare your sample for next week's lab:

1. Select a can & write your name on a piece of masking tape with a Sharpie pen and attach the tape to the side of the can.
2. Write your name on the form provided.
3. Record the weight of the can.
4. Fill the can 1/2 full with soil from the designated bucket.
5. Record the weight of the moist soil plus can.
6. Place the uncovered can on the tray.

# 5 Soil Water

**Objectives**

- Understand field capacity for soils of different textures
- Be able to use and interpret tensiometer readings
- Calculate soil water problems

**Key Words & Concepts**

- Tensiometer
- Field capacity
- Saturation
- Capillary action

## 5.1 INVESTIGATION A: Constructing Water Retention Curves

On the bench, you will see six plants. Three of these are growing in a silt loam and three are growing in a sand. We have placed these soils (and thus the plants) under different water treatments: Saturation, slightly wetter than field capacity, and wilting point:

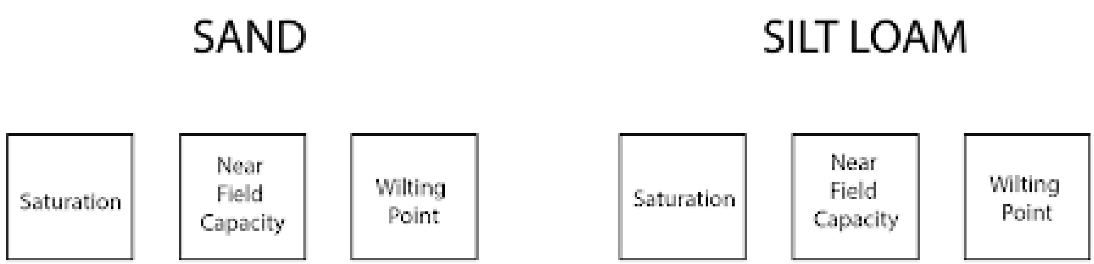



Figure 5.1: Water Treatments

Using a moisture meter, you will construct a water retention curve for each of these soils. You will use the moisture meter to measure the volumetric water content and the tensiometer to measure the matric potential in bars.

**Watch brief video on how to use moisture meter. If you have any questions, please ask the TA for assistance.**

Fill out the following table:

| | **Matric Potential (Bars)** | **Volumetric H2O Content (θv)** |
|---|---|---|
| Sand (@ Saturation) | 0 | |
| Sand (~FC) | -0.33 | |
| Sand (@ WP) | -15 | |
| Silt Loam (@ Saturation) | 0 | |
| Silt Loam (~FC) | -0.33 | |
| Silt Loam (@ WP) | -15 | |

Use the data from the table on the previous page to construct water retention curves (volumetric water content vs. matric potential (i.e., tension, or negative pressure) note that the scale is logarithmic) for each of these soils on the table on the next page and answer the following questions:

1. Using the graph above, estimate the total plant available water (in % by volume) for each of these soils. FC is defined as -0.33 bars and wilting point is defined as -15 bars.

2. Which soil will hold more plant available water when at field capacity? WHY?

3. Describe the plant responses to these different treatments (i.e. field capacity and wilting point) - what do the plants look like?

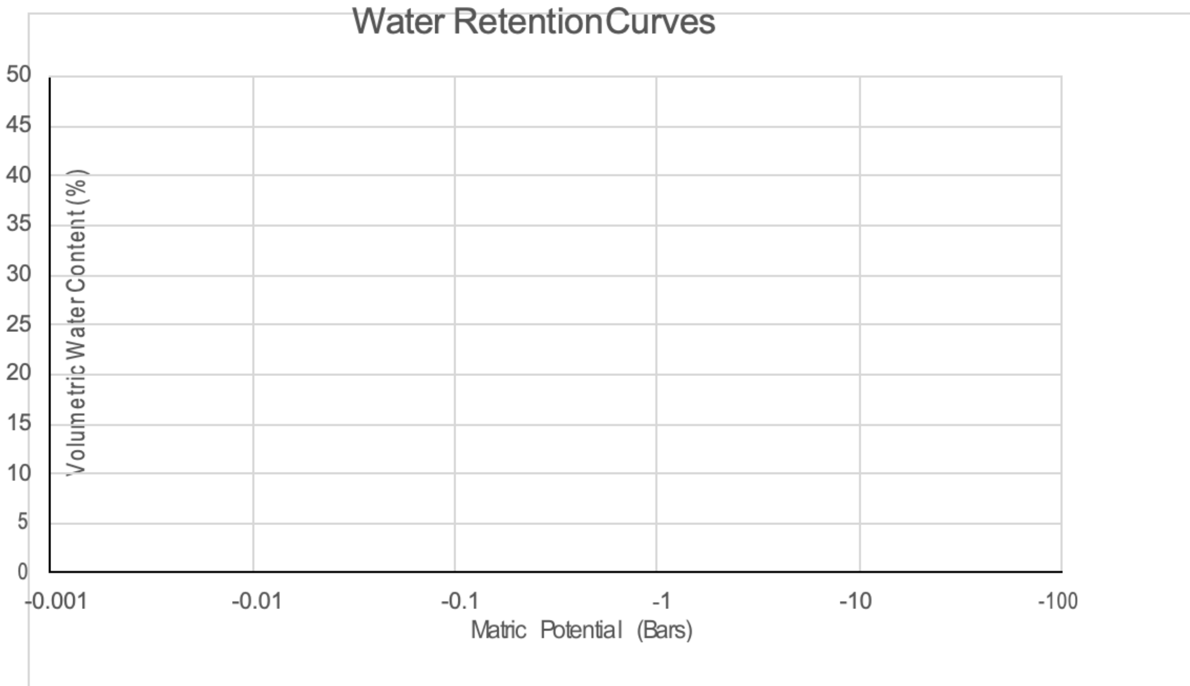



Figure 5.2: Water Retention Curve

4. Using what you know about soil at this point in the class, describe the processes that are driving the plant response in each treatment. For example, think about why plants experiencing the saturated treatment look the way they do? Why do the plants experiencing the wilting point treatment look the way they do?

## 5.2 INVESTIGATION B: Determining Field Capacity

**Watch brief video on how to do this exercise. If you have any questions, please ask the TA for assistance.**

**Preparation**

1. Weigh a small plastic tray on the balance.
2. Move the weight on the far beam to 20 grams.
3. With a spoon, add soil to the tray until balanced.
4. Take a single sheet of the round filter paper and fold it in half and then fold it in half again. You should be able to create a small cone of filter paper that will fit inside one of the funnels.
5. Once you have the filter in place in the funnel, add 20 grams of soil to the funnel.
6. Carefully fill one of the graduated cylinders (BLUE base) with 25 mL of water.
7. Place the funnel with the filter paper and soil on top of one of the 100 mL graduated cylinder.
8. Carefully pour all 25 mL of water on top of the soil. Add about a third of the water, wait for it to be absorbed into the soil. Then slowly add the remainder. Do not add so much water at one time that it overtops the filter paper. *The silt loam may take 10 minutes or so to add all of the water.*
9. Record the amount of water (in mL) that has passed through the soil sample and has collected in the graduated clynder. Assume that 2 mL of water is absorbed by the filter paper.
10. Repeat this process for the soils labeled Sand and Silt Loam and record your results in the table below.

**Volume retained in the soil** = (25mL) - (Volume retained on filter paper) - (Volume passed through the soil). This is an estimate of field capacity.

**θg at Field Capacity** = (mL $H_2O$ retained) / (g dry soil), because 1 mL $H_2O$ = 1 g $H_2O$. Assume your 20 g of soil was oven dry.

| | Volume Retained on the Filter Paper | Volume Passed Through the Soil | Volume Retained in the Soil | Calculate θg at Field Capacity |
|---|---|---|---|---|
| Sand | 2 mL | | | |
| Silt Loam | 2 mL | | | |

1. Explain why the different soil textures retained differing amounts of water.

2. Which of these textures has the highest water content at field capacity?

## 5.3 INVESTIGATION C: Tensiometer Observation

In this investigation, you can observe the use of a tensiometer to measure matric potential (the tension at which water is pulled by the soil) for two different soils at different water contents. The tensiometer is essentially a water column with a porous ceramic tip at the bottom. The pores in the ceramic are so small that water will not move through the ceramic under the influence of gravity alone (i.e. the force of gravity does not pull down hard enough for the water to move through). However, you now know that due to adhesion, cohesion, and capillary action that soils can exert a tension on water and pull it against gravity. The vacuum gauge readings show the relative amount of tension that the soil is exerting on the water.

To make the gauges reasonable for the general public to use, scales are usually from 0-100 in positive numbers – a high reading on the gauge is caused by a dry soil that has a high tension. Note that this is different than what we discussed in lecture in that the values are positive rather than negative – these are designed for consumer use and are scaled and calibrated based on convenient numbers, not fundamental principles, but the concepts are exactly the same. These types of tensiometers are commonly used for irrigation scheduling to let the land managers know when to turn on the sprinklers, such as at a golf course.

Read the tension gauge. The units are in centibars of tension (if you put a negative in front of the number and divide by 100, you would have "bars" of tension as we discussed in class). Note how it has changed since the start of the week for each soil. Mark the current gauge reading and time on the graph so we can chart the changes throughout the week.

**Tensiometer Readings:**

Loamy Sand: ______________ Silt Loam: ______________

## 5.4 INVESTIGATION D: Observations of Capillary Action

Capillary action enables soil moisture to move in any direction within the soil as water moves from wetter areas to drier areas. Observe the different sized capillary tubes and the height at which the water reaches in each tube.

1. Explain the relationship between the height of the water in the capillary tubes and the tube diameter using the terms adhesion, cohesion and gravity.

2. Now observe the two soil columns – one is fine sand (particles ~ 200um in diameter) and the other a coarse sand (particles ~ 750um in diameter) and observe the height of water rise in each column. Explain the differences in the height of rise based on what you know about soil textural class, particle size, and pore size.

3. The zone between the totally saturated soil material below the water surface in the tub and the highest height of rise due to matric potential is sometimes called the "capillary fringe" – it represents the height at which water has been pulled up from a saturated zone against gravity by capillary action or matric potential. Would you expect a silty clay or a sandy clay loam to have a larger capillary fringe (you might want to reference your textural triangle)? Why?

## 5.5 INVESTIGATION E: Determining Soil Moisture by Weight and Volume

The soil can that you prepared last week (present soil condition) has been oven dried. Weigh the oven dry soil along with the can and lid.

Using the data you recorded last week, fill in the table below:

| Property | Measurement |
|---|---|
| Weight of can | grams |
| Weight of moist soil + can | grams |
| Weight of moist soil | grams |
| Weight of oven dry soil + can | grams |
| Weight of oven-dried soil | grams |
| $\theta g$ of moist soil last week | % |

The bulk density of the moist soil in the bucket last week was 1.3 g/cm3. Calculate the volumetric water content ($\theta v$):

## 5.6 INVESTIGATION F: Soil Water Problems

You need to know how to calculate the amount of water in a soil at various water potentials. This knowledge will help you understand that it is not the total amount of water in a soil that determines whether water is available to plants but it is the plant available water (PAW) that matters.

Given:

Soil Core Volume = **250 cm$^3$** (for each soil core below)

Weight of soil core at -0.33 bar (field capacity: FC) = **420 g**

Weight of soil core at -15 bar (wilting point: WP) = **350 g**

Weight of soil core at present sampling time = **395 g**

Weight of Oven dry soil core = **300 g**

1. What is the **bulk density**?

2. What is **θg(FC)**? What is **θg(WP)**? What is **θg(at present)**?

3. What is **θv(FC)**? What is **θv(WP)**? What is **θv(at present)**?

4. What is the total possible plant available water by volume? Remember, total possible plant available water (PAW) for a given soil texture is the difference between the volumetric water content at field capacity (FC) and the wilting point (WP): **θv(FC) – θv(WP)**? (*Use your results from question 3 above*)

5. How many *inches* of plant available water would there be at field capacity if the soil layer was 3 ft. thick?

6. How many inches of plant available water are left in the 3 ft. soil layer in the present condition *(i.e. at the time of sampling in the field)*?

7. If a corn crop requires ~ 0.3 inches of water per day during the height of the growing season and the roots have access to the entire 3 ft layer you used for calculations in 5 and 6, how many days of corn growth can the current soil moisture storage support (without additional rainfall or irrigation) before the corn begins to wilt?

# 6 Biological Processes (1)

Objectives

- Understand the dynamics of the nitrogen cycle.
- Observe nodules involved in symbiotic N2 fixation.
- Understand the effect of biological activity and soil organic matter on aggregate stability.
- Observe soil fauna.
- Inoculate plates.

Key Words & Concepts

- Leaching
- Nitrification
- Mineralization
- Denitrification
- Volatilization
- Aggregates
- Microbial Gums
- Symbiotic Fixation
- Nodules
- *Rhizobium*

## 6.1 INVESTIGATION A: Forms of Nitrogen

You will probably come across many complex and confusing representations of the nitrogen cycle in other venues. Use your knowledge of the simplified representation of the nitrogen cycle that we discussed in class to fill in the blanks in the appropriate places on the diagram below (which I note is also incomplete).

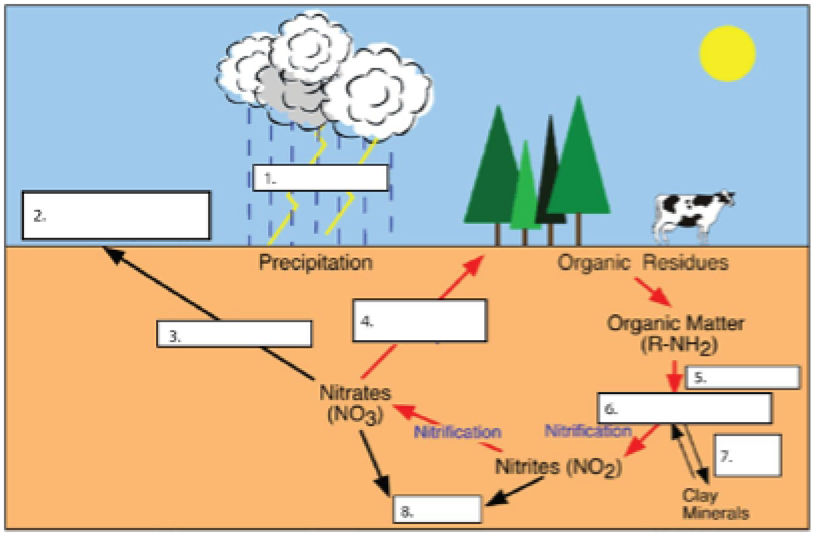



Figure 6.1: The Nitrogen Cycle

| **Fill in Each Number with Best Choice from Word Bank** | **Word Bank** |
|---|---|
| 1. | N2 |
| 2. | Abiotic N Fixation |
| 3. | Cation Exchange |
| 4. | NH4+ |
| 5. | Mineralization |
| 6. | Plant Uptake |
| 7. | Denitrification |
| 8. | Leaching |

## 6.2 INVESTIGATION B1: Observing Nodules

Observe the roots of the live alfalfa and soybean plants (both uninoculated (no nodules) and inoculated (nodules)) which have been provided for you to look at. Don't be afraid to pull a plant out and look at the roots! Put it in the container of soil when finished. Rhizobia is the common name given to a group of small, rod- shaped, Gram negative bacteria, which collectively have the ability to induce nodule production on the roots of leguminous plants. Observe the nodules on the plants in the jars.

