

Soil Science

Laboratory Manual

EVSC 427 - Department of Environmental Sciences
The University of Virginia

This document consists of a group of procedures and exercises for use in EVSC 427, Soil Science. It is available to all students who register for the course, and it will be referred to frequently in the lectures and laboratories of the course. Before coming to the lab each week, a student should become familiar with the content of the material assigned for that week's exercise.

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SOIL TEXTURE

The determination of the particle-size distribution in a soil sample is one of the most fundamental procedures in soil science. The relative proportions of sand, silt, and clay form a basic soil property known as texture. The texture of a soil controls its moisture holding capability and many of its chemical properties. The textural classification of a soil is nearly always applied to the name of a particular soil series, e.g. Cecil sandy clay loam. The determination of soil texture involves the determination of the relative amounts of sand, silt, and clay in a sample. The process whereby soil texture is determined is usually referred to as mechanical analysis (although some other physical properties are often included in a complete mechanical analysis).

I. Determination of Soil Texture by Feel

Several containers of soil are in the laboratory, each containing soil of differing sand, silt, and clay composition. Take a small amount of each of the soils in your hand and "feel" its characteristics. Try to determine the texture of each of the soils according to the modified textural triangle that accompanies this exercise.

Procedure:

(1) Think of the textural triangle in a modified manner as shown in Figure 1. Basically, it is made up of clays (sandy clay, clay, and silty clay) which will form good ribbons; clay loams (sandy clay loam, clay loam and silty clay loam) which form medium ribbons; loams (sandy loam and silt loam) which form poor or no ribbons and the sands which do not form ribbons. (The loamy sands and silt classes are omitted from this triangle for the sake of simplicity).

(2) Determine whether the soil fits best into a clay, clay loam, or loam class by determining whether it makes a good, medium, or poor ribbon. To do this, place about 1/2 to 1 teaspoon of soil in the palm of the hand. Add water very slowly, drop by drop, from a water bottle or tap. Knead the soil all the while and bring it to the consistency of moist, workable putty. When the soil is at the proper consistency, try to press it into a ribbon between the thumb and forefinger.

(3) Once it has been determined whether the soil is a clay, clay loam, or loam; re-examine the sample. If it is definitely sandy, call it a sandy clay, a sandy clay loam or a sandy loam, depending on the type of ribbon it made. If it is exceptionally smooth, call it a silty clay, silty clay loam, or silty loam. If it is neither rather sandy nor exceptionally smooth, call

it a clay, a clay loam, or a loam, depending on the type of ribbon produced.

(4) Soils that are loose and single grained when dry and form a fragile cast when moist are called sands.

II. The Hydrometer Method For Mechanical Analysis

This method is one of the simplest and most rapid methods for mechanical analysis of soils. A dispersed sample of soil is thoroughly mixed with water in a tall glass cylinder and allowed to settle. To understand the basis for the method, consider an imaginary plane some distance below the surface of the soil-water suspension. The time required for a given size of particle, say 0.05 mm diameter to fall from the surface of the water to this plane can be calculated. When this time has elapsed, all particles 0.05 mm in diameter and larger (because these will fall faster) will be below the plane. Immediately above the plane, the concentration of particles smaller than 0.05 mm will be the same as the concentration of these particles in the entire suspension before sedimentation began. Therefore, if one devises a method for measuring this concentration, one can calculate the total mass of particles in the soil sample. Of course, the total weight of the sample and the volume of the liquid in the cylinder must be known. By selecting appropriate times, one can determine in this manner the percent by weight of particles smaller than any desired size limit.

A hydrometer is used in this method to measure the density of the soil suspension. In some laboratories the hydrometer is calibrated to measure the amount of soil in suspension directly. In our lab, the hydrometer is calibrated to measure specific gravity of the suspension, and the grams of soil particles must be calculated. (If you can use this method, the "Bouy-

ucos" hydrometer is trivial.) First, a thoroughly dispersed sample of soil in water is mixed in a graduated cylinder. The hydrometer is placed in the suspension and a reading is taken after a settling time of 40 seconds. This time is chosen so that the sand particles (0.05 mm and larger) will have fallen below the imaginary plane. The hydrometer then measures the density of the silt-plus-clay suspension because the buoyant force on the hydrometer is determined by the silt and clay in suspension above the imaginary plane. After two hours have elapsed to allow the smallest silt particle to fall below the imaginary plane, a second reading is taken to measure the density of the clay suspension.

The hydrometer is calibrated at 20°C. Hydrometer readings must be corrected for the variation in temperature because the viscosity of the water and, to a lesser extent, the density of water change with the change in temperature. We will make a composite correction for temperature, density, and viscosity differences as directed below.

Procedure:

The general sequence of steps is 1) removal of particles larger than 2-mm diameter, 2) treatment to remove cementing agents and organic matter, 3) dispersion, and 4) sedimentation. Note that steps (1) and (2) (below) have been done by the TA.

