

**- Physical and Chemical Properties of Soils -**

This Soils 201 Exam II study guide contains both information and questions. You will be responsible for the questions posed here. Questions are drawn directly from course lectures and Exploratory Sessions. Clarifying material can be found in the appropriate book chapter. Symbols used are those from Brady and Weil's texts

**General concepts covered:**

1. Units
2. Density
3. Porosity
4. Aggregation
5. Factors that influence physical properties
6. Managing for good tilth
7. Soil Water
  - a. Content (gravimetric, volumetric)
  - b. Potential
  - c. Hydraulic conductivity
8. Managing for water use efficiency
9. pH
10. Septic systems
11. Soil colloids and CEC
12. Exploratory Session Exercises

**Units**

Converting between

- Length: mm, cm, m
- Mass: g, kg, Mg
- Volume:  $\text{cm}^3$ ,  $\text{m}^3$ ; (remember,  $1 \text{ m}^3 = 1 \times 10^6 \text{ cm}^3 = 1,000,000 \text{ cm}^3$ )

**Density:**  $\text{mass/unit volume} = \frac{\text{Mg}}{\text{m}^3} = \frac{\text{g}}{\text{cm}^3}$

Particle density: density of individual particles:  $\frac{\text{mass particle}}{\text{Volume particle}}$

Why do substances have different particle densities? How would particle density compare for a local soil compared to a tropical soil? Which one has more silica and which one has more Fe/Al oxides? How does particle density of organic matter compare to particle densities of minerals?

Bulk density:  $D_b = \frac{\text{mass solids}}{\text{Volume of complete soil (that is, solids + pores)}}$

Which is affected by management: bulk density or particle density? Why?

- Rank  $D_b$  from least dense to most dense for different soil textures.  
Answer: clay → silt loam → sand

- What are typical values for each of the above textures?
- Why does sand have a higher  $D_b$  than clay? (Think about the pore space in clay particles.)
- Which includes pore space: bulk density or particle density? Try drawing a picture of a 3-d box. One is filled to the top with soil, the other is compacted and only half fills the box. Which one includes pore space and which one is  $D_b$ ?

$$\text{Porosity} = \% \text{ pore space} = \frac{\text{volume pores}}{\text{Total soil volume}}$$

- How much of total soil volume is taken up by pores? Total pore space includes pores that are filled with air and water. Answer: 50%. This average is optimal for plant growth.
- What soil would have higher porosity: one with higher OM content, or a sandy clay?
- There are three kinds of pores: 1) macropores (which includes 2) biopores), and 3) micropores. Which one is found between pedes (i.e. which ones are interpedes?); which ones are actually between soil particles; which ones are caused by actions of soil macrofauna?
- Which of the pore classes are generally filled with water?
- Water-filled pores slow air movement.

### Aggregation

Micro-aggregates are cohered dominantly by the chemical and physical forces

Macro-aggregates are biologically bound by plant roots, fungal hyphae, slimes exuded by soil microbial life and roots

Good and stable soil aggregation is a sign of soil *tilth* = good general soil physical characteristics (a non-scientific term)

Factors that influence soil tilth

1. Compaction
  - a. Know 2-4 factors that influence compaction
  - b. Does compaction act mainly on micropores or macropores?
  - c. Understand action of raindrops on soil surface crusting (silt loam soils experience the worst crusting)
2. Oxidation of soil carbon (conversion of OM-carbon to  $\text{CO}_2$ ) when bare soil is exposed to the air, including when soil aggregates are pulverized, exposing more surface area to react with the air
3. Organic matter content
  - a. Understand relationships between aggregate stability and soil OM level
  - b. Is a mineral soil with high or low OM best able to hold both water and air?
  - c. Which retains its structure, which turns to mud? Why?

Managing for for tilth

1. Understand management practices that enhance soil tilth; these include, but are not limited to the following. Be able to provide 2-3 management strategies for each.
  - a. Minimize compaction
  - b. Maintain and enhance soil OM

- c. Avoid Na<sup>+</sup> (sodium) additions (fertilizer, poor quality irrigation water)
  - i. What is a structural indication of Na<sup>+</sup> buildup?
  - ii. Are clay silicate layers repelled or attracted in the presence of Na<sup>+</sup>?