Draw a diagram of a nodule and a root:

## 6.3 INVESTIGATION B2: Dissecting Nodules

Pluck a nodule off of either a soybean or alfalfa root and cut it open with a razor blade under the dissecting scopes. When you cut open an active nitrogen-fixing nodule, a significant portion of the nodule should be pink or red in color. This color is due to the presence of a hemoglobin similar to that found in blood (known as “leghemoglobin” in legumes), and regulates oxygen supply, in this case, to the bacteria. The amount of hemoglobin present is usually closely correlated to amount of nitrogen fixed, with white or green-colored nodules usually very limited in their ability to fix nitrogen. Remember though that nodules have a finite life span (in the case of soybean estimated at 50-60 days) so that toward the end of the growing season many of the initial nodules will have already begun to senesce, and are brown or green in color, while the more active nitrogen-fixing nodules may now be located on lateral roots. Cut open a nodule from the samples provided, view under the microscope, and complete the following table.

| Nodule Color | Explanation |
|---|---|
| | |

## 6.4 INVESTIGATION C: Aggregate Stability

The ability of a soil aggregate to withstand disruption by water depends in large part on the amount of microbial exudates and gums present in the soil organic matter. An aggregate stability test consists of moving soil slowly up and down on a screen suspended in water. Observe differences in water stability of the aggregates in the A and E horizon of a soil by:

1. Obtain similar sized aggregates from samples of A and E horizons.
2. Place each aggregate on a screen.
3. Immerse the screen below the water level of the container.
4. Observe differences between the aggregates in terms of their ability to withstand disruption by water. You should see that one of the aggregates "slakes" or falls apart significantly faster than the other.

| Horizon | Observation |
|---|---|
| A | |
| E | |

## 6.5 INVESTIGATION D: Soil Organism Observation

We have placed some soil from the field in a funnel which has a screen at the bottom. At the top is a heat lamp. Mobile organisms in the soil (like microarthropods) move downwards away from the heat and fall into the petri dish full of water. Observe the organisms extracted in the petri dish from this soil under the microscope and complete the following table. See if you can find any "soil critters" in the soil.

| Type of Organism | Number/Size Observed and Description |
|---|---|
| | |
| | |
| | |
| | |

NOTE: See the list of organisms. Lots are possible!

## 6.6 SETUP FOR NEXT WEEK'S LAB: Culturing Microorganisms from Soil Materials

Soils are literally teeming with microbiota and it is very easy to culture them on many different types of media. Because soil microorganisms are highly diverse, we can only ever culture a small portion of the total in the lab. However, this exercise will show you that (unsterilized) soil materials are literally bursting at the seams with life.

Watch this video before you make your PDA plate - work in groups of 2-3 if possible.

1. Take a plate of PDA (Potato Dextrose Agar). Without opening it, flip it over and with a permanent marker, draw 2 perpendicular lines to divide the plate into 4 quadrants, label the quadrants as shown in the example plate, and put your names and today's date on the bottom of the plate.
2. Put on a pair of gloves (this is not a sterile environment!).
3. Using the sterilized toothpicks provided (use a different toothpick or set of toothpicks for each soil material provided!), inoculate each labelled quadrant of the plate. Inoculate by swishing a sterile toothpick through them and gently wiping the proper quadrant with the toothpick, leaving small bits of soil should be sufficient.
4. There are 4 materials to inoculate with:
    1. Autoclaved – Sterilized sand,
    2. Topsoil from the campus experimental fields,
    3. Dried soil which is high in organic matter but has been sitting, air-dried, for over 10 years, and
    4. A saturated wetland soil.
5. Seal your plate with parafilm and place in the tray provided.

# 7 Biological Processes (2)

Objectives

- Observation of inoculated plates.
- Understand concepts of redoximorphic features in soils.
- Understand concepts in bioturbation.

Key Words & Concepts

- Redoximorphic
- Well-drained
- Depletions
- Aerobic
- Poorly-drained
- Bioturbation
- Anaerobic
- Concentration

## 7.1 INVESTIGATION A: Observation of Inoculated Plates

The plates you inoculated with various soil materials last week are on display. Find and look at your plate and many others to see the diversity of microorganisms that have grown from your soil inoculants. Take a look at some of the plates under the microscopes provided and look at even the seemingly "empty" parts of the dish – you might be surprised at what you see growing there.

**Fungi** – the most ubiquitous soil fungi are in the *Trichoderma* and *Fusarium* genera. Most soil *Fusarium* sp. are non-pathogenic, but this genus is highly diverse and responsible for many important crop diseases. Fungi are readily identifiable in culture by their filamentous growth pattern (known as hyphae), which appear as strands to the naked eye and under the microscope. In addition to these two genera, there is a huge diversity of fungi that live in soils.

**Bacteria** – bacteria will form colonies (roughly spherical in shape). Actinobacteria are one of the most important groups of soil bacteria and include the *Streptomyces* genus, which are the origin of many modern antibiotics (these are also the "Geosmin" producing bacteria – the earthy smell of soil). In addition to the Actinobacteria, there is a huge diversity of bacteria that live in soils.

1. Are you surprised at the amount and diversity of organisms that grew in only one week from your soil inoculants?

2. Some of the plates have been completely overgrown. However, find one that wasn't. Does it appear that anything grew from the autoclaved (sterilized) soil material?

3. *Estimate* the total number of distinct colonies or organisms on your plate. If you were going to study soil microorganisms, does it make sense why you would need to do a soil dilution of 1,000 to 10,000 times in order to get individual countable colonies that you could work with in a lab?

4. *Estimate* the total number of different organisms on your plate (that look different to the naked eye).

5. Finally, under the microscope, look at the small aggregate of air-dried soil (Soil 3) that you placed on the plate. Do see fungal hyphae growing out of it? Does it surprise you how many organisms are still alive and viable in soil that has been sitting air-dried for over 10 years?

## 7.2 INVESTIGATION B: Observation of Redoximorphic Features in Mini-Monoliths

Observe the mini-monolith labelled “Mottles” to see redoximorphic features (one kind of mottling in soils) that are zones of iron depletion and iron concentrations. These zones are formed when the soil is saturated for a period of time (the iron oxides ($Fe^{3+}$) coating the mineral grains are reduced by anaerobic bacteria which use the $Fe^{3+}$ as an electron acceptor, reducing it to $Fe^{2+}$, which is colorless, soluble and mobile in the soil solution). If the soil is then dried out during a drier part of the year, the iron reoxidizes into concentrations, but the zones in between the concentrations where the Fe was depleted will still appear grey because they won’t have iron oxide coatings.

Because redoximorphic features only form where the soil is saturated for a significant period of time during the year, when we see them in a soil profile, they give us a record of the highest depth that the soil is saturated at throughout the year. For this reason, redoximorphic features play a large role in field determinations of septic system design as well as wetland delineation.

Therefore, in general, *well-drained* (aerobic) soils will have continuous coatings of iron-oxides on all the mineral grains and will appear the typical Fe-oxide colors throughout (brown, red, orange, yellow), while *poorly drained* soils will exhibit redoximorphic features in the form of iron concentrations and depletions (mottles), or a completely grey color if iron has been reduced (solubilized) and removed by moving groundwater.

**Question:** Based on the colors you see in the *poorly drained* mini-monolith, what is the depth (measured from the soil surface) that the soil is saturated to at some point during the year?

> Tip
>
> 1 cm on the mini-monolith = 3 cm in the actual soil it was taken from; so multiply your depth measurement on the mini-monolith x 3 to get the actual depth.

## 7.3 INVESTIGATION C: Observation of Redox Features in Vials

Three weeks ago, you filled two vials with a orangish-colored soil material from Tennessee. You saturated the soil materials in both vials by filling the vial up with water. In one vial (your control), you did not add anything. In the second vial (your experiment), you added a teaspoon of sugar and a small pinch of inoculant from an anaerobic wetland soil. Find the vials that your discussion group made and observe the vials of other groups as well. **Do not open the vials.**

You will also notice that your demo vial probably smells terrible. That is from the reduction of SO42- (sulfate) to H2S (hydrogen sulfide gas) and CO2 (carbon dioxide) to CH4 (methane), as evidenced by the large gas bubbles. Hydrogen sulfide and methane smell bad and are produced in copious amounts in saturated soils (like wetlands). This is why wetlands can sometimes smell bad as you walk through them.

Describe the differences you see between the vials. Do you see differences in the color of the soil materials and the quantity of gas bubbles?

| Treatment | Refridgerated | Room Temperature | Heated |
|---|---|---|---|
| Control (No sugar or inoculum) | | | |
| Sugar + inoculum | | | |

**Question:** Explain the differences between the three vials in terms of what you know about how redoximorphic features form and the effects of saturation on iron forms and the color of soil materials. Look at the chalkboard for help.

## 7.4 INVESTIGATION D: Earthworm Activity

Earthworms play a significant role in mixing the soil. Observe the differences in the three columns and, based on your observations, provide four examples of how earthworm activity changes soil properties. Many of these changes are positive from a plant growth perspective, but can have other ecological effects as well. Please refer to Lecture 2-7 for assistance in answering the questions below.

| **Earthworms change soil properties by:** |
|---|
| 1. |
| 2. |
| 3. |
| 4. |

# 8 Rocks, Weathering, and Master Horizons

Objectives

- Identify rocks that are commonly found in Minnesota.
- Observe and identify physical and chemical weathering processes.
- Differentiate between soil horizons and soil transformation processes.

Key Words & Concepts

- Chelating
- Exfoliation
- Abrasion
- Hydration
- Hydrolysis
- Effervescence
- Hydroxides
- Dissolution
- Acidification
- Oxidation/Reduction
- Precipitated

## 8.1 INVESTIGATION A: Mineral Identification

Minerals, even of the same type, can vary in color and physical properties making visual identification challenging. Some of the most common and important primary soil minerals are quartz, orthoclase (feldspar), micas (biotite and muscovite), apatite, and calcite, and amphiboles/pyroxenes. Common iron-containing soil minerals are goethite and hematite. Check each one off as you read the description and examine the specimen provided.

**PRIMARY MINERALS** are formed from the original crystallization and solidification of magma). These minerals are present in igneous rocks and can be present in sedimentary rocks and metamorphic rocks if they survive the weathering process (sedimentary) or increased heat and pressure (metamorphic).

□ **Quartz** is a framework silicate mineral (composed almost entirely of $SiO_2$) that is very common in soils. It is fairly easy to recognize. It is usually colorless, transparent to translucent, and often is slightly "frosted." It is generally spherical in shape but may appear as chips or flakes. Quartz is highly resistant to weathering, which accounts for its predominance in the sand fraction of most soils and as the major component of many sand beaches.

□ **Orthoclase** ($KAlSi_3O_8$) is an important member of the **Feldspar** family. It is also known as potassium feldspar and is a good source of potassium in the soil. The Feldspars are also framework silicates and are more susceptible to weathering than quartz because they contain other elements in the framework (K, Ca, Na) besides Si that form less stable bonds with O. Feldspar color varies from pink to grey depending on elemental composition.

□ **Mica** is an important primary phyllosilicate that is found primarily in two forms: biotite and muscovite. **Biotite** is dark brown to black iron-rich mica which is susceptible to weathering, while **muscovite** is generally colorless or lightly tinted. Note the iridescence. They both consist of thin flexible sheets that tend to separate into smaller sheets or flakes. Muscovite is named after the Principality of Moscow in Russia, where it is found in large sheets and was (believe it or not) used as a glass alternative in windows centuries ago.

□ **Apatite** is actually the name of a group of calcium phosphate minerals that vary slightly in composition. Apatite is present at low concentrations in many igneous rocks and can also be formed as secondary minerals in sedimentary rocks. The most common form is fluorapatite, ($Ca_5PO_4$)3F. The color of apatite varies. As apatite weathers, it releases phosphorus and calcium into the soil. Large deposits are an important source of commercial phosphorus fertilizer.

□ **Amphiboles/Pyroxenes** (Magnesium/Iron-rich Silicates) are examples of Magnesium and Iron-rich silicate minerals (present primarily in Basalt) that are usually highly susceptible to weathering and therefore only present as primary minerals in some soils. They tend to be dark in color, unlike quartz, feldspar and the phyllosilicates, which are grey to colorless.

**SECONDARY MINERALS** are formed in the process of weathering and transformation of primary minerals. They are present only in sedimentary and metamorphic rocks.

□ **Illites, Vermiculite/Smectite, and Kaolinite** are the other phyllosilicate groups that are not present in igneous rocks but are a major constituent of the clay fraction of soils. **Illite** is the term used for secondary micas found in the clay fraction of soils. **Vermiculites** and **Smectites** have shrink/swell properties and are formed from the weathering of micas and illites. **Kaolinite** is very stable and resistant to weathering (no isomorphous substitution, so no charge imbalance = a stable structure) and formed from the weathering of the other phyllosilicates.

□ **Calcite** ($CaCO_3$) occurs in limestone or similarly as dolomite (Ca,Mg)$CO_3$ in sedimentary rocks (it can be precipitated from ocean water by organisms such as *Foraminifera* and corals). It can also be precipitated in arid regions where soil water containing ions and carbonates is drawn to the surface and evaporated, leaving carbonate salt residues. It often appears slightly chalky and white, whether as consolidated rock or as small nodules in the soils of dry regions. Their presence in soils can buffer soil pH from the effects of acid producing processes. It is used as an amendment to raise pH.

□ **Goethite** (FeOOH) (pronounced GUR-tite) is an oxidized iron mineral (iron oxide) that gives many Minnesota soils their brown color. In soils, it is found mostly as thin coatings on soil particles. Goethite is often a secondary mineral, meaning that it forms through the weathering of other primary minerals such as basalt. The example given is from a large geologic deposit of Goethite – we would never observe such a large accumulation of pure Goethite in soils.

□ **Hematite** ($Fe_2O_3$) is another iron oxide mineral that gives other Minnesota soils a reddish color, especially those in northeast Minnesota. Hematite is the iron oxide mineral that made the Iron Range of Minnesota famous. Like goethite, it is found as thin coatings on soil particles. The example given is from a large geologic deposit of Hematite – we would never observe such a large accumulation of pure Hematite in soils.