- (1) Weigh 40 g of oven dry soil.
- (2) Add 50 mL Clorox to the soil sample. Allow to stand for 24 h.
- (3) Add 100 mL of dispersant (40 g sodium hexametaphosphate liter⁻¹) solution and 100 to 200 mL of distilled water. Allow to stand 10 min with occasional stirring.
- (4) Transfer the sample to a dispersing cup and mix for 5 minutes. This will thoroughly disperse the soil particles. **CAUTION:** Agitation of Clorox, dispersant and water causes a lot of foam. Use 3-5 drops of amyl alcohol to defoam.
- (5) Transfer the dispersed sample to a sedimentation cylinder, add distilled water to bring to 1000 mL. Use more amyl alcohol if needed.
- (6) Mix by inversion of the cylinder using your hand to seal the top. (For those with small hands, use a rubber stopper.)
- (7) Immediately after mixing, place the cylinder upright on the table, start the timer and carefully insert the hydrometer in the suspension.
- (8) Read the hydrometer, at the top of the meniscus, 30 seconds after the start of sedimentation. This reading is R.

(9) Remove, rinse and dry the hydrometer. **DO NOT DISTURB OR REMIX THE SUSPENSION.**

(10) Repeat readings at 3, 10, 30, 90, and 120 min after the start of sedimentation.

(11) Calibrate your particular hydrometer in a solution of 50 mL Clorox and 100 mL dispersant solution diluted to one liter in a sedimentation cylinder. Take a similar reading in a column of distilled water. R_L (see below) is the difference between these readings. **RECORD THE TEMPERATURE.**

Calculations:

The formula for calculation of the percentage of original sample still in suspension is :

$$P = \frac{[(100000 / W)G](R_c - G_L)}{(G - G_L)}$$

where

- P = % of soil remaining in suspension
- W = oven dry weight of sample
- G = specific gravity of soil particles (=2.65)
- G_L = specific gravity of liquid (= 1)
- R_c = hydrometer reading corrected by the "composite correction factor" related to temperature.

$$R_c = R - R_L$$

where **R** is the reading in the soil suspension and **R_L** is the difference between the hydrometer reading in distilled water at the same temperature as the settling column, and the hydrometer reading in a column of the dispersing agent plus hypochlorite. This value should be determined for each hydrometer – it can vary.

NOTE: **IF** you are using air-dry soil for this exercise, it still contains some water. In order to correct the weight of the soil that you add to the hydrometer jar for that water, weigh out a portion of the same soil and dry it in the oven at 105°C overnight. Re-weigh the soil. The difference in the weights represents the weight of the water lost upon oven drying. Use a simple proportion to determine the actual "oven dry weight" of the air-dry soil you placed in the jar. Your TA can help with this simple calculation.

The diameter of a soil particle corresponding to the percentage indicated by the hydrometer reading may be computed by the equation:

$$D = K \sqrt{\frac{L}{T}}$$

where D is the diameter of the particle in mm, K is a constant that depends on the temperature of the suspension and the specific gravity (density) of the soil particles (values for K can be obtained from Table 1), L is the distance (cm) from the surface of the suspension to the level at which the density is being measured. (Values of L can be obtained from Table 2.), and T is the interval of time from the beginning of sedimentation to the taking of the reading (min).

As part of your report, prepare a graph of the "Percent Passing" (y-axis) against the "Grain Diameter" (x-axis). You may find it necessary to plot the abscissa as the logarithm of the particle size.

III. References

- ASTM, 1981. *Annual Book of ASTM Standards*. American Society for Testing and Materials, Philadelphia, PA.
- Liu, C., and J.B. Evett. 1984. *Soil Properties: Testing, Measurement, and Evaluation*. Prentice Hall, Englewood Cliffs, NJ.

Table 1. Values of K for use in computing the diameter of particles in the hydrometer analysis. (Reprinted from Liu and Evett, 1984)

Temperature (°C)	Specific Gravity of Soil Particles								
	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.01510	0.01505	0.01481	0.01547	0.01435	0.01414	0.01394	0.01374	0.01356
17	0.01511	0.01486	0.01462	0.01439	0.01417	0.01396	0.01376	0.01356	0.01338
18	0.01492	0.01467	0.01443	0.01421	0.01399	0.01378	0.01359	0.01339	0.01321
19	0.01474	0.01445	0.01425	0.01403	0.01382	0.01361	0.01342	0.01323	0.01305
20	0.01456	0.01431	0.01408	0.01386	0.01365	0.01344	0.01325	0.01307	0.01289
21	0.01438	0.01414	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291	0.01273
22	0.01421	0.01397	0.01374	0.01353	0.01332	0.01312	0.01294	0.01376	0.01258
23	0.01404	0.01381	0.01358	0.01337	0.01317	0.01297	0.01297	0.01279	0.01243
24	0.01388	0.01365	0.01342	0.01321	0.01301	0.01282	0.01264	0.01246	0.01229
25	0.01372	0.01349	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232	0.01215
26	0.01357	0.01334	0.01312	0.01291	0.01272	0.01253	0.01235	0.01218	0.01201
27	0.01342	0.01319	0.01297	0.01277	0.01258	0.01239	0.01221	0.01204	0.01188
28	0.01327	0.01304	0.01283	0.01264	0.01244	0.01225	0.01208	0.01191	0.01175
29	0.01312	0.01290	0.01269	0.01249	0.01230	0.01212	0.01195	0.01178	0.01162
30	0.01298	0.01276	0.01256	0.01236	0.01217	0.01199	0.01182	0.01165	0.01149