### Soil Water

1. Water content: how wet a soil is
2. Water potential: energy status of water which affects its ability and direction for movement:
  - a. In soil
  - b. In plants
  - c. Into the atmosphere
3. Soil permeability to water: hydraulic conductivity
4. Need to know water potential and hydraulic conductivity to determine direction and rate (amount) of water movement

### Water content

$$\text{Gravimetric water content} = \Theta_m = \frac{\text{mass wet soil} - \text{mass dry soil}}{\text{Mass dry soil}} = \frac{\text{mass water}}{\text{mass dry soil}}$$

$$\text{Volumetric water content} = \Theta_v = \frac{\text{volume water}}{\text{volume soil}} = \Theta_m \times D_d \quad (\text{includes a 'hidden term for density of water'})$$

- What is the difference between gravimetric and volumetric water content? When would you use each?

**Water potential** is a measure of the soil water's potential energy; i.e. the potential of the water to *move*. Four sets of forces determine this potential energy:

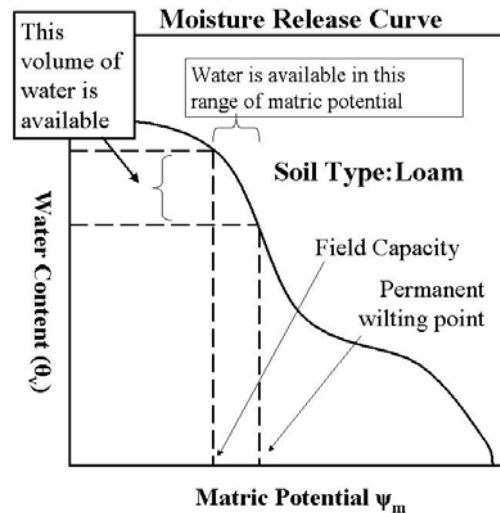
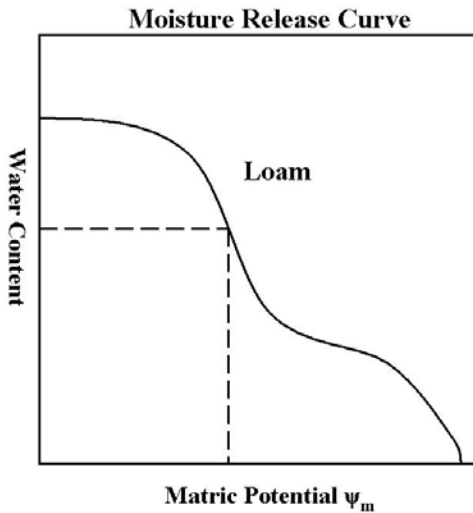
1. Matric potential ( $\psi_m$ ): attraction of soil particles for water and of water molecules to other water molecules
  2. Osmotic ( $\psi_o$ ): attraction of water molecules to dissolved materials (like salts) such that water has reduced energy
  3. Gravity ( $\psi_g$ ): the attraction of water to the center of the earth
  4. Pressure ( $\psi_p$ ): the force of water upon itself when it is increasingly concentrated or accumulated within a finite volume by some kind of barrier (a diving well, plant membranes, a barrel, etc.. In soil is mainly important when there is a high water table)
- The water potential list above does not include complete definitions. Know how to provide complete definitions of each of these forces, making drawings if necessary. Know circumstances under which is important.
  - What two actions in combination are responsible for capillarity (the movement of water into small spaces (pores) despite the force of gravity) and therefore matric potential? Describe.
  - If greater surface contact between water and capillary walls increases capillarity, then what exerts a greater force on water: narrower or wider capillaries?
  - Capillaries exist in our lungs and in the soil; they are finely divided spaces with a maximum of surface area to volume that are ideal for gas and other forms of chemical exchange

- Water content and water potential are related to each other, but are not the same thing. What is the difference between water content and water potential? Be able to describe the difference, and to explain the relationship between them.

Water potential ( $\psi$ ) is the energy status of water:  $\psi = \psi_m + \psi_o + \psi_g + \psi_p$

Water potential is measured in kPa and is the energy/pressure required to move water through the soil

Moisture release curves describe relationships between soil water content and matric potential. This relationship is unique for every soil type.



### Hydraulic conductivity (K)

= the permeability of soil to water.