## 8.2 INVESTIGATION B: Rock Identification – Rocks are Aggregates of Minerals

Rocks are composed of minerals. Observe the rock displays and complete the following tables on igneous, sedimentary, metamorphic, and organic rocks. Record the one or two characteristics of each rock that you find most obvious or most helpful for distinguishing one from the other *within each rock type* (i.e. within Igneous/Sedimentary/Metamorphic groups). For example, compare granite to basalt; then compare sandstone, shale, limestone, and so on.

#### 8.2.0.1 Igneous Rock

**FORMED BY THE COOLING AND SOLIDIFYING OF MOLTEN MATERIALS BROUGHT FROM THE INTERIOR OF THE EARTH TO ITS SURFACE OR NEAR SURFACE.**

| Rock | Principle Minerals | Major Elements | Dominant Characteristic(s) (e.g. color, grain size, density, etc) |
|---|---|---|---|
| Granite is a common intrusive igneous rock of varying color and composition. | Quartz, Feldspar, Micas, Phosphates (Apatite) | Si, Al, O, K, Ca, P | |
| Basalt is a common extrusive igneous rock that often "rusts" due to its high iron content (sometimes referred to as "mafic" because of its high magnesium and iron content). | Fe and Mg-rich silicates (Amphiboles & Pyroxenes) | Al, O, K, Fe, Ca, Mg, some Si | |

#### 8.2.0.2 Sedimentary Rock

**FORMED FROM MATERIAL THAT IS DEPOSITED ON THE BOTTOM OF AN OCEAN OR LAKE AND THEN CEMENTED INTO ROCK.**

| Rock | Principle Minerals | Major Elements | Dominant Characteristic(s) (e.g. color, grain size, density, etc) |
|---|---|---|---|
| Sandstone is essentially sand-size particles cemented together by calcite, silica, or iron oxides. | Quartz, some Feldspars | Si, O, K, Ca | |
| Shale is derived from small particles (< 0 mm) that were deposited in slow-moving water. | Quartz, Phyllosilicates, Calcite (CaCO3) | Si, Al, O, Ca | |
| Limestone is a fine-grained chemical precipitate and is a common soil material in many Minnesota soils. | Calcite (CaCO3), Dolomite (Ca/MgCO3) | Ca, Mg, C-inorganic | |

#### 8.2.0.3 Metamorphic Rock

**ROCK THAT WAS ONCE ONE FORM OF ROCK BUT HAS CHANGED TO ANOTHER UNDER THE INFLUENCE OF HEAT, PRESSURE, OR SOME OTHER AGENT WITHOUT PASSING THROUGH A LIQUID PHASE.**

| Rock | Principle Minerals | Major Elements | Dominant Characteristic(s) (e.g. color, grain size, density, etc) |
|---|---|---|---|
| Quartzite is formed from the metamorphism of quartz sandstone. | Quartz, some Feldspars | Si, O, K, Ca | |
| Schist is formed by a continual metamorphosis of shale and often contains mica minerals. | Micas | Si, Al, O, K, Na | |
| Gneiss may form from metamorphosed granite, or schist. | Micas, Quartz, Feldspar | Si, Al, O, K, Ca, Fe | |

## 8.3 INVESTIGATION C: Mineral Identification in the Sand Fraction

Minerals, even of the same type, can vary in color and physical properties making visual four soil samples have been washed and sieved to remove the silt and clay leaving only the larger sand grains. Sand grains can range in size from 0.05 to 2 mm in diameter. Observe the four samples under the microscope. Fill out the Soil Mineral Observations table below. Record the presence of any quartz, feldspars, amphiboles/pyroxenes, shale, limestone, and organic matter. Use your findings from Investigations A and B and other examples provided to help with identification. Record the quantity of each fragment as “N,” “F,” “C,” or “M” in the square under the corresponding mineral or mineral color. Consult the table legend and two other tables below. Describe the color of any coatings and state which minerals have coatings. Coatings usually only partially cover the grain.

**SOIL MINERAL OBSERVATIONS**

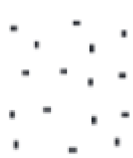
| Soil | Color | Qz | Feld | A/P | Sh | Ls |
|---|---|---|---|---|---|---|
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |

Qz = quartz (colorless/frosted) Feld = feldspars (pink/grey) A./P. = amphiboles/pyroxenes (dark/black) Sh = shale (dull gray/brown) Ls = limestone (chalky white) Color = overall sand color (grey, brown, red, etc.)

**Quantity of Fragments**

| Class | Abbr | % of Area Covered |
|---|---|---|
| None | N | Not observed |
| Few | F | Less than 2 |
| Common | C | 2 to less than 20 |
| Many | M | 20 or more |

**Area of Coverage**



2%

20%

## 8.4 INVESTIGATION D1: Physical Weathering

Physical weathering involves mechanical processes by which rocks exposed to weathering break down into smaller rocks or to their constituent minerals. Smaller rocks and particles are more susceptible to chemical weathering. Note that some sources of physical weathering can also be involved in chemical weathering.

- **Abrasion**: Water carrying suspended rock fragments has a scouring action on surfaces. Examples are the grinding action of glaciers, gravel, pebbles and boulders moved along and constantly abraded by fast-flowing streams. Particles carried by wind also have a "sand-blasting" effect.
- **Wetting and drying**: Water penetrates into rocks and reacts with their constituent minerals resulting in recrystallization and increased stress. Wetting and drying is sometimes accompanied by shrinking and swelling, which also increasing internal stress.
- **Freezing and thawing**: When water is trapped in the rock (or in cracks) repeated freezing and thawing results in forces of expansion and contraction (when water freezes, its volume increases by about 9%).
- **Heating and cooling**: Each different mineral in the rock will expand and contract by a different amount and at a different rate with surface-temperature fluctuations. With time, the stresses produced are sufficient to weaken the bonds along grain boundaries resulting in flaking off of rock fragments at the rock's surface.
- **Unloading/Exfoliation**: Many rocks are formed at great depth under intense temperatures and pressures. As these rocks make their way to the surface and overlying rock is removed through erosion, some of the pressure is released. This release of pressure causes the rock to fracture horizontally. Cracks of this type increase in number as the rock reaches the surface.

Observe the examples of physical weathering, then complete the table below. Record ONE POTENTIAL weathering process for each example and give a brief description of the process.

| Example | Physical Weathering Observations |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |

## 8.5 INVESTIGATION D2: Chemical Weathering

Chemical weathering involves chemical processes by which rocks and minerals exposed to the weather undergo changes in composition or crystallinity, or are removed from the rock.

- **Hydration**: Ions have the tendency to attract water molecules (hydrate) and dissociate when water is present. This kind of weathering happens in arid environments where salts are present.
- **Hydrolysis**: Water molecules at the rock's mineral surface dissociate into $H^+$ and $OH^-$ and the mobile $H^+$ ions penetrate the rock's crystal lattice. This creates a charge imbalance that causes cations (e.g. $Ca^{2+}$, $Mg^{2+}$, $K^+$ and $Na^+$) to diffuse out.
- **Oxidation-Reduction**: Several primary minerals contain $Fe^{2+}$ and $Mn^{2+}$. In an oxidizing environment, $Fe^{2+}$ is oxidized to $Fe^{3+}$. The change in oxidation state changes the size of the ion resulting in internal stresses and accelerated weathering. Reduced iron ($Fe^{2+}$) is soluble and can be removed from the rock or mineral, while oxidized iron ($Fe^{3+}$) is insoluble and remains in place.
- **Dissolution**: Occurs when the component minerals of rocks are dissolved by water. The dissolved material is transported away leaving a space in the rock.
- **Acidification**: Dissolving of calcium carbonate (limestone) in acidic groundwater. One consequence of this process is the formation of caves in limestone areas.

Observe the examples of chemical weathering then complete the table below. Record ONE POTENTIAL weathering process for each example and give a brief description of the process.

| Example | Chemical Weathering Observations |
|---|---|
| 1 | |
| 2 | |
| 3 | |

## 8.6 INVESTIGATION D3: Biological Weathering

Biological weathering involves physical and chemical processes by which organisms weather rocks.

- **Plant roots**: Woody plant rots, especially trees, can preferentially grow into fissures in rocks and split them apart as the roots grw and expand.

- **Digging and crushing by animals**: Animals (including humans) assist in the physical breakdown of rocks by digging burrows, bioturbation, or even purposely crushing rock materials such as in many human activities.
- **Lichen**: Lichen play an important part in chemical weathering because they producing organic acids that act as chelating (chelate = claw, it is a compounds that "grabs" elements such as Fe) agents that trap the insoluble elements of the decomposing rock in soluble organo-metallic complexes and destroy the crystal structure of the component minerals.

Observe the examples of biological weathering then complete the table below. Record ONE POTENTIAL weathering process for each example and give a brief description of the process.

| Example | Biological Weathering Observations |
|---|---|
| 1 | |
| 2 | |

## 8.7 INVESTIGATION E: Weathering Examples

1. Using an eye dropper, apply a drop of 10% hydrochloric acid to the limestone rock located in the test plates.

a. Describe what you see when the acid makes contact with the limestone rock.

b. Describe what happens to the rock.

c. What type of weathering does this represent (i.e. chemical, physical, or biological - and specific type therein)?

2. These two salt samples (NaCl crystals; common table salt) were equal in size at the beginning of this experiment. Using the squirt bottle, apply a stream of water to an edge or corner of the salt block on the left.

a. Describe what you see when the water makes contact with the salt.

b. Describe what happens to the salt block.

c. What type of weathering does this represent (i.e. chemical, physical, or biological - and specific type therein)?

3. How might physical weathering help promote chemical weathering?

## 8.8 INVESTIGATION F: Naming Master Horizons - Review

Observe the six mini-monoliths on the table. The monoliths are scaled so that one inch on a monolith equals four inches on a soil profile. Label the master horizons and the mark depths of these horizons for monoliths 2 through 3. Monolith 1 is done for you. Note that horizon depth is always measured from the soil surface. All profiles are 48" deep. NOTE: There are no "O" (organic) horizons in this investigation.

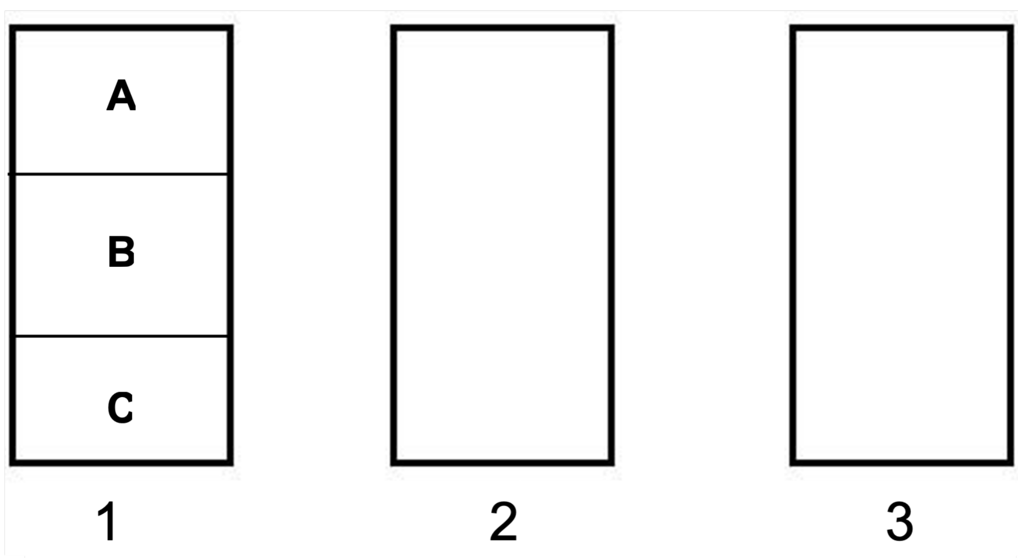



Figure 8.1: Naming Master Horizons

**Remember: 1 monolith inch = 4 soil profile inches**

# 9 Five Soil Forming Factors

Objectives

- To understand the interaction of soil forming factors and the soil forming processes in the formation and evolution of soils. Soils will develop different characteristics due to the action of climate and biotic factors acting on a parent material on a particular landscape position over time. The additions, losses, translocations, and transformations to the soil profile develop soil horizons.

Key Words & Concepts

- Residuum
- Catena
- Soil "age"
- Lacustrine
- Alluvial
- Till
- Eolian
- Loess
- Calcareous
- Colluvial
- Esker
- Moraine
- Leaching
- Evapotranspiration
- Native vegetation
- Erosion
- Deposition
- Aspect
- Horizonation
- Backslope
- Summit
- Shoulder
- Footslope
- Infiltration
- Drainage classes
- Mottles
- Sesquioxides

## 9.1 INVESTIGATION A: Residual Parent Materials

Soils develop in many different kinds of parent materials. Parent material, in some cases, can be the bedrock under the soil and this non-transported parent material is called residuum. The soils that develop in residuum can be shallow if the rock is hard and difficult to weather, or deep if the rock is soft or has weathered for a long time. In Minnesota, four types of bedrock can be located that are only thinly or not covered by glacial drift and thus can become residual parent material— limestone, sandstone, basalt, and granite. Use the depth to bedrock map and simplified geological map to describe the most likely rock type for residual soils at points A, B and C.