Table 2. Values of effective depth based on hydrometer and sedimentation cylinders of specified sizes (ASTM 151H). (Taken from Liu and Evett, 1984)

<i>Actual Hydrometer Reading</i>	<i>Effective Depth L(cm)</i>	<i>Actual Hydrometer Reading</i>	<i>Effective Depth L(cm)</i>	<i>Actual Hydrometer Reading</i>	<i>Effective Depth L(cm)</i>
1.000	13.3	1.013	12.9	1.026	9.4
1.001	16.0	1.014	12.6	1.027	9.2
1.002	15.8	1.015	12.3	1.028	8.9
1.003	15.5	1.016	12.1	1.029	8.6
1.004	15.2	1.017	11.8	1.030	8.4
1.005	15.0	1.018	11.5	1.031	8.1
1.006	14.7	1.019	11.3	1.032	7.8
1.007	14.4	1.020	11.0	1.033	7.6
1.008	14.2	1.021	10.7	1.034	7.3
1.009	13.9	1.022	10.5	1.035	7.0
1.010	13.7	1.023	10.2	1.036	6.8
1.011	13.4	1.024	10.0	1.037	6.5
1.012	13.1	1.025	9.7	1.038	6.2

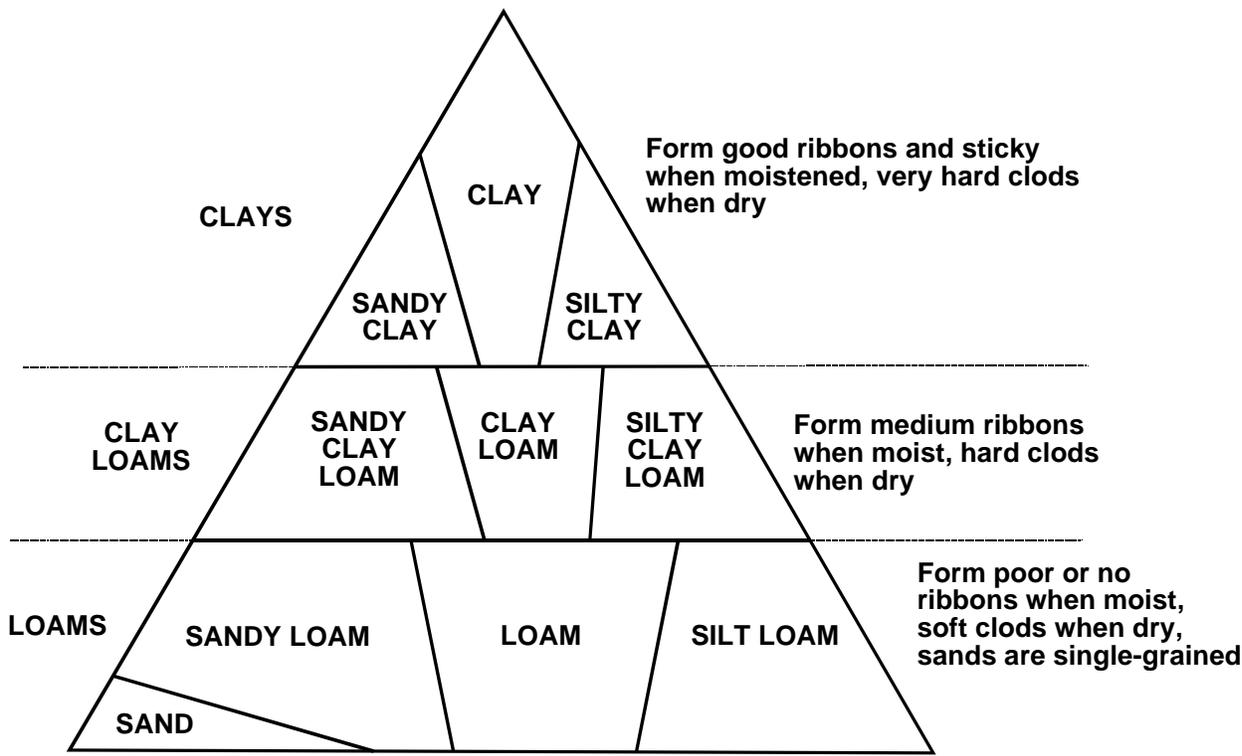
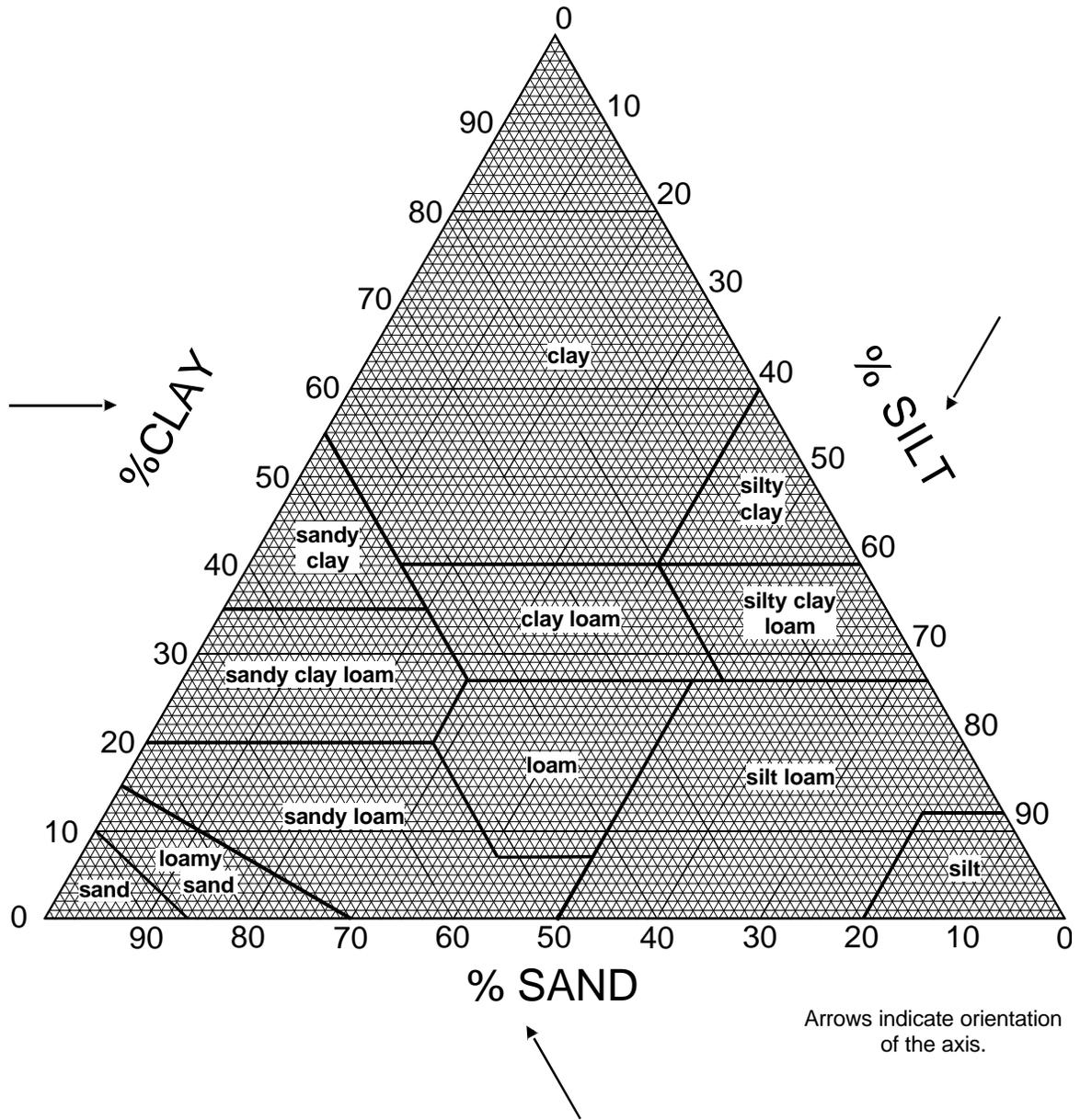


Figure 1. Modified textural triangle for used in determining soil texture by feel.

Figure 2. Particle size classifications as defined by several agencies

American Society for Testing and Materials	Colloids	Clay	Silt	Fine sand	Coarse sand	Gravel				
American Association of State Highway Officials Soil Classification	Colloids	Clay	Silt	Fine sand	Coarse sand	Fine gravel	Medium gravel	Coarse gravel	Boulders	
Unified Soil Classification (Corps of Engineers, Department of the Army, and Bureau of Reclamation)	Fines (silt or clay)			Fine sand	Medium sand	Coarse sand	Fine gravel	Coarse gravel	Cobbles	
Civil Aeronautics Administration Soil Classification	Clay	Silt	Fine sand	Coarse sand	Gravel					
U.S. Department of Agriculture Soil Classification	Clay	Silt	Very Fine sand	Fine sand	Med-ium sand	Coarse sand	Very coarse sand	Fine gravel	Coarse gravel	Cobbles
Sieve sizes										
270 200 140 60 40 20 10 4 1/2" 3/4" 3"										
.001 .002 .003 .004 .006 .008 .01 .02 .03 .04 .06 .075 .1 .15 .2 .3 .4 .6 .8 1.0 2.0 3.0 4.0 5.0 6.0 10 20 30 40 60 80										
Particle size - mm										