- 1.) Hydraulic conductivity depends on soil texture and structure
- 2.) Hydraulic conductivity for a given soil varies as the water content varies, due to changes in pore diameter, connectivity, and tortuosity (winding of pore pathways)
- 3.) For a given soil, hydraulic conductivity is always higher in wetter soils, and is highest in saturated soils. In fact, we often talk in particular about the saturated hydraulic conductivity ( $K_{sat}$ )

- Explain why the hydraulic conductivity of an unsaturated soil is lower than when the same soil is saturated
- Which is more affected by soil structure – saturated or unsaturated hydraulic conductivity?
- Which has a higher saturated hydraulic conductivity – a clay loam or a sand? How about for unsaturated soil?

### Septic Systems

1. Septic systems rely on physical, biological, and chemical actions to treat household wastewater.
  2. Pre-treatment occurs in the septic tank, “final” treatment occurs in the leachfield if it is constructed properly.
  3. A variety of alternative types of septic systems, often involving expensive pumps, have been developed to sufficiently treat wastes where there is a high water table.
- What occurs in each component of the septic system?
  - Explain the biomat formation and function.
  - What are the potential pollutants present in wastewater that we rely on a septic system to treat? How is the pollution potential of each type of pollutant treated in an ideally functioning septic system? Which of the pollutants are most easily treated? Least?

### Soil Colloids and CEC

#### Cation exchange capacity

- What is it?
- Does it have a positive or negative charge?
- What charge do cations and anions have?
- CEC is determined by:
  - Soil texture
  - Kinds of silicate clay minerals present
  - Amounts of clay silicate minerals present
  - Amount of OM
  - Soil pH
- You should have an understanding of how these factors influence CEC

#### CEC

- Know how to diagram the cation exchange process, in which cations on a clay can be replaced by incoming cations
- CEC units are cmolc/kg.
- Soil CEC depends on the relative proportions of the different CEC sources (clays and OM - we can ignore sand, silt because their relative surface area is so small)
- Identify acid and non-acid (base) cations

#### Calculating CEC

- Note that cmolc = cmols of \*charge\*
- One cmol  $\text{Ca}^{2+}$  requires \*two\* cmols of net negative charge to be adsorbed
- Hence  $1 \text{ cmol } \text{Ca}^{2+} = 2 \text{ cmolc}$
- One way of calculating the CEC is to know the relative proportion of the different colloids, look up the table CEC value for each and weight it (multiply it) by the percent that colloid is in the soil overall
- Ex. total CEC = (kg colloid / kg soil) x cmolc/kg for colloid x) + ....(add in terms for remaining colloids).
- Alternately, you can sum up the cmolc of adsorbed cations present in a sample of soil
- $1 \text{ cmol } \text{Al}^{3+} = 3 \text{ cmolc}$

## Soil colloids

- What are the four major types of soil colloid?
- They have different inherent negative charge (so have different CEC); understand the general ranking of the major types
- What is the difference between adsorption and absorption?

## Silicate clays

- There are 1:1 and 2:1 type silicate clay minerals
- Type of clay mineral is determined by octahedral and tetrahedral layers, and the particular sequence (arrangement) of these layers
- This variation in silicate clay layer arrangement determines the CEC for each particular mineral
- You should be able to describe 2 kinds of silicate clay minerals and why CEC is different for these
- Think about internal and/or external charges, total surface area, interlayer spacing, ability of ions or water to get into these interlayers (there may be no interlayer spacing: kaolinite; or it may be entirely occupied by an ion like potassium: illite; or the silicate clay layers may expand when wet: vermiculate and smectite; these factors influence CEC (see the book; see your notes)
- What effect does surface area have on CEC?