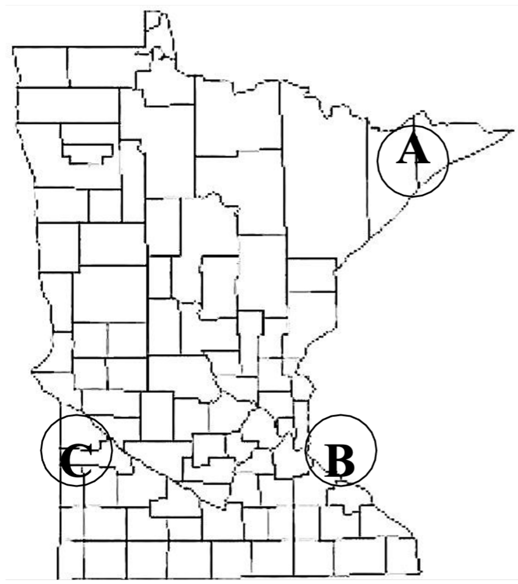



Figure 9.1: Minnesota

A: B: C:

## 9.2 INVESTIGATION B: Transported Parent Materials

In Minnesota, most soils are formed in a parent material that was transported by ice, wind or water. Ice deposited glacial till, water deposited glacial outwash, glacial lacustrine and alluvium, and wind deposited eolian sand and loess. Observe the samples of transported parent materials and note characteristics for each sample. These characteristics (particularly color and texture) are very useful for identifying the parent material of many Minnesota soils.

| **GLACIAL TILL** | **Observed Characteristics (Color, texture, coarse fragments)** |
|---|---|
| Superior Lobe Till | |
| Des Moines Lobe Till | |

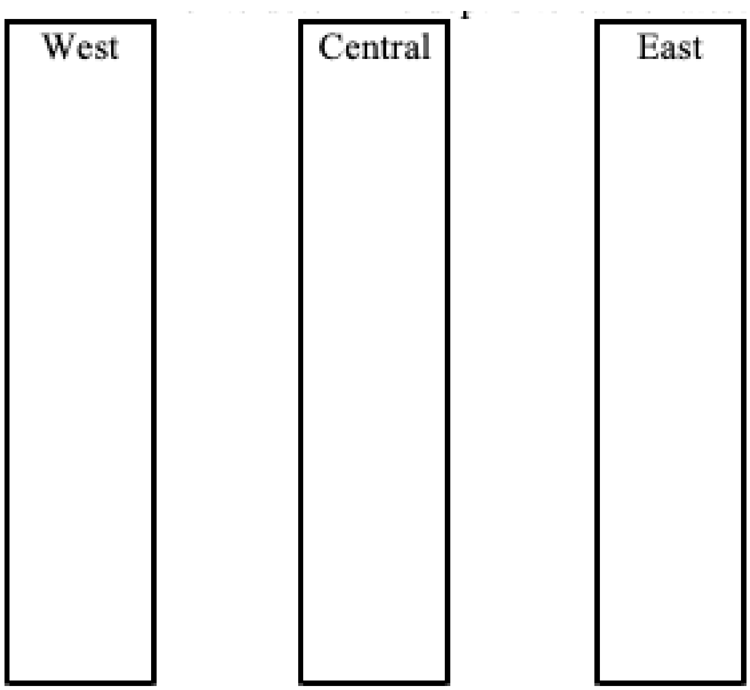
| **WATER SORTED** | **Observed Characteristics (Color, texture, coarse fragments)** |
|---|---|
| Lacustrine | |
| Outwash | |
| Alluvium | |

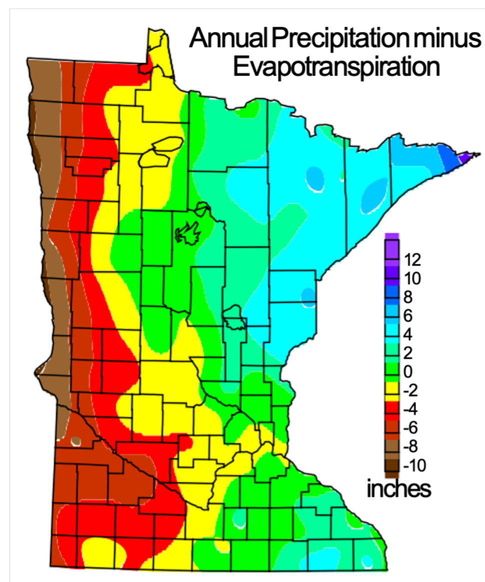
| **WIND SORTED** | **Observed Characteristics (Color, texture, coarse fragments)** |
|---|---|
| Dune sand (eolian; transported very locally by wind) | |
| Loess | |

## 9.3 INVESTIGATION C: Climatic Factors

Climate refers to the amount of precipitation (rain, snow, humidity) and the temperature in a given locale. The hotter and more humid a climate, the faster and more completely it is going to weather into soil. If a climate is cool and or dry, the weathering process proceeds more slowly. Below are temperature and precipitation maps for Minnesota. The difference in temperature will not change the weathering of rocks in Minnesota. However, the precipitation and temperature together will influence the leaching and horizon formation. Calcium carbonate will occur closer to the surface in soils with less leaching as in western Minnesota. NOTE: The diagram below shows the general pattern but DOES NOT correspond to the exact depth of leaching for any one particular profile.

1. Match each soil profile with its location in Minnesota by the depth to $CaCO_3$ (Bk or Ck). Mark the depth to effervescence in each case - use HCl to determine depths to carbonates. 1 inch on the monolith = 4 inches in real life.




2. For a more detailed and complex representation of the depth to carbonates in soils across Minnesota, see the depth to carbonates map in Soil Explorer on the iPads. In addition to climate, which of the other four soil forming factors contribute the most to these patterns, and why? (HINT: See lecture 3.3)

## 9.4 INVESTIGATION D: Biotic Factors (Vegetation)

One of the most obvious biotic factors is the effect that vegetation has on soil formation. The most common pre-European settlement vegetative types (this is the vegetation the soil formed under for ~ 10,000 – 13,000 years after glaciation – the native vegetation in many areas has been replaced by agriculture or other land uses, but only very recently) in Minnesota are forest, grassland (prairie), and a transitional zone between forest and grassland prairie (called savannah). Using the six micro-monoliths (1/4 scale), determine the vegetation that the following soils were formed under, and briefly explain your answer.

| **Soil** | **A horizon thickness (1 in on monolith = 4 in actual)** | **Most likely historic vegetation (Forest, Prairie, or Savannah (Transition))** |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |

## 9.5 INVESTIGATION E: Topographic Factors

When forming within a landscape, soils with the same parent material, vegetation, and climate often have different depths to the water table (e.g. are different due to topography only). This grouping of soils is called a catena. Find and examine the Clarion, Nicollet, Webster, and Glencoe monoliths against the elevator shaft in the display area and determine the location of each soil on the following catena block diagram and explain your answers.

| Topography | Soil Name | Explanation |
|---|---|---|
| Summit/Well Drained; No Mottles | | |
| Backslope/Moderately Well Drained; Gray mottles 50-75 cm deep | | |
| Footslope/Somewhat Poorly Drained; Gray mottles 25-50 cm deep | NOT PRESENT IN DISPLAY | NOT PRESENT IN DISPLAY |
| Toeslope/Poorly Drained; Gray (Bg) colors below dark A | | |
| Depression/Very Poorly Drained; Gray Cg colors below thick A | | |

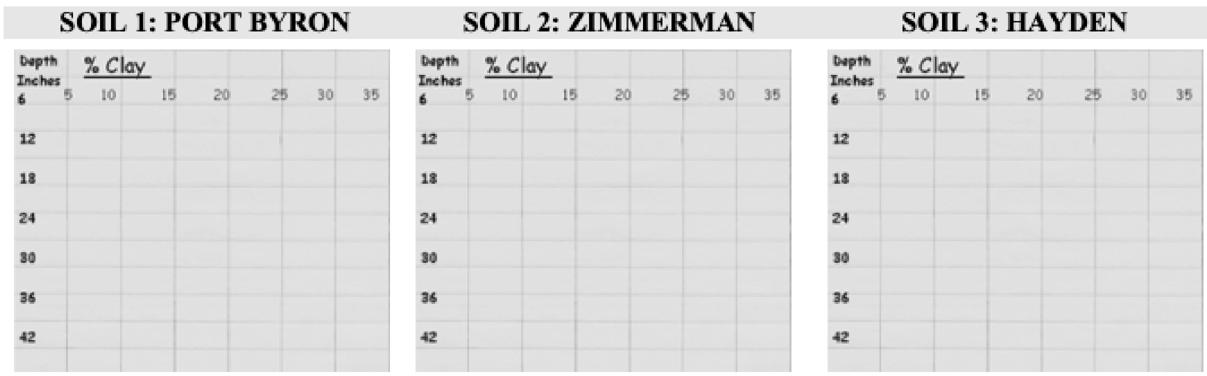
## 9.6 INVESTIGATION F: Time Factors

Soil "age" is measured in geologic terms (Minnesota soils are quite young due to glacial deposits that happened only 10,000 – 13,000 years ago), as well as measured in terms of development (soils in colder climates develop slower and therefore show "young" morphology). For practical purposes, the number and type of horizons and the depth of soil development (pedogenic processes or A, E, & B horizons) is a decent starting indicator of a soil's age. Determine the "age" sequence for the three micro-monoliths on display.

| **Age** | **Soil Name (Soil series: Moody, Ontonagon, or Menahga) and Reasoning** |
|---|---|
| Youngest | |
| Middle | |
| Oldest | |

## 9.7 INVESTIGATION G: Clay Eluviation/Illuviation and the Soil Forming Factors

**Graph** the % clay for each profile with depth. When we graph the clay % with depth we can easily identify whether or not there is a peak in clay percentage in the B horizon which is indicative of the eluviation of clay from the top of the profile and its illuviation lower in the profile. (Note: these are micro-monoliths at 1:4 scale, or 1 inch on monolith = 4 inches on the graph).




All three of these soils developed under a similar climate in central-eastern Minnesota. The Zimmerman soil is formed in outwash under forest vegetation. The Port Byron soil is formed in loess under grassland vegetation. The Hayden soil is formed in glacial till under forest vegetation. REMEMBER: Soils developed under grasslands typically have more organic matter and organic matter is an excellent binding agent of mineral particles (remember the pictures of granular structure and the clay particles bound by OM).

1. Which of these soils exhibits a clear peak in clay with depth?

2. Knowing what you know about the soil forming factors and their effect on soil development and soil morphology, explain why the soil listed in your answer to question 1 has a peak in clay due to eluviation/illuviation while the other soils do not.

## 9.8 INVESTIGATION H: Properties from Factors and Factors from Properties

Some knowledge of soil forming factors at work on a particular landscape or in the formation of a particular soil allow us to predict soil properties such as horizon morphology, texture, color, organic matter, and mineralogy. Below, complete the tables with the choices given on the handout (use each only once) based on your knowledge from class. Use the information on both the “Soil Forming Factors” and “Soil Properties” tables to fill in the blanks. All of the information you need should be present in these tables, however, you can use the monoliths in the display area to help you with your choices if that helps you to better visualize the soils.

| Soil Series Name | Parent Material | Climate | Organisms (Vegetation) | Relief (Hillslope Position) | Time (approximate) |
|---|---|---|---|---|---|
| Hayden | Des Moines Lobe Till | Humid Temperate | Forest | Summit/ Shoulder | 10,000 years |
| Port Byron | | Humid Temperate | | Summit/ Shoulder | 10,000 years |
| Zimmerman | | Humid Temperate | Forest | Summit/ Shoulder | 10,000 years |
| Cecil | Igneous/ Metamorphic Residuum | Humid Subtropical | | Summit/ Shoulder | 200,000 years |
| Rifle | Organic Deposits | | Wetland | Toeslope | 10,000 years |
| Balaton | Des Moines Lobe Till | | Grassland | Summit | 10,000 years |
| Kingsley | Superior Lobe Till | Humid Temperate | Forest | Summit/ Shoulder | 10,000 years |

| Soil Series Name | Dominant Texture | Subsoil Color | Drainage Class | Topsoil Organic Matter Content (%) | Mineralogy | Coarse Fragments |
|---|---|---|---|---|---|---|
| Hayden | Clay Loam/Silty Clay Loam | 2.5Y | Well Drained | | Illites/ Smec./ Verm. | Y |
| Port Byron | Silt/ Silt Loam | 10YR | | 10% | Illites/ Smec./ Verm. | N |
| Zimmerman | Sand/Loamy Sand | 10YR | Well Drained | 5% | Quartz | Y |
| Cecil | Clay Loam/Clay | 2.5R | Well Drained | 5% | | N |
| Rifle | N/A | 10YR | | | N/A | N |
| Balaton | Clay Loam/Silty Clay Loam | | Well Drained | 10% | | Y |
| Kingsley | Sandy Clay Loam/Loam | | Well Drained | 8% | Illites/ Amphiboles/ Pryoxenes/ Iron Oxides | Y |

# 10 Soil Classification

**Objectives**

- Identify soil epipedons, subsurface diagnostic horizons.
- Locate the 12 soil orders in the United States.
- Break down a taxonomic soil name.

## 10.1 INVESTIGATION A: Soil Classification

**READ THESE INSTRUCTIONS COMPLETELY!**

For all eight monoliths, determine the correct order of horizons from the choices given, epipedon, diagnostic subsurface horizon, and soil order/suborder. All monoliths are from Minnesota, except for the Cecil, which is from North Carolina. The most important take-aways are horizon nomenclatures and classifying a soil based on morphology. Characteristics are given to assist you with your classifications – use your 1 page cheat sheet!

**Note**: Mollic epipedons are darker than 3/3 (no matter what the hue) and must be at least 25cm (~10 inches) thick. If the epipedon is not mollic, it must be ochric or histic. None of these soils have an umbric epipedon. Bw = cambic (except for Bw that have sand/loamy sand textures – these are not considered as any diagnostic horizon for the purposes of classification); Bt = argillic; Bs, Bhs, Bhsm, etc. = spodic; Bo = oxic

## 10.2 SOIL 1: CROMWELL

HORIZON CHOICES: Bw1, A, Bw2, BA, 2C

NOTES: B.S. = 62%

| Horizon | Texture | Color | Depth |
|---|---|---|---|
| | Loam | 7.5YR 2/2 | 0-13 cm |
| | Loam | 7.5YR 3/4 | 13-28 cm |
| | Loam | 7.5YR 4/4 | 28-36 cm |
| | Loam | 7.5YR 4/4 | 36-51 cm |
| | Sand | 7.5YR 5/4 | 51+ cm |

Epipedon: Explain:

Diagnostic Subsurface: Explain:

Soil Order: Explain:

Soil Suborder: Explain:

## 10.3 SOIL 2: WEBSTER

HORIZON CHOICES: Cg, Ap, AC, A2, A1

NOTES: BS = 68%

| Horizon | Texture | Color | Depth |
|---|---|---|---|
| | Silty Clay Loam | 10YR 2/1 | 0-15 cm |
| | Silty Clay Loam | 10YR 2/1 | 15-40 cm |
| | Clay Loam | 10YR 3/2 | 40-69 cm |
| | Clay Loam | 5Y 4/1 | 69-89 cm |
| | Clay Loam | 5Y 6/2 | 89+ cm |

Epipedon: Explain:

Diagnostic Subsurface: Explain:

Soil Order: Explain:

Soil Suborder: Explain:

## 10.4 SOIL 3: RIFLE

HORIZON CHOICES: Oa, Oe2, Oe1, Oe3, 2C

| Horizon | Texture | Color | Depth |
|---|---|---|---|
| | Mucky-peat | 5YR 2/2 | 0-20 cm |
| | Mucky-peat | 5YR 2/2 | 20-51 cm |
| | Mucky-peat | 5YR 2/2 | 51-63 cm |
| | Muck | 5YR 2/1 | 63-94 cm |
| | Loam | 2.5Y 5/1 | 94+ cm |

Epipedon: Explain:

Diagnostic Subsurface: Explain:

Soil Order: Explain:

Soil Suborder: Explain:

## 10.5 SOIL 4: FARGO

HORIZON CHOICES: Cg, Bss, Bg1, Bg2, Bg3, Ap

NOTES: BS = 100%; large cracks open during the dry season; all horizons > 55% clay

| Horizon | Texture | Color | Depth |
|---|---|---|---|
| | Silty Clay | 10YR 3.1 | 0-23 cm |
| | Silty Clay | 10YR 4/2 | 23-41 cm |
| | Clay | 2.5Y 3/1 | 41-53 cm |
| | Clay | 5Y 5/2 | 53-66 cm |
| | Clay | 2.5Y 5/2 | 66-86 cm |
| | Clay | 5Y 6/3 | 86+ cm |