Figure 3. The Textural Triangle



POROSITY AND BULK DENSITY OF CLODS / PARTICLE DENSITY OF SOIL

Soil structure, one of the important physical properties of soil, can be evaluated by measurements of both density and porosity. The purpose of this exercise is to determine bulk density and porosity of two clods, one with normal field structure, the other a "puddled" clod.

I. Definitions

Particle Density - the ratio of the mass (oven dry weight) of the soil particles to the *particle* volume expressed in grams per cubic centimeter.

Bulk Density - the ratio of the mass (oven dry weight) of the soil to the bulk volume expressed in grams per cubic centimeter.

Percent Pore Space (porosity) - the ratio of the volume of voids in a soil to the total volume (bulk volume) of the soil times 100. Percent pore space is calculated by means of the following equation:

$$\% \text{Pore Space} = 100 - \left[\frac{\text{Bulk Density}}{\text{Particle Density}} \times 100 \right]$$

II. Particle Density

The particle density of most mineral soils lies within the narrow limits of 2.5 to 2.7 g·cm⁻³. The average density of mineral particles in soils is approximately 2.65 to 2.7 g·cm⁻³. The density of organic matter in soils is approximately 1.2 - 1.5 g·cm⁻³. When the average particle density is not known, a value of 2.65 g·cm⁻³ is generally assumed as the average particle density of mineral soils.

A determination of particle density requires measurements of oven dry weight and volume of the soil particles. The volume of soil particles is determined by measuring the weight of water displaced by the particles. A specific gravity bottle or pycnometer is used for this purpose.

A pycnometer is a bottle which can be filled accurately with a definite amount of liquid without any air space left in the bottle. In our case we will use a 50-mL volumetric flask which can be

accurately filled to hold a known volume. In effect, it functions the same as the pycnometer. It is utilized in measuring the density of soil particles as follows:

Procedure:

- Fill bottle with water and weigh
- Pour out approximately half of the water; weigh again
- Add a small amount of oven dry soil to the bottle and reweigh
- Transfer the bottle to a vacuum desiccator and evacuate to remove air bubbles. Fill bottle with water at same temperature as originally used and weigh again.
- Record the weights obtained in the data table.

Calculations: (Make sure you understand each step)

- The oven dry weight of the soil (line 5) is the difference in weight of the bottle half full of water before and after the soil sample is added (line 3 minus line 2).
- The weight of water displaced is obtained by adding the oven dry weight of the soil sample (line 5) to the weight of bottle filled with water only (line 1) and subtracting from this the weight of the bottle containing the soil sample and enough water to completely fill it (line 4).
- The volume of water displaced is calculated from the weight and density of the water. The particle volume is equal to the volume of water displaced.
- Particle density is obtained by dividing the oven dry weight of the soil by the particle volume.

DATA TABLE

1. Wt. bottle + water (full)	_____
2. Wt. bottle + water (1/2 full)	_____
3. Wt. bottle + soil + water (1/2 full)	_____
4. Wt. bottle + soil + water (full)	_____
5. Oven dry wt. of soil	_____
6. Wt. of water displaced by soil	_____
7. Volume of water displaced by soil	_____
8. Particle density of soil	_____

Calculations: (Make sure you understand each step)

- a) The oven dry weight of the soil (line 5) is the difference in weight of the bottle half full of water before and after the soil sample is added (line 3 minus line 2).
- b) The weight of water displaced is obtained by adding the oven dry weight of the soil sample (line 5) to the weight of bottle filled with water only (line 1) and subtracting from this the weight of the bottle containing the soil sample and enough water to completely fill it (line 4).
- c) The volume of water displaced is calculated from the weight and density of the water. The particle volume is equal to the volume of water displaced.
- d) Particle density is obtained by dividing the oven dry weight of the soil by particle volume.

III. Bulk Density

The paraffined clod method will be used in this exercise to determine bulk density. The basis for this method is the measurement of the volume of a clod by utilizing the buoyancy principle which may be stated as follows: When a solid material (density greater than water) is immersed in water, an upward directed force equal to the weight of the water displaced, is exerted upon it. Thus, if a solid object is weighed first in air (the buoyant force of air can be considered negligible in this case) and then in

water, the difference between the two weights represents the weight of displaced water. The weight of displaced water in grams equals its volume in cubic centimeters (assuming that the density of the water is 1 g-cm^{-3}).