## Colloids and CEC

- Know the \*general ranking\* of different colloids with respect to CEC - esp vermiculite, smectite, illite, kaolinite, oxide and hydroxide clays, and OM
- Exact numbers will be given if you need them

**Exploratory Session Exercises**

1. How to read soil surveys
  - a. Identify locations on soil survey maps
  - b. Calculate areas identified on survey maps
  - c. Know what kind of information can be found in soil surveys
  - d. Know how to read range and township locations
2. Calculations for measuring gravimetric and volumetric water content, bulk density, and porosity
3. Compare methods used to determine water potential, drawing from both book chapters and exploratory session
4. Compare methods used to measure soil pH; understand 3 methods of measuring pH
  - a. Why does the pH meter need to be calibrated?
  - b. What is the pH of the different solutions used to calibrate the pH meter?
  - c. Why do we use two solutions to calibrate the meter?
  - d. Why did I not pay attention to exploratory session explanations?
5. CEC and Soil Colloids
  - a. What is cation exchange capacity?
  - b. Relationship between pH and CEC
  - c. What role does clay play in septic systems?
  - d. What effect can hydrogen ions in soil solution have on  $\text{Ca}^{2+}$  ions adsorbed to clay or humus colloids

## Calculations Worksheets

### Calculation 1. Replacing Cations on Soil Colloids

**Remember:** Cations are replaced on soil colloids on a charge basis. That is, we know the charge of the cation that we want to replace. We then know that it takes an equal amount of charge of another cation to replace it. If we have 2 cmol(+)/kg soil (centimoles charge per kilogram soil) of both hydrogen and aluminum ions, we have 4.0 total cmol(+)/kg that we want to replace. If we want to replace these charges with calcium, we will need 4.0 cmol(+)/kg of calcium cations. Study the example below.

**Question:**

Determine the weight of  $\text{Ca}^{2+}$  required to replace 2.0 cmol(+)/kg  $\text{H}^+$  and 2.0 cmol(+)/kg  $\text{Al}^{3+}$  with  $\text{Ca}^{2+}$  cations in a soil.

	Steps	Calculations
1	Determine # of cmol(+)/kg that you need to replace	$2.0 \text{ cmol(+)/kg H}^+ + 2.0 \text{ cmol(+)/kg Al}^{3+} = 4.0 \text{ cmol(+)}$ . Therefore, we want to replace 4.0 cmol(+)/kg of $\text{Al}^{3+}$ and $\text{H}^+$ cations with 4.0 cmol(+)/kg $\text{Ca}^{2+}$
2	Look up the atomic weight of the cation that will be used to replace the charge from step 1	40 g/mol $\text{Ca}^{2+}$
3	Determine the molar charge conversion for by converting the atomic weight of $\text{Ca}^{2+}$ from g/mol to g/mol(+). Note that $\text{Ca}^{2+}$ has two moles charge per its atomic weight of 0.40 g/mol.	$\frac{40 \text{ g Ca}^{2+}}{\text{Mol}} \times \frac{1/100}{1/100} = \frac{0.40 \text{ g Ca}^{2+}}{2 \text{ cmol(+)}}$
4	To determine g/kg $\text{Ca}^{2+}$ , multiply the charge (step 1) by the molar conversion for $\text{Ca}^{2+}$ to get the weight of $\text{Ca}^{2+}$ needed to replace this specified charge (step 1) on a g/kg basis	$\frac{4 \text{ cmol(+)}}{\text{Kg}} \times \frac{0.40 \text{ g Ca}^{2+}}{2 \text{ cmol(+)}} = \frac{0.8 \text{ g Ca}^{2+}}{\text{kg}}$

**Calculation 2. Determining the CEC of a soil from soil colloid charges**

You should also be familiar with this kind of calculation that we covered in the exploratory session. This kind of example is also explained in the book, so look it up if you are having trouble.

**Example 1**

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A soil contains 20% smectite, 5% Fe/Al oxides, and 4% humus.  
Calculate its CEC.

**(5% = 0.05 kg per 1 kg soil)**

Visit Table 8.3: pH of 7 is neutral; smectite CEC = 100 cmolc/kg

Organic Matter CEC = 200 cmolc/kg

Gibbsite/Goethite (Fe/Al oxide) CEC = 4 cmolc/kg

From the clays:  $0.2 \text{ kg} \times 100 \text{ cmolc/kg} = 20 \text{ cmolc}$

From O.M.:  $.04 \text{ kg} \times 200 \text{ cmolc/kg} = 8 \text{ cmolc}$

From oxides:  $0.05 \text{ kg} \times 4 \text{ cmolc/kg} = 0.2 \text{ cmolc}$

Sand does not carry a charge, so...

Total CEC of the soil =  $20 + 8 + 0.2 = 28.2 \text{ cmolc/kg soil}$