Epipedon: Explain:

Diagnostic Subsurface: Explain:

Soil Order: Explain:

Soil Suborder: Explain:

## 10.6 SOIL 5: KALKASKA

HORIZON CHOICES: BC, A, E, Bhs, C, Bs

NOTES: BS = 42%

| Horizon | Texture | Color | Depth |
|---|---|---|---|
| | Loamy Sand | 7.5YR 2.5/1 | 0-5 cm |
| | Loamy Sand | 7.5YR 6/1 | 5-27 cm |
| | Loamy Sand | 7.5YR 4/4 | 27-41 cm |
| | Loamy Sand | 5YR 3/3 | 41-54 cm |
| | Sand | 10YR 5/6 | 54-80 cm |
| | Sand | 10YR 6/4 | 80+ cm |

Epipedon: Explain:

Diagnostic Subsurface: Explain:

Soil Order: Explain:

Soil Suborder: Explain:

## 10.7 SOIL 6: ZIMMERMAN

HORIZON CHOICES: Bw2, A, Bw1, C

NOTES: BS = 41%

| Horizon | Texture | Color | Depth |
|---|---|---|---|
| | Loamy Sand | 7.5YR 2.5/1 | 0-12.5 cm |
| | Loamy Sand | 7.5YR 6/1 | 12.5-43 cm |
| | Loamy Sand | 5YR 3/3 | 43-84 cm |
| | Loamy Sand | 10YR 6/4 | 84+ cm |

Epipedon: Explain:

Diagnostic Subsurface: Explain:

Soil Order: Explain:

Soil Suborder: Explain:

## 10.8 SOIL 7: LESTER

HORIZON CHOICES: EB, Bt2, C, Ap, Bt1

NOTES: BS = 78%, Udic moisture regime

| Horizon | Texture | Color | Depth |
|---|---|---|---|
| | Loam | 10YR 3/2 | 0-20 cm |
| | Loam | 10YR 4/3 | 20-31 cm |
| | Clay Loam | 10YR 4/4 | 31-51 cm |
| | Clay Loam | 10YR 4/4 | 51-91 cm |
| | Loam | 10YR 5/4 | 91+ cm |

Epipedon: Explain:

Diagnostic Subsurface: Explain:

Soil Order: Explain:

Soil Suborder: Explain:

## 10.9 SOIL 8: CECIL

Note, the suborder for Cecil is not in course handouts - make a guess!

HORIZON CHOICES: Bt2, A, Bt1, C

NOTES: BS = 18%, Udic moisture regime

| Horizon | Texture | Color | Depth |
|---|---|---|---|
| | Loam | 10YR 4/4 | 0-15 cm |
| | Clay | 10YR 4/8 | 15-41 cm |
| | Clay | 10YR 4/8 | 41-76 cm |
| | Clay Loam | 2.5YR 4/8 | 76+ cm |

Epipedon: Explain:

Diagnostic Subsurface: Explain:

Soil Order: Explain:

Soil Suborder: Explain:

## 10.10 INVESTIGATION B: Location of Soil Orders

Use the large map in the lab to label the major soil order present at each boxed location in the U.S. (i.e. put the best choice of a soil order - using the numbers below - at that location in the box). There may be more than one location for some Orders and some locations may have more than one dominant Order – just pick the most obvious one.

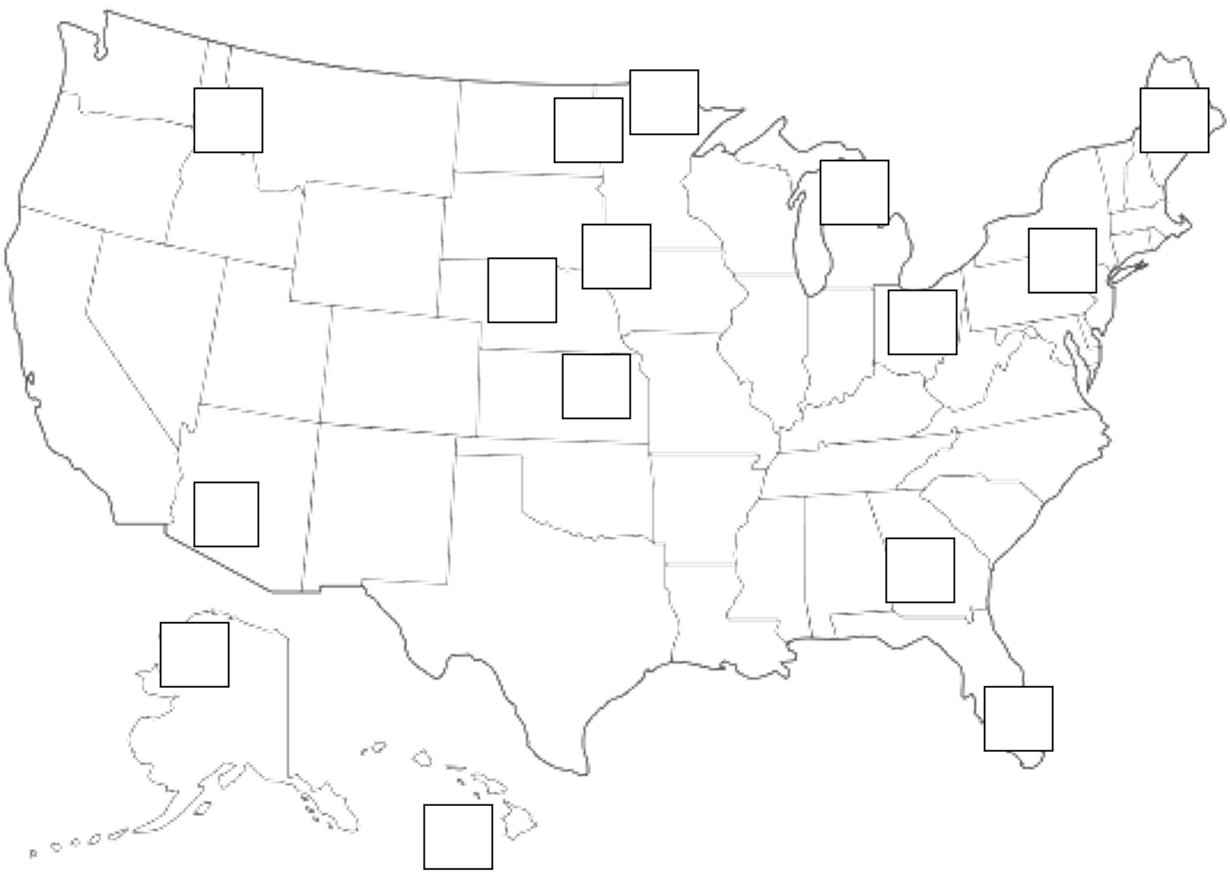


Figure 10.1: Soil Orders in the USA

1. Alfisols
2. Andisols
3. Aridisols
4. Entisols
5. Gelisols
6. Histisols
7. Inceptisols
8. Mollisols
9. Oxisols
10. Spodosols
11. Ultisols
12. Vertisols

## 10.11 INVESTIGATION C: Nomenclature

There are twelve soil orders at the highest hierarchical level of soil taxonomy. The names for these orders relate to Greek, Latin, or other root words that reveal something about the soil. Fifty-four suborders are recognized at the next level of classification. There are over 200 great groups and more than 1,100 subgroups. Soil families have similar physical and chemical properties that affect their response to management. The lowest category – soil series – is usually named after a geographic feature in the region in which it was originally found and described. The taxonomic class includes the prefix plus all the following syllables, e.g., a Great Group would be "Haplosaprists", not just the prefix "Haplo-". To help you recognize syllables, remember familiar descriptive terms like sapric, hemic, mesic, ustic, udic, aquic. In addition, look for the prefixes hapl- (simple), orth- (central), epi- (above), argi- (clay) and psamm- (sandy).

Answer the following questions about soil names. #1 is already answered for you.

1a. **(EXAMPLE)** Name the order and suborder for the Okeechobee soil (Euic, hyperthermic, Hemic Haplosaprists).

Order - **Histosol**; Suborder: **Saprist**

1b. **(EXAMPLE)** List two characteristics of the Okeechobee based on the suborder name.

**Large accumulation of organic materials Sapric organic materials (well decomposed)**

2. Name the family for the Clarion soil (Fine-loamy, mixed, mesic, Typic Hapludolls).

3a. Name the order and suborder for the Fargo soil (Fine, smectitic, frigid, Typic Epiaquerts).

3b. Name one characteristic of the Fargo based on the suborder name.

3c. Look at the *family* name of the Fargo – what property of this soil might you predict based on the properties of the dominant mineral?

4a. Name the order and suborder for the Lester soil (Fine-loamy, mixed, mesic, Mollic Hapludalfs).

4b. Name one characteristic of the Lester based on the suborder name.

5a. Name the order and suborder for the Hubbard soil (Sandy, mixed, frigid, Entic Hapludolls).

5b. List two characteristics of the Hubbard based on the suborder name.

6. Name the order and suborder for the Omega soil (Sandy, mixed, frigid, Typic Haplorthods).

7. Name the suborder for the Rifle soil (Euic, frigid, Typic Haplohemists).

8. Name the soil order for the Ves soil (Fine-loamy, mixed, mesic, Calcic Hapludolls).

9. Name the soil order for the Valentine soil (Mixed, mesic, Typic Ustipsamments).

# 11 Legal Land Descriptions and Soil Survey

Objectives

- Understand components of a soil survey.
- Use a legal land description to identify parcels of land.

Key Words & Concepts

- Township
- Range
- Principal meridian
- Section
- Soil mapping unit
- Soil name
- Geographic information systems

## 11.1 INVESTIGATION A: Legal Land Descriptions

A legal description/land description is the method of locating and describing land in relation to the public land survey system. Land is broken down into areas called townships. Townships are approximately 6 square miles and are divided into 36 sections (each section being approximately 640 acres). Townships have two designators:

1. A Township designator (T) that describes the distance and direction (north or south) from the Baseline, and
2. A Range designator (R) that describes the distance and direction (east or west) from the Principal Meridian.

Townships highlighted (with numbers written in the center) in Figure 7 include:

- T4N, R4W
- T3N, R3E
- T1S, R2E
- T3S, R4W

The number after the T (township) gives the number of townships N or S of the Baseline, while the number after the R (range) gives the number of townships E or W of the Principal Meridian.

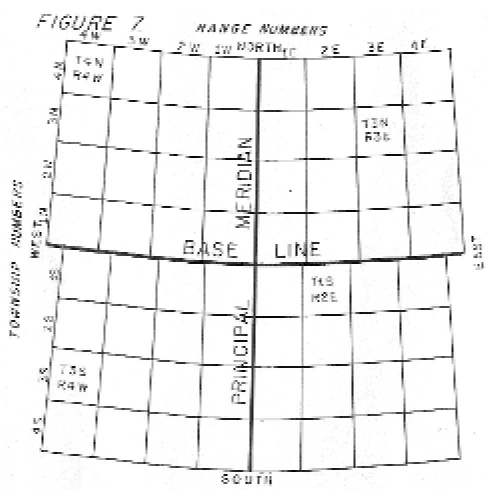



Figure 11.1: Figure 7

Sections in each township are numbered consecutively beginning with number 1 in the northeast corner of the township and counting from right to left then left to right and so on, weaving back and forth through the sections of the township in a serpentine manner, and ending with number 36 in the southeast corner.

Additionally, sections may be broken into any number of parcels or divisions. When you *write* a legal description, always start with the smallest division first and proceed in steps to the largest division. When you are attempting *read* a legal description to find a parcel of land, do the opposite: start with the largest division first, then proceed to the smallest, reversing the order in which the legal description is written.

Practice writing legal land descriptions by describing areas A through F in the table below the images. Make sure you include Township, Range, and Section designators shown by the X's on the maps above.