When measuring the volume of a soil clod, the clod is coated with paraffin to keep water out of the pores. The volume of water displaced by the clod is equal to the volume of the paraffin coated minus the volume of the paraffin.

Procedure:

- a) Two clods, a normal clod and a puddled clod, are provided.
- b) Tie a piece of thread around each clod and make a loop in the other end of the thread so that the clod may be hung on the balance.
- c) Weigh each clod.
- d) Dip the clod rapidly into liquid paraffin at 60°C and let it cool. Weigh each coated clod only after continuous paraffin coating is obtained.
- e) Place a beaker of water so that the clod is completely immersed in the water and re-weigh.

Calculations:

- a) The oven dry weight of the clods must be calculated from the air dry moisture content

(P_w). This may be done using the following formula:

$$\text{Oven dry wt.} = \frac{\text{air dry wt. of clod}}{1 + P_w}$$

The value of air dry P_w must be in decimal form:

$$\left[\frac{P_w}{100} \right]$$

- b) The difference between the weight of the paraffined clod in air and its weight in water is the weight of water displaced by the clod. We will assume the density of water is 1 g·cm⁻³. (The actual value is 0.9982 g·cm⁻³ at 20°C). Hence, the weight of water displaced in grams is equal to the volume of the clod and paraffin in cubic centimeters.
- c) To obtain the volume of the clod alone, subtract the volume of the paraffin. The paraffin's volume is calculated from its weight and density which is 0.80 g·cm⁻³.
- d) The bulk density is determined by dividing the oven dry weight of the soil by its bulk volume.

IV. Bulk Density of soil horizons

To determine the bulk density of several soil horizons, a detipped plastic syringe will be used to extract a measurable volume of soil from several points in the soil profile. The volume will be determined by assuming the "core" is a cylinder.

Procedures

In the field:

- a) Insert a detipped syringe into the soil profile at the desired point (be sure to make any necessary measurements to permit description of the location of the sample; e.g. "A-horizon, 10 cm from surface"). In a "real" situation, replicates at each depth would be essential.
- b) Remove the syringe and soil core and measure the length of the soil core.
- c) Place the soil core into an appropriate container for return to the lab.
- d) Repeat this procedure for each soil horizon or depth that you wish to sample. (Make replicate measurements if you wish.)

In the laboratory:

- e) Place the soil sample into a tared (pre-weighed) and labeled aluminum-foil weighing dish.
- f) Weigh the soil and dish.
- g) Place the dish into the oven and dry the soil for 24 h at 105°C.
- h) After 24 h, remove the soil from the oven, allow it to cool (in a desiccator if possible), and weigh it again.

Calculations

This type of repetitive calculation for many samples can be handled very simply in a spreadsheet program for the personal computer. Lotus 123, Excel, Quattro, etc., can provide a rapid means of calculating and graphing the results for a large number of samples.

The weight of the dish is referred to as the "tare weight." This weight needs to be accounted for in several of the measurements. Values determined based on a single weighing (e.g. wet weight of soil or dry weight of soil) **must** have the tare weight subtracted from the total. For values that represent the difference on two successive weighings (e.g. weight of water [weight loss on drying]) the tare needn't be accounted for. In this exercise, we computed the weight loss by subtracting the dry weight of the soil from the wet weight (line e-line g). Note that we could have gotten the same number by (line d-line f).

The bulk volume of the soil core (j) is computed by the equation for volume of a cylinder: $V = L\rho r^2$, where L = the length of the soil core and r = the radius of the core.

The P_w (line i) of the soil is determined by dividing the weight of the water (line h) by the dry weight of the soil (line g) and multiplying by 100:

$$(i = 100[h/g])$$

The bulk density of the soil is simply the dry weight of the soil (g) divided by the bulk volume of the soil (j). Units are in g · cm⁻³

The percentage pore space of the soil sample (line l) is calculated by the formula:

$$\% \text{Pore Space} = 100 - \left[\frac{\text{Bulk Density}}{\text{Particle Density}} \times 100 \right]$$

where the particle density is either measured or assumed to be 2.65 g · cm⁻³.

As part of your report, prepare a graph of bulk density and porosity vs. depth for the soil profile you examined. Pool all the data from the laboratory.

DATA/CALCULATION TABLE

- a) WEIGHT OF PAN _____
- b) LENGTH OF SOIL CORE _____
- c) DIAMETER OF SOIL CORE _____
- d) WEIGHT OF PAN + SOIL _____
- e) WEIGHT OF WET SOIL _____
- f) DRY WEIGHT OF SOIL AND
DISH _____
- g) DRY WEIGHT OF SOIL _____
- h) WEIGHT OF WATER _____
- i) P_w OF SOIL _____
- j) BULK VOLUME OF SOIL CORE _____
- k) BULK DENSITY OF SOIL CORE _____
- l) PERCENTAGE PORE SPACE _____

SOIL WATER

INTRODUCTION

Soil water content and the availability of soil water are among the most important values that can be determined about the soil. Certainly the content of the soil water is important to the engineer and the soil scientist, but the availability of water, since the potential for crop growth is involved, is indirectly important to everyone, and vitally so to the agronomist. Primarily because of agricultural needs, a variety of methods for describing the condition of water in soils has been developed. We must distinguish between soil water content, that is, the percent water on an oven-dry weight basis, and the soil water potential (the energy status of water in the soil) which is usually expressed in terms of pressure. As we have learned, this pressure can be positive in some instances, but is usually considered in its negative form, tension.

The amount of water that is available to plants is dependent on plant, climatic, and soil variables. Stage and rate of growth, drought tolerance, and rooting characteristics are important plant factors. Climatic variables include air temperature, humidity, and wind conditions. Some soil characteristics influencing water availability to plants are moisture tension relations, soil stratification, and soil depth.

The lab will examine soil water relations using several field and laboratory techniques and some lab demonstrations. There are a number of things to be done over a 2-week period. Your lab instructor will arrange which things will be done each week to maximize the utility of the laboratory time.

I. P_w at sticky point

The moisture content of soils is most commonly determined by weighing a wet soil sample, drying it in an oven at 105°C to remove water, and weighing it again. The loss in weight on drying is the weight of water originally present. Moisture content of soils is expressed as percentage of the oven dry weight of the soil. The symbol P_w is used to designate this percentage. The P_w of a soil is the ratio of weight of the soil water to the weight of oven dry soil multiplied by 100.

$$P_w = \left[\frac{\text{wet weight of soil} - \text{dry weight of soil}}{\text{dry weight of soil}} \times 100 \right]$$

The procedure for the determination of moisture contents of soils at Sticky Point will be started during this laboratory period and completed next period.

Procedure:

- a. Number and weigh each of three evaporating dishes and record weight on the data sheet. Use any three of the soils available.
- b. Take a small handful of the first soil and wet it slowly by adding water drop by drop and kneading all the time. (Do not let any drops run out of the sample as they will carry away the fine particles).
- c. When the soil is a sticky mass in the hand, stop adding water but continue kneading. Break up all aggregates and make the sample as uniform as possible.
- d. As kneading continues the soil with dry out to the point where the lump of soil will no longer stick to the film of soil on your hand. This is the "Sticky Point".
- e. Test for sticky point by adding one drop of water and seeing whether this makes the soil sticky again. If it does, you have the correct point. Knead until it just loses its stickiness once more, place in the weighed evaporating

- dish and weigh. (Combine weight minus weight of dish - weight of soil at Sticky Point).
- Repeat the procedure with two other soil samples of different textures.
 - Place evaporating dishes in the drying oven at 105°C to drive off moisture. Leave until next laboratory period. (The TA may recommend a shorter drying period).
 - Next period, remove from oven, cool and weigh.
 - Calculate Pw at Sticky Point by using the formula given above.

DATA SHEET FOR STICKY POINT DETERMINATION

Sample number	
Soil Texture	
Wt. dish	
Wt. dish + wet soil	
Wt. dish + dry soil	
Wt. dry soil	
Wt. soil water	
Pw of soil	

II. Resistance Method - Bouyoucous gypsum blocks

Within the Bouyoucous gypsum block are embedded two fine mesh steel screen electrodes. Such a block, when buried in the soil, absorbs moisture and releases it at about the same rate as

does the surrounding soil. When the block has a very high water content, its electrical resistance is low and as it dries, its resistance increases. Since tension, or suction, increases as the soil dries, a measure of the soil water's electrical resistance will give a direct correlation with soil water tension.

Methods and Procedure:

The blocks have been buried in the soil for more than 72 hours. They were buried at 30 cm. intervals so that the entire profile's soil moisture condition can be evaluated. The lab instructor may have determined some other type of arrangement of the gypsum blocks to demonstrate some appropriate point about water distribution in soils. To read the electrical resistance of the soil moisture, this procedure should be followed:

- Connect the lead wires from the blocks to the post on the meter.
- Press button marked "CAL".
- Rotate CAL knob until needle is at the CAL line on right-hand end of scale.
- Press the two buttons, "PRESS TO READ" and read the meter when the needle comes to rest.
- Record the values of Ohms.
- Using the attached Resistance versus Soil Moisture Tension graph, determine the soil water tension for each reading. Then using the Soil Moisture Characteristics Curve, determine the percent soil moisture for each reading.

Things to Think About:

Is all the moisture we measured available to plants? Why or why not? Compare the upland soil and the bottomland soil moisture conditions. Was either "well-drained"? What does the Soil Moisture Characteristics Curve assume?

References

Brady, p. 171-212.
Beckman Instruments, Operating Manual, 10 pages.

III. Demonstrations

The TA will describe the Soil Percolation and Capillary Rise devices at the beginning of the appropriate laboratory period.