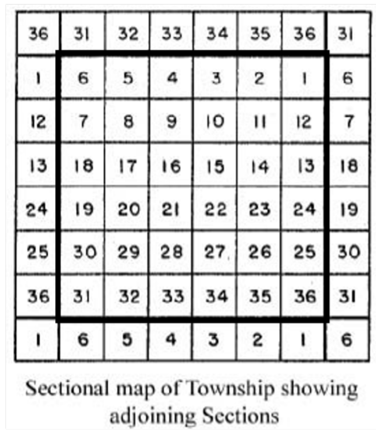



Figure 11.2: Sections within a Township

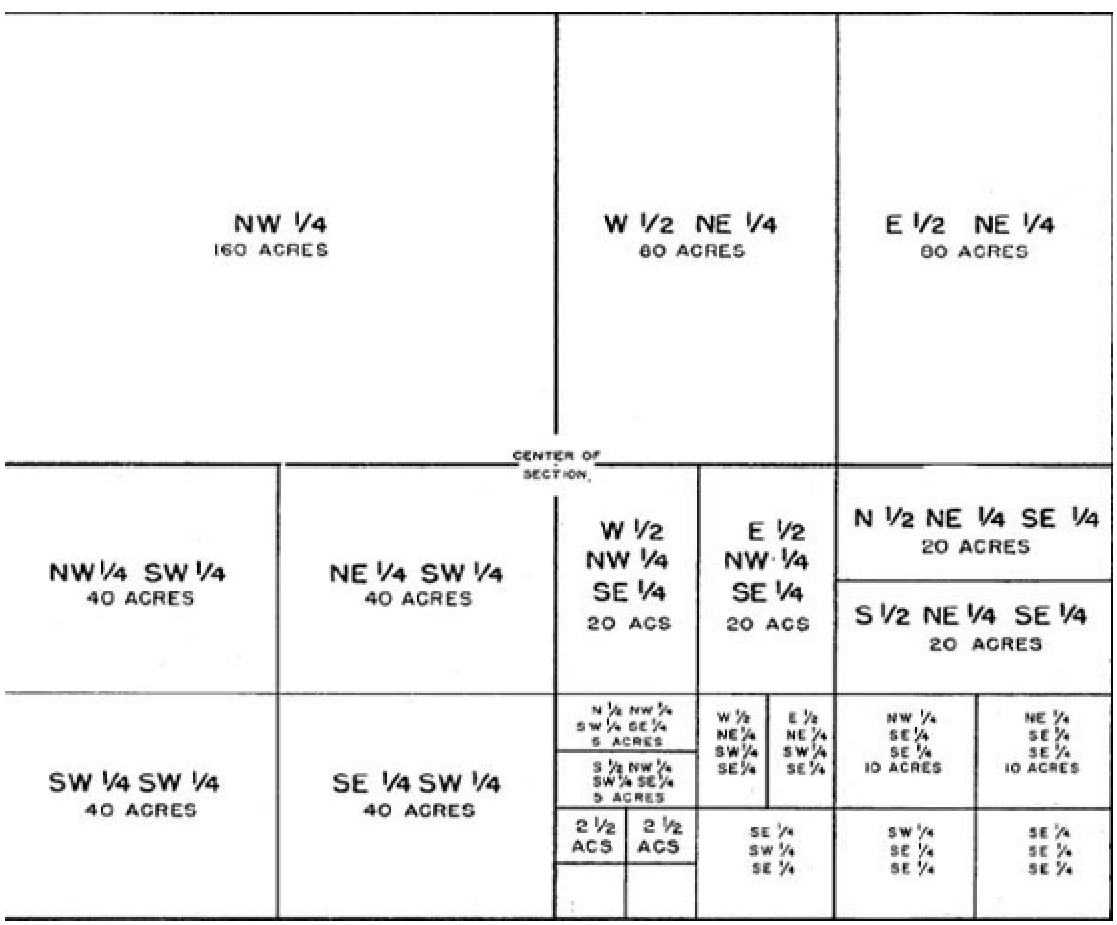



Figure 11.3: One Section, Labeled

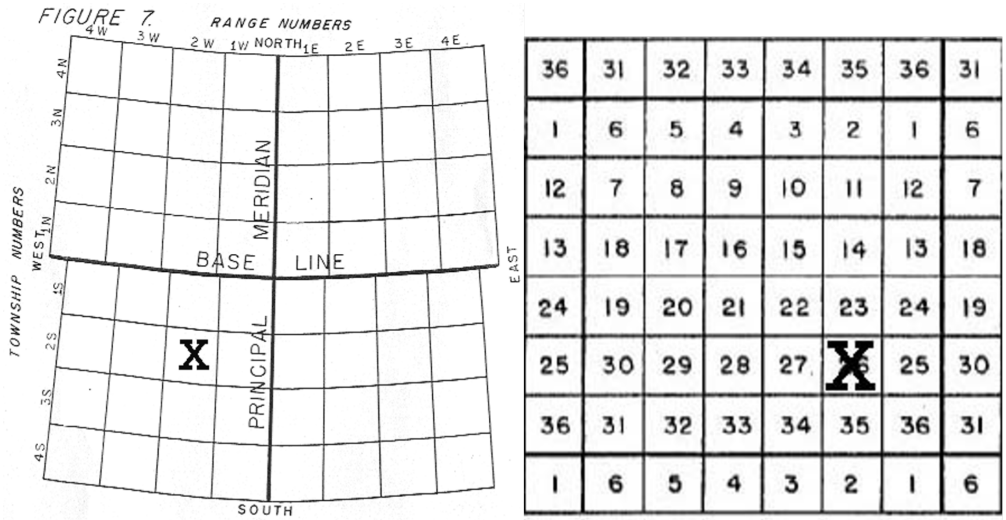



Figure 11.4: Sections Compared to Their Township

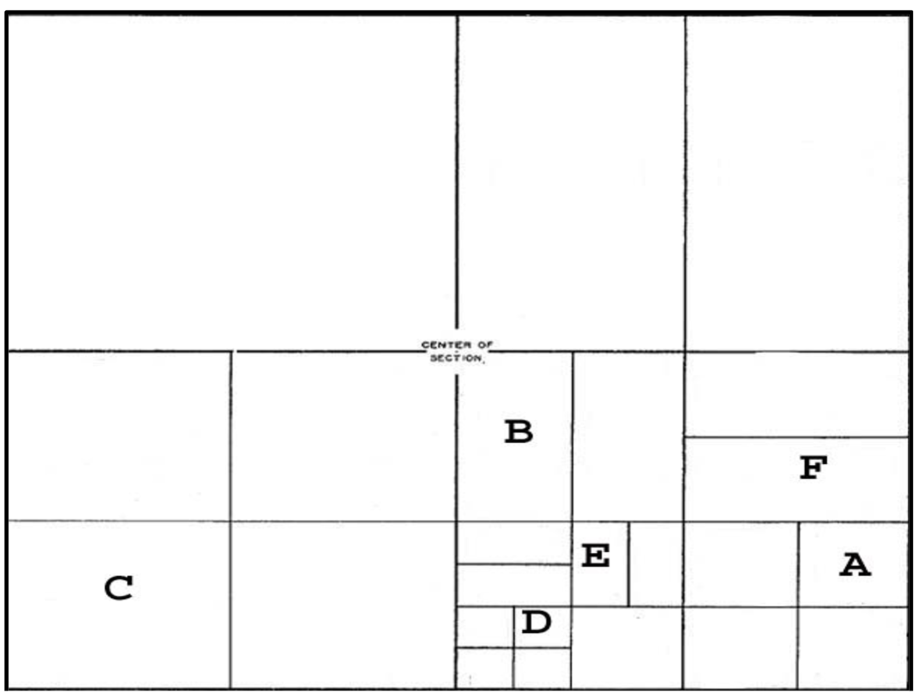



Figure 11.5: Labeling Areas Within a Section

| Label | Subdivision of Section | Section | Township | Range | Acres |
|---|---|---|---|---|---|
| A | | | | | |
| B | | | | | |
| C | | | | | |
| D | | | | | |
| E | | | | | |
| F | | | | | |

## 11.2 INVESTIGATION B: Using Web Soil Survey to Make Land-use Recommendations

**HYPOTHETICAL SITUATION**: The College of Food, Agricultural, and Natural Resource Sciences has received funding to build a new research, learning, and outreach center. An alumnus of SOIL 2125 has offered a quarter section of land in Sibley County, Minnesota as a possible location of a new center. The legal land description is NE1/4 of Section 10, T113N, R29W, 5th Principal Meridian. The following questions need to be answered to assess this piece of property.

1. Go to Web Soil Survey: http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm
2. Click the green button to start WSS.
3. Under "Quick Navigation" in the menu bar on the left, click on PLSS (Section, Township, Range).
4. Enter the information for the property given in the first paragraph, above (i.e., Minnesota, 5th Principle Meridian, Section 10, Township 113N, Range 29W), and click "View".
5. WSS will take you directly to that section.
6. Define the AOI for the parcel. Remember, the property is only the NE ¼ of the section.
7. Once the AOI is defined, click on the "Soil Map" tab to view the Soil Map.
8. Check to ensure you have identified the right parcel by comparing it to the figures on the last page of this document.
9. Use information from properties and interpretations under the "Soil Data Explorer" tab to fill in the table below for each map unit. Navigate to each item then click "View Rating".

#### 11.2.0.1 Inventory of Soils in NE 1/4 of Section 10

To assess the property, an inventory of soil map units was done. Now the usefulness of these soils for proposed construction and other uses and activities is needed. Double check you have the right location with this figure:

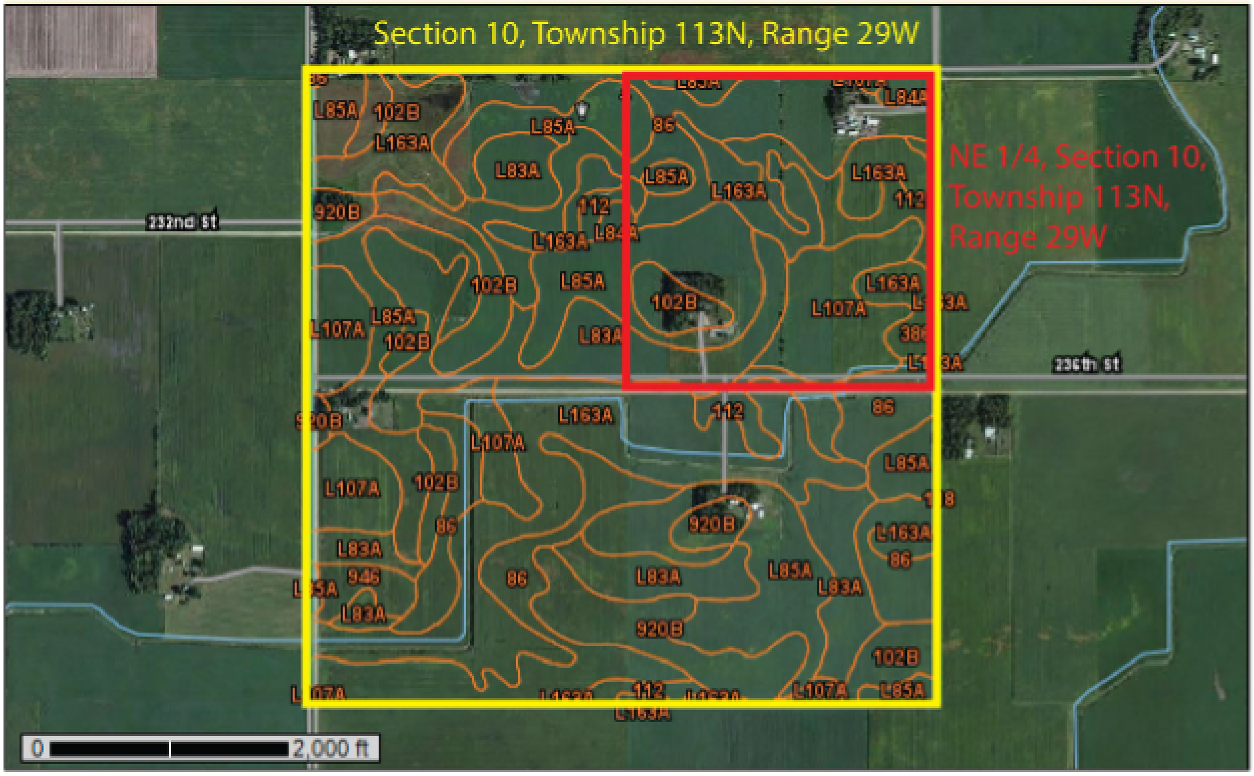



Figure 11.6: Soil Map

Use the properties and interpretations from each of the map units given in Web Soil Survey to fill in the following table. The following information shows you where to find that piece of information in Web Soil Survey menus:

**Suborder**: >Suitability & Limitations for Use >Land Classification >Soil Taxonomy Classification

**Small Commercial Buildings**: >Suitability & Limitations for Use >Building Site Development >Small Commercial Building

**Paths and Trails**: >Suitability & Limitations for Use >Recreational Development >Paths and Trails

**At-Grade Septic**: >Suitability and Limitations for Use >Sanitary Facilities >Septic Tank Absorption Fields >At-Grade (MN)

**Farmland of Statewide Importance**: >Suitability and Limitations for Use >Land Classifications >Farmland Classifications

The College would like to construct the facilities listed in the table below. Indicate in the table on what soil map unit(s) in this piece of land you would locate each. Include the symbol and soil series for each unit as listed in the previous table. Ignore existing building locations in your choices as the College wishes to make the best possible land-use choices in each case, regardless of current development.

Make suitability determinations based on the Soil Survey data alone.

| Symbol | Soil Order | Suborder | Small Commeri-cal Buildings | Paths and Trails | At-Grade Septic | Farmland of Statewide Impor-tance |
|---|---|---|---|---|---|---|
| 86 | Canisteo clay loam | | | | | |
| 102B | Clarion loam | | | | | |
| 386 | Okoboji mucky silty clay loam | | | | | |
| L83A | Webster clay loam | | | | | |
| L84A | Glencoe clay loam | | | | | |
| L85A | Nicollet clay loam | | | | | |
| L107A | Canisteo-Glencoe complex, depressions | | | | | |
| L163A | Okoboji silty clay loam, depressions | | | | | |

| **Facility** | **Most suitable soil map unit(s) and soil series names** |
| --- | --- |
| Plant, Animal, and Environmental Science Building (small commercial) | |
| Septic system for whole unit (At-Grade Septic) | |
| Restored wetland (Aquic Suborders and/or Histosols | |
| Permanent soil pit displaying Farmland of Statewide Importance | |
| Nature and bike trail (Paths and Trails) | |

# 12 Soil Management: Chemical

Objectives

- Understand factors that affect nutrient management
- Learn how to read a soil test report
- Determine the best nutrient source to meet soil test nutrient recommendations
- Observe the impact of lime and acid on high and low base saturation soils
- Interact with personal soil samples to determine general idea of nitrate and pH levels

Key Words & Concepts

- Nutrient management
- Soil testing
- Fertilizer grade

## 12.1 PRE-LAB PREP

Collect approximately 1 cup of soil from anywhere! A garden or farm, park, boulevard, or yard are all good places, but anywhere else is fine too! Make sure to sample only to a 0-3 inch depth. **Optional**: Determine the texture of your soil sample using the ribbon method and record it.

## 12.2 INVESTIGATION A: Macronutrient Cycles

For this investigation, we will consider N-P-K, three essential plant macronutrients. You may recognize these letters from bags of fertilizer in the hardware store or garden centers. We have gone over the Nitrogen cycle in detail as Nitrogen is ubiquitously the most limiting nutrient for plant growth. Phosphorus and Potassium undergo their own cycles which are unique processes. The following exercise will provide an opportunity to understand the characteristics and movement of these three major macronutrients.

Fill in the following information pertaining to the nutrient cycles.

| **Nutrient Cycle** | **Is Mineral Weathering a Factor? (Yes/No)** | **Is Soil Organic Matter a Factor? (Yes/No)** | **What is the Plant Available Form?** |
|---|---|---|---|
| N | | | |
| P | | | |
| K | | | |

1. The plant available form of phosphorus PO43- is an anion, yet phosphorus is not generally susceptible to leaching, unlike nitrogen. Why?

2. How is potassium (K) availability controlled by mineral weathering?

3. In Minnesota, what is the best time to soil test for an accurate understanding of plant available nitrogen (N)?

## 12.3 INVESTIGATION B: Measuring Soil pH and Nitrate Levels with Test Strips

Below are instructions for prepping two different setups for soil analysis using pH and nitrate strips. **Preparing them in advance will be helpful to you as they need 10 mins before reading.** We are using test strips in the lab to provide a rapid indication of the pH and nitrate in your soil sample. However, note that for making detailed decisions regarding soil management and plant growth, you would want a more accurate, laboratory measurement of pH and nitrate.

**Soil pH**

1. Locate your soil (check-in with TA on duty to provide your sample to you), 50 ml tube, DI water, pH strips.
2. Fill the 50 ml tube with 10 ml of your soil.
3. Saturate the soil with DI water and fill up to the 20 mL line. This makes a 1:1 ratio of soil/water.
4. Shake vigorously for roughly 30 sec and let sit for 10 mins.
5. When ready to read, take a pH strip and dip into the tube. Try not to dip directly in the soil.
6. The pH paper will react; line it up with the color chart to what closely matches the strip. Record your result.

**Nitrate**

1. Locate your soil (soil from same sample as for your pH reading), filter paper, funnel, catch receptacle, DI water, nitrate strip.
2. Fold the filter paper into a cone shape. You can do this by folding it in half and then in half once more (making it into a quarter). Open the filter up to make a cone shape and place it in a funnel.
3. Pre wet the paper by squirting DI water around it. It doesn't need to be saturated but wetting it will help the filtering go faster.
4. Put a scoop of your soil (approximately one spoonful/scoop) into the filter and add water to the top of the filter line. It is very important that no soil overflows into the catch. It will make reading your result difficult.
5. Allow to sit for ~10 mins.
6. Use the bottom square of the nitrate strip to read result. It is very important that no soil gets on the strip, as you will not be able to see the color otherwise. Dip the strip into the clear liquid, wait 30 sec and record the range.

**Estimated Nitrate-Nitrogen (NO3 – N) in lbs /acre formula below.**

Note that "NO3 – N" does not mean subtract a value for N from a value for NO3; it just refers to the form of nitrogen, which is nitrate. It is pronounced as "nitrate nitrogen" and is one value - the value given by the test strip.

Assume a bulk density of 1. Refer to the Pre-Lab Prep for depth.

$$NO\ 3 - N\ (lbs/ac) = \frac{(ppm\ extract\ NO_3 - N)\ *\ (depth\ of\ soil\ sampled\ in\ cm)\ *\ (bulk\ density)\ *\ 0.89}{10}$$

| **Approximate Soil pH** | **Approximate Soil Nitrate (ppm)** | **Approximate Soil Nitrate (lbs/acre)** |
|---|---|---|
| | | |

## 12.4 INVESTIGATION C: Soil pH and Nutrient Availability

Recall that soil pH has a profound impact on plant uptake of nutrients. Soils which are too acidic and too basic will result in difficulty accessing certain nutrients for plants. Use the nutrient availability diagram to identify ideal pH ranges for each plant nutrient.

| Nutrient | pH Range Most Available | pH Range Least Available |
|---|---|---|
| N | | |
| P | | |
| K | | |
| S | | |
| Fe | | |
| Ca | | |

What are your thoughts on potential issues or nonissues with plant growth in your soil after measuring your soil's pH?

Using your soil's nitrate result from investigation B, what is a plant you could grow without needing to add any more Nitrogen? Use the table on the next page.

| NITROGEN REQUIREMENTS OF COMMON VEGETABLES | | | |
|---|---|---|---|
| **VEGETABLE** | **HIGH** | **MEDIUM** | **LOW** |
| Asparagus | x | | |
| Beans | | | x |
| Beets | | x | |
| Broccoli | | x | |
| Brussel Sprouts | | x | |
| Cabbage | | x | |
| Carrots | | x | |
| Cauliflower | | x | |
| Celery | x | | |
| Corn | | x | |
| Cucumbers | | x | |
| Eggplant | | x | |
| Horseradish | | x | |
| Lettuce | | x | |
| Kale | | x | |
| Onions | | x | |
| Parsnips | | x | |
| Peas | | | x |
| Peppers | | x | |
| Potatoes | | x | |
| Pumpkins | | x | |
| Radishes | | x | |
| Rutabaga | | | x |
| Squash | | x | |
| Swiss Chard | | x | |
| Tomato | | x | |
| Turnip | | x | |

| | |
|---|---|
| **HIGH** | > 131 lbs/acre |
| **MEDIUM** | 44-131 lbs/acre |
| **LOW** | < 44 lbs/acre |

Figure 12.1: Nitrogen Requirements of Vegetables

## 12.5 INVESTIGATION D: Liming and Base Saturation

In the field, quick lime or elemental sulfur is used to adjust pH to a desired range. The following investigation demonstrates a soil with low base saturation (Low B.S.) and a soil with high base saturation (High B.S.) combined with two different amendments. The diagram shows six variations of soil + solution and the pH for each sample. We used HCl in place of elemental sulfur. Before recoding the diagram provided in lab, answer the following questions.

How do you think the quick lime will impact the Low B.S. sample?

How will the addition of acid affect the pH in soil with High B.S.?

**Record the pH of each solution here.**

| Type of Solution | pH |
|---|---|
| Low Base Saturation Soil Slurry | |
| Low Base Saturation and 1 scoop Lime | |
| Low Base Saturation and 10 scoops Lime | |
| High Base Saturation Soil Slurry | |
| High Base Saturation and 1 mL of 5% Acid | |
| High Base Saturation and 5 mL of 10% Acid | |

Explain the impact on the pH of each soil after the different solutions were added. Did the results surprise you?

## 12.6 INVESTIGATION E: Observation of Plant Nutrient Deficiencies

Nutrient deficiencies in plants can sometimes have complex causes and symptoms, and can also be related to drought and other types of stress. Just having a sufficient total amount of an element in the soil does not always eliminate deficiencies because plant nutrient uptake is dependent on a wide range of factors including nutrient form, mobility, and soil properties such as pH, mineralogy, and organic matter. Nutrient deficiencies can be outwardly manifested in different ways in different plant species, and the symptoms of some nutrient deficiencies can mimic other forms of stress. However, experts with enough experience can diagnose nutrient deficiencies in the field. In this investigation, you will examine the outward effect of N, P and K deficiencies in corn. Note that symptoms in other plant species may look similar or may vary, depending on biology and growth conditions.

Observe and read through examples of nutrient deficiencies in corn. Then, look at the unknown corn plants with nutrient deficiencies and determine which particular nutrient is most likely deficient in each case.

| **Unknown Plant** | **Suspected Nutrient Deficiency** |
|---|---|
| 1 | |
| 2 | |
| 3 | |

## 12.7 INVESTIGATION F: Common Fertilizer Materials

**Inorganic Fertilizers**

Plant roots absorb the majority of their nutrients from the soil solution as simple, inorganic ions (charged atoms or molecules). Larger molecules can also be absorbed, but their rate of absorption is slow. Most inorganic fertilizers dissolve readily in water and are immediately available to plants for uptake. When used according to recommendations, these types of fertilizers efficiently supply the required nutrients for plant growth and are safe for the environment. However, excessive rates can injure plant roots due to high salts and potentially lead to environmental degradation.

Review the inorganic fertilizers and complete the following table.

| Name of Inorganic Fertilizer | Analysis (Grade) |
|---|---|
| Ammonium nitrate | |
| Urea | |
| Triple super phosphate | |
| Monoammonium phosphate | |
| Diammonium phosphate | |
| Potassium chloride | |

### Organic Fertilizers

Organic fertilizers are comprised of a diverse mixture of organic molecules and usually contain more complex chemical substances that take time to be broken down into forms usable by plants. These are usually considered slow-release type fertilizers, compared to the quick-release characteristics of most inorganic fertilizers. It is important to apply these organic fertilizers well before periods of rapid plant growth. Organic fertilizers usually have a low salt index, so larger amounts can be applied at one time without causing injury to plant roots. However, even organic fertilizers applied at excessive rates can cause environmental degradation due to nitrate leaching or runoff of soluble organic compounds. The cost of organic fertilizers on a per-pound of nutrient basis is usually higher than quick-release inorganic fertilizers. Manure, compost, and many other materials used as organic fertilizers add considerable quantities of organic matter to the soil. The beneficial effects of organic matter on soil structure can have a greater effect on plant growth than the fertilizer value of some of these organic materials. Most organic fertilizers also provide a variety of macronutrients (besides NPK) as well as many micronutrients.

| Name of Organic Fertilizer | Typical Analysis (Grade)- can be variable! |
|---|---|
| Dairy cattle manure | 2-0-2 |
| Sheep Manure | 2-1-2 |
| Poultry manure | 4-3-2 |
| Seaweed | 0-0-1 |
| Fish meal | 10-6-0 |
| Sewage sludge | 2-3-0 |
| Bone meal | 1-12-0 |
| Milorganite | 6-3-0 |

Complete the table below. For each situation described, decide which form of fertilizer would be preferred, inorganic or organic. Make an X in the appropriate box.

| Situation | Preferred form: Inorganic | Preferred form: Organic |
|---|---|---|
| Need to make nutrients quickly available to plants | | |
| Desire to minimize fertilizer cost | | |
| Concerned about increasing the salt content in the soil | | |
| Need to improve soil structure | | |
| Minimize nitrate leaching into groundwater | | |
| Want to provide only one or two nutrients per application | | |

## 12.8 INVESTIGATION G: Reading and Using a Soil Test Report

Soil testing is a useful nutrient management tool. If used in a predictive mode, a soil test can reduce the environmental risks from the addition of nutrients to the soil while optimizing plant growth. There are two soil reports from the soil we observed in the field last week on the bench. One has soil test results and recommendations for a lawn and garden, while the other report is for future farm and field planting. Fill in the following table of each soil test. Note that recommendations are in P2O5 and K2O, so there is no need to convert. Use the farm and field report to make a recommendation for planting corn or grain.

| Question | Lawn & Garden Report | Farm & Field Report |
|---|---|---|
| What is the pH of the soil? | | |
| What is the estimated soil texture? | | |
| Was the soil test for P Bray or Olsen? | | |
| Why was that particular method chosen? (see lecture 4-4 slide 7) | | |
| What is the K soil test result? (ppm) | | |
| What is the nitrogen (N) recommendation? | lb N/1000 sq ft | lb N/acre |
| What is the phosphate (P) recommendation? | lb P2O5 /1000 sq ft | lb P2O5/acre |
| What is the potash (K) recommendation? | lb K2O/1000 sq ft | lb K2O/acre |

# 13 Soil Management: Physical

Objectives

- Learn how to use the Universal Soil Loss Equation, USLE.
- Determine the effect of crop management and cropping practices on soil loss.

Key Words & Concepts

- USLE
- T
- Conservation tillage
- Conventional tillage
- Crop management
- Cropping practice

## 13.1 INVESTIGATION A: Soil Water Erosion: Raindrop Impact

Soil erosion occurs naturally on all land. Soil erosion may proceed relatively unnoticed or it may occur at an alarming rate — causing serious loss of topsoil. The loss of soil from farmlands is usually reflected in reduced crop production potential, lower surface water quality and damaged drainage networks.

**Raindrop Impact**

Spread a thin layer of each soil on separate pieces of paper. Hold the water dropper one foot above the surface of the soil-covered paper. Allow a single drop of water to fall from the dropper onto the soil. Observe the effects on the silty and sandy soils.

1. What effect does the impact of the water have on each soil (explain any differences that you observe)?

2. How would the presence of plant cover change this?

## 13.2 INVESTIGATION B: Soil Water Erosion: Residue Cover and Runoff

### Water Runoff

Pour just enough water (about ½ of the small beaker) into each funnel at the top of each column so that a small amount of water runs off the soil surface and collects in a larger beaker. Compare the difference in erosion between the uncovered and covered soil. Complete the following table.

| Soil | Rate (High/Moderate/Low) | Explanation |
|---|---|---|
| Bare | | |
| Crop, no residue | | |
| 100% residue cover | | |
| Grass cover | | |

## 13.3 INVESTIGATION C: Predicting Erosion with the Universal Soil Loss Equation

Determine the erosion rates for the Seaton and Frontenac soils (located on the plaster landscape model). Use the white-painted lines and indicated lengths for the LS factor for the three erosion estimates. These soils are located in Winona County, MN.

$$USLE: \ A = R * K * LS * C * P$$

A = Soil loss in tons per acre

R = Rainfall factor

C = Crop management factor

K = Soil erodibility factor (use surface values)

LS = Slope length and slope steepness factor

P = Erosion control practice factor

T = Tolerable loss

Complete the table below following steps 1 – 5.

| | **R** | **K** | **LS** | **C** | **P** | **A** | **T** |
|---|---|---|---|---|---|---|---|
| Site 1: Corn-oats-pasture rotation; no conservation practices | | | | | | | |
| Site 2: Corn-soybean rotation; no conservation practices | | | | | | | |
| Site 3: Woodland; no conservation practices | | | | | | | |

1. R is found on the laminated map in the lab.

2. K and T are found in the Winona County Soil Survey, Table 16, page 261.
3. LS is found as follows:

a. Measure the slope length on the plaster model by placing a ruler between the black lines on the laminated plastic marker at each location. Measure to the nearest 1/16 inch. Record your measurement in Table 2 below.

b. Convert the measurement from Step 1 to feet. Multiply your measurement obtained in Step 1 using the horizontal scale factor (1:1,520), then divide by 12. Do this at each sampling location. Record your result in Table 2 below.

c. Read the slope in degrees off the dial on the side of the clinometer (Figure 1) at each sampling location on the plaster model (the white lines). Some of the sampling sites on the model are not are not flat so the clinometer will tend to rock back and forth. Try to average the variation by finding a middle point. Record your reading in Table 2.

Watch this video on use of the clinometer

d. Divide the measured slope obtained in Step 3c by 2 to correct for the vertical exaggeration of the model. For example, if you obtain a clinometer reading of 16° on the model, the corrected slope is 8° (16° ÷ 2 = 8°). Record your calculation in Table 2.

e. Using the Extended LS Factor Table on the next page, find the slope in degrees in Column 1 corresponding to the corrected value obtained in Step 3d. Record the corresponding slope in percent from Column 2 in Table 2. You will need percent slope to determine P.

f. Continue moving across the row to the column that corresponds to the slope length in feet found in Step 3b and read the LS factor from the body of the table. There is no need to interpolate. Record the LS factor in Tables 1 and 2.

4. C and P are found in the corresponding tables in Investigation D (last page of book). Use the information given in the first column of Table 1.
5. To obtain A, multiply R, K, LS, C, and P in Table 1.
6. Check with the lab TA to be sure your calculations of soil loss (A) for Investigation A are acceptable before going on to Investigation D.

| Site | Length on Model (in; step 3a) | Length on Earth (ft; step 3b) | Slope (degrees; step 3c) | Slope / 2 (degrees; step 3d | Slope (%; step 3e) | LS (step 3f) |
|---|---|---|---|---|---|---|
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |

## 13.4 INVESTIGATION D: Modifying Soil Loss

The tolerable soil loss for most soils in Minnesota is approximately 3 to 5 tons per acre per year. Which area(s) from Table 1 in Investigation C exceed T (circle two)?

**Site 1** **Site 2** **Site 3**

Modify C and P to reduce erosion below T for the areas you circled. Fill out the tables below.

Keep in mind that the landowner wants to maximize their income from the land while implementing conservation practices. Converting a field to woodland significantly reduces income and requires ten to twenty years' investment before realizing any return. Consequently, converting a field to woodland is the least desirable option and should be used only if no other combination to reduce A to below T can be found.

Fill out the table with your new management strategy.

| Site | C | P |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |

Show new calculations in the table below.

| | R | K | LS | C | P | New A | T |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |

## Extended LS Factor Table

| Slope angle (°) | (%) | Slope Length (feet) 75 | 103 | 150 | 238 | 250 | 253 | 300 | 400 | 500 | 600 | 700 | 800 | 1000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.07 | 0.07 | 0.08 | 0.08 | 0.08 | 0.08 | 0.09 | 0.09 | 0.10 | 0.10 | 0.10 | 0.11 | 0.11 |
| 0.5 | 0.9 | 0.11 | 0.12 | 0.13 | 0.14 | 0.14 | 0.14 | 0.15 | 0.15 | 0.16 | 0.17 | 0.17 | 0.18 | 0.19 |
| 1.0 | 1.7 | 0.17 | 0.18 | 0.20 | 0.23 | 0.24 | 0.24 | 0.25 | 0.27 | 0.29 | 0.31 | 0.32 | 0.34 | 0.36 |
| 1.5 | 2.6 | 0.23 | 0.25 | 0.29 | 0.33 | 0.33 | 0.33 | 0.35 | 0.38 | 0.41 | 0.43 | 0.45 | 0.47 | 0.50 |
| 2.0 | 3.5 | 0.31 | 0.35 | 0.41 | 0.49 | 0.50 | 0.50 | 0.54 | 0.60 | 0.66 | 0.71 | 0.75 | 0.79 | 0.87 |
| 2.5 | 4.4 | 0.39 | 0.45 | 0.52 | 0.62 | 0.64 | 0.64 | 0.69 | 0.77 | 0.84 | 0.91 | 0.96 | 1.02 | 1.11 |
| 3.0 | 5.2 | 0.49 | 0.58 | 0.70 | 0.88 | 0.90 | 0.90 | 0.98 | 1.14 | 1.27 | 1.39 | 1.50 | 1.61 | 1.80 |
| 3.5 | 6.1 | 0.60 | 0.70 | 0.85 | 1.07 | 1.09 | 1.10 | 1.20 | 1.38 | 1.55 | 1.69 | 1.83 | 1.96 | 2.19 |
| 4.0 | 7.0 | 0.72 | 0.84 | 1.01 | 1.27 | 1.31 | 1.32 | 1.43 | 1.65 | 1.85 | 2.02 | 2.19 | 2.34 | 2.61 |
| 4.5 | 7.9 | 0.84 | 0.99 | 1.19 | 1.50 | 1.54 | 1.55 | 1.69 | 1.95 | 2.18 | 2.38 | 2.58 | 2.75 | 3.08 |
| 5.0 | 8.7 | 0.98 | 1.15 | 1.39 | 1.75 | 1.79 | 1.80 | 1.96 | 2.27 | 2.53 | 2.77 | 3.00 | 3.20 | 3.58 |
| 5.5 | 9.6 | 1.13 | 1.32 | 1.60 | 2.01 | 2.06 | 2.08 | 2.26 | 2.61 | 2.92 | 3.19 | 3.45 | 3.69 | 4.12 |
| 6.0 | 10.5 | 1.29 | 1.51 | 1.82 | 2.29 | 2.35 | 2.37 | 2.58 | 2.98 | 3.33 | 3.64 | 3.94 | 4.21 | 4.70 |
| 6.5 | 11.4 | 1.46 | 1.71 | 2.06 | 2.59 | 2.66 | 2.68 | 2.92 | 3.37 | 3.76 | 4.12 | 4.45 | 4.76 | 5.32 |
| 7.0 | 12.3 | 1.64 | 1.92 | 2.32 | 2.92 | 2.99 | 3.01 | 3.28 | 3.78 | 4.23 | 4.63 | 5.01 | 5.35 | 5.98 |
| 7.5 | 13.2 | 1.83 | 2.14 | 2.59 | 3.26 | 3.34 | 3.36 | 3.66 | 4.23 | 4.72 | 5.17 | 5.59 | 5.98 | 6.68 |
| 8.0 | 14.1 | 2.03 | 2.38 | 2.87 | 3.62 | 3.71 | 3.73 | 4.06 | 4.69 | 5.25 | 5.75 | 6.21 | 6.64 | 7.42 |
| 8.5 | 14.9 | 2.24 | 2.63 | 3.17 | 3.99 | 4.10 | 4.13 | 4.49 | 5.18 | 5.80 | 6.35 | 6.86 | 7.33 | 8.20 |
| 9.0 | 15.8 | 2.47 | 2.89 | 3.49 | 4.39 | 4.51 | 4.54 | 4.94 | 5.70 | 6.38 | 6.98 | 7.54 | 8.06 | 9.02 |
| 9.5 | 16.7 | 2.70 | 3.17 | 3.83 | 4.81 | 4.94 | 4.97 | 5.41 | 6.25 | 6.98 | 7.65 | 8.26 | 8.83 | 9.88 |
| 10.0 | 17.6 | 2.95 | 3.46 | 4.17 | 5.25 | 5.39 | 5.43 | 5.90 | 6.82 | 7.62 | 8.35 | 9.02 | 9.64 | 10.78 |
| 10.5 | 18.5 | 3.21 | 3.76 | 4.54 | 5.71 | 5.86 | 5.90 | 6.42 | 7.41 | 8.29 | 9.08 | 9.81 | 10.49 | 11.72 |
| 11.0 | 19.4 | 3.48 | 4.08 | 4.92 | 6.19 | 6.36 | 6.40 | 6.96 | 8.04 | 8.99 | 9.85 | 10.63 | 11.37 | 12.71 |
| 11.5 | 20.3 | 3.76 | 4.41 | 5.32 | 6.70 | 6.87 | 6.92 | 7.53 | 8.69 | 9.72 | 10.64 | 11.50 | 12.29 | 13.74 |
| 12.0 | 21.3 | 4.06 | 4.75 | 5.74 | 7.22 | 7.41 | 7.46 | 8.11 | 9.37 | 10.48 | 11.48 | 12.40 | 13.25 | 14.81 |
| 12.5 | 22.2 | 4.36 | 5.11 | 6.17 | 7.77 | 7.97 | 8.02 | 8.73 | 10.08 | 11.27 | 12.34 | 13.33 | 14.25 | 15.93 |
| 13.0 | 23.1 | 4.68 | 5.49 | 6.62 | 8.33 | 8.55 | 8.61 | 9.36 | 10.81 | 12.09 | 13.24 | 14.30 | 15.29 | 17.10 |
| 13.5 | 24.0 | 5.01 | 5.88 | 7.09 | 8.92 | 9.15 | 9.21 | 10.03 | 11.58 | 12.94 | 14.18 | 15.32 | 16.37 | 18.31 |
| 14.0 | 24.9 | 5.36 | 6.28 | 7.58 | 9.53 | 9.78 | 9.85 | 10.72 | 12.37 | 13.83 | 15.15 | 16.37 | 17.50 | 19.56 |
| 14.5 | 25.9 | 5.71 | 6.70 | 8.08 | 10.17 | 10.43 | 10.50 | 11.43 | 13.20 | 14.75 | 16.16 | 17.46 | 18.66 | 20.87 |
| 15.0 | 26.8 | 6.08 | 7.13 | 8.60 | 10.83 | 11.11 | 11.18 | 12.17 | 14.05 | 15.71 | 17.21 | 18.59 | 19.87 | 22.22 |
| 15.5 | 27.7 | 6.47 | 7.58 | 9.15 | 11.51 | 11.81 | 11.89 | 12.94 | 14.94 | 16.70 | 18.29 | 19.76 | 21.12 | 23.62 |
| 16.0 | 28.7 | 6.87 | 8.05 | 9.71 | 12.22 | 12.53 | 12.62 | 13.73 | 15.85 | 17.73 | 19.42 | 20.97 | 22.42 | 25.07 |
| 16.5 | 29.6 | 7.28 | 8.53 | 10.29 | 12.95 | 13.28 | 13.37 | 14.55 | 16.80 | 18.79 | 20.58 | 22.23 | 23.76 | 26.57 |
| 17.0 | 30.6 | 7.70 | 9.03 | 10.89 | 13.71 | 14.06 | 14.15 | 15.40 | 17.79 | 19.89 | 21.78 | 23.53 | 25.15 | 28.12 |
| 17.5 | 31.5 | 8.14 | 9.54 | 11.51 | 14.49 | 14.86 | 14.96 | 16.28 | 18.80 | 21.02 | 23.03 | 24.87 | 26.59 | 29.73 |
| 18.0 | 32.5 | 8.60 | 10.07 | 12.16 | 15.30 | 15.69 | 15.80 | 17.19 | 19.85 | 22.19 | 24.31 | 26.26 | 28.07 | 31.39 |
| 18.5 | 33.5 | 9.06 | 10.62 | 12.82 | 16.13 | 16.55 | 16.66 | 18.13 | 20.93 | 23.41 | 25.64 | 27.69 | 29.61 | 33.10 |
| 19.0 | 34.4 | 9.55 | 11.19 | 13.51 | 16.99 | 17.44 | 17.55 | 19.10 | 22.05 | 24.66 | 27.01 | 29.17 | 31.19 | 34.87 |
| 19.5 | 35.4 | 10.05 | 11.78 | 14.21 | 17.88 | 18.35 | 18.47 | 20.10 | 23.21 | 25.95 | 28.43 | 30.70 | 32.82 | 36.70 |
| 20.0 | 36.4 | 10.57 | 12.38 | 14.94 | 18.80 | 19.29 | 19.42 | 21.13 | 24.40 | 27.28 | 29.89 | 32.28 | 34.51 | 38.58 |
| 20.5 | 37.4 | 11.10 | 13.01 | 15.70 | 19.75 | 20.26 | 20.40 | 22.20 | 25.63 | 28.66 | 31.39 | 33.91 | 36.25 | 40.53 |
| 21.0 | 38.4 | 11.65 | 13.65 | 16.47 | 20.73 | 21.27 | 21.41 | 23.30 | 26.90 | 30.07 | 32.95 | 35.59 | 38.04 | 42.53 |
| 21.5 | 39.4 | 12.21 | 14.31 | 17.27 | 21.74 | 22.30 | 22.45 | 24.43 | 28.21 | 31.54 | 34.55 | 37.32 | 39.89 | 44.60 |
| 22.0 | 40.4 | 12.80 | 15.00 | 18.10 | 22.77 | 23.37 | 23.52 | 25.60 | 29.56 | 33.04 | 36.20 | 39.10 | 41.80 | 46.73 |
| 22.5 | 41.4 | 13.40 | 15.70 | 18.95 | 23.85 | 24.46 | 24.63 | 26.80 | 30.95 | 34.60 | 37.90 | 40.94 | 43.76 | 48.93 |
| 23.0 | 42.4 | 14.02 | 16.43 | 19.83 | 24.95 | 25.60 | 25.77 | 28.04 | 32.38 | 36.20 | 39.65 | 42.83 | 45.79 | 51.19 |
| 23.5 | 43.5 | 14.66 | 17.18 | 20.73 | 26.09 | 26.76 | 26.94 | 29.32 | 33.85 | 37.85 | 41.46 | 44.78 | 47.88 | 53.53 |
| 24.0 | 44.5 | 15.32 | 17.95 | 21.66 | 27.26 | 27.96 | 28.15 | 30.63 | 35.37 | 39.55 | 43.32 | 46.79 | 50.02 | 55.93 |
| 24.5 | 45.6 | 15.99 | 18.74 | 22.62 | 28.46 | 29.20 | 29.40 | 31.99 | 36.94 | 41.30 | 45.24 | 48.86 | 52.24 | 58.40 |
| 25.0 | 46.6 | 16.69 | 19.56 | 23.61 | 29.70 | 30.48 | 30.68 | 33.39 | 38.55 | 43.10 | 47.21 | 51.00 | 54.52 | 60.95 |
| 25.5 | 47.7 | 17.41 | 20.40 | 24.62 | 30.98 | 31.79 | 32.00 | 34.82 | 40.21 | 44.96 | 49.25 | 53.19 | 56.87 | 63.58 |
| 26.0 | 48.8 | 18.15 | 21.27 | 25.67 | 32.30 | 33.14 | 33.36 | 36.30 | 41.92 | 46.87 | 51.34 | 55.45 | 59.28 | 66.28 |
| 26.5 | 49.9 | 18.91 | 22.16 | 26.75 | 33.66 | 34.53 | 34.76 | 37.83 | 43.68 | 48.84 | 53.50 | 57.78 | 61.77 | 69.06 |
| 27.0 | 51.0 | 19.70 | 23.08 | 27.86 | 35.05 | 35.96 | 36.20 | 39.40 | 45.49 | 50.86 | 55.72 | 60.18 | 64.33 | 71.93 |
| 27.5 | 52.1 | 20.51 | 24.03 | 29.00 | 36.49 | 37.44 | 37.69 | 41.01 | 47.36 | 52.95 | 58.00 | 62.65 | 66.97 | 74.88 |
| 28.0 | 53.2 | 21.34 | 25.01 | 30.18 | 37.97 | 38.96 | 39.22 | 42.68 | 49.28 | 55.09 | 60.35 | 65.19 | 69.69 | 77.91 |
| 28.5 | 54.3 | 22.19 | 26.01 | 31.39 | 39.49 | 40.52 | 40.79 | 44.39 | 51.25 | 57.30 | 62.77 | 67.80 | 72.48 | 81.04 |
| 29.0 | 55.4 | 23.08 | 27.04 | 32.63 | 41.06 | 42.13 | 42.41 | 46.15 | 53.29 | 59.58 | 65.27 | 70.50 | 75.36 | 84.26 |
| 29.5 | 56.6 | 23.98 | 28.10 | 33.92 | 42.68 | 43.79 | 44.08 | 47.96 | 55.39 | 61.92 | 67.83 | 73.27 | 78.33 | 87.57 |
| 30.0 | 57.7 | 24.92 | 29.20 | 35.24 | 44.34 | 45.49 | 45.79 | 49.83 | 57.54 | 64.33 | 70.47 | 76.12 | 81.38 | 90.98 |

Figure 13.1: Extended LS Factor Table. Use values from steps 3b and 3d.

Crop management factor, **C**.

| C | Management |
|---|---|
| 1.000 | No crop; moldboard plow |
| 0.550 | Continuous corn; moldboard plow |
| 0.400 | Corn-soybean rotation |
| 0.300 | Continuous corn; conservation tillage |
| 0.200 | Corn-oats rotation |
| 0.080 | Corn-oats-pasture rotation |
| 0.040 | Continuous corn; no till |
| 0.006 | Pasture |
| 0.005 | Woodland |

Erosion control practice factor, ratio of soil loss compared to farming up and down the slope, **P**.

| Slope % | No Practice | Contouring Alone | Contouring plus alternate strips with small grains | Contouring plus alternate strips with grass |
|---|---|---|---|---|
| 1.1-2.0 | 1.0 | 0.6 | 0.4 | 0.3 |
| 2.1-7.0 | 1.0 | 0.5 | 0.4 | 0.2 |
| 7.1-12.0 | 1.0 | 0.6 | 0.4 | 0.3 |
| 12.1-18.0 | 1.0 | 0.8 | 0.6 | 0.4 |
| 18.1-24.0 | 1.0 | 0.9 | 0.7 | 0.4 |