IV. The Tensiometer Method for Deriving the Tension/Soil Moisture Curve

Soils of different structures and textures differ also in their water retention capacities. For a given negative pressure (termed soil moisture tension or suction) different soils may therefore have different soil moisture contents. For example, as shown in Chapter 7 of Brady, at a tension of one atmosphere a sand soil will have a moisture content of 10%, whereas the value is closer to 25% for a silty loam at the same tension. A tension (suction)/moisture curve is derived from knowing the soil moisture content of a given soil over a range of soil water potentials.

One technique used to determine this curve, both in the field and in lab, makes use of the tensiometer, which relates water content values to water retention properties (See Black, pp. 153-160, 299-307, 128-131). The tensiometer constructed for our use records suction in terms of the height of a unit column of water in centimeters. With the tensiometer the water content of the soil at various suctions is determined. This method is more sensitive at low tensions (less than 1/10 bar) than is the pressure plate techniques.

A tensiometer is illustrated below. Any difference in the set-up will be pointed out by the TA.

A = Aluminum foil covers

B = Sample in cylinder with mesh bottom Volume = V_b

C = Fritted glass porous plate

D = Buchner funnel

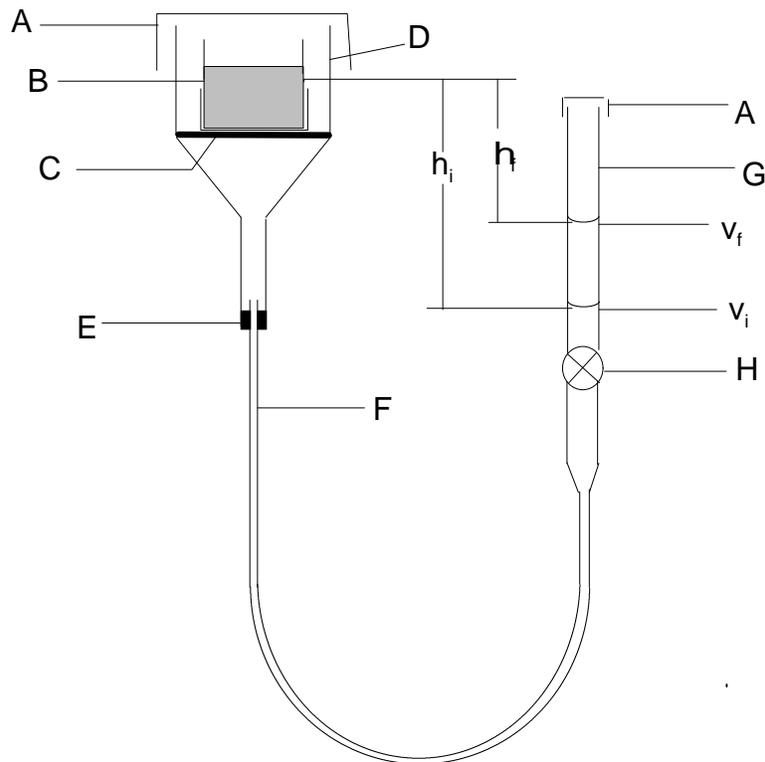
F = Flexible tubing

G = Buret, least division < 0.1% sample volume

H = Stopcock of buret

h_i = cm of water suction (initial)

h_f = cm of water suction (final)



Procedure:

1. Cover the porous plate with 20.0 g of very fine sand to insure good conduction of water between the sample and the plate
2. Place the retainer ring (cylinder) in the funnel and fill to the brim of the ring (without spillover) with the soil sample.
3. Saturate the soil from underneath (demonstrated by the TA) by filling with water through the burette, to drive the air from the sample.
4. Siphon the excess water above the plate from between the funnel wall and the retainer wall.
5. Close the stopcock. Drain water from the burette until it is about at the 40-mL mark.
6. Raise the burette until the water level is about one cm below the bottom of the soil sample. Open the stopcock. This allows free water in the plate to drain.
7. Record this initial volume of the water in the burette.
8. Cover both the funnel and the burette with foil to reduce water loss from the apparatus by evaporation.

The above was all done in an effort to saturate the sample and equilibrate the apparatus at 0 cm suction. Now, the actual application of suction begins.

1. Lower the mark of the burette which indicates equilibrium water level about 22 cm below the center of the sample.
2. The water level will slowly rise. Allow drainage of the soil to proceed, which may take 8-24 hours. When the volume of water in the burette remains constant for six hours record the new burette reading (V_f) and the new vertical distance to the center of the sample (h_f). The outflow volume just measured is the difference of the initial volume (V_i) and V_f .
3. Move the burette down again so that the V_f mark from above is 40 cm below the sample. Repeat step two above. Do this also at the 60, 80, and 100 cm levels.
4. On completion of the last drainage step, calculate the bulk volume of the sample according to:

$$V = \frac{d^2}{4}ph$$

where d is the inner diameter of the ring and h is the height of the sample.

5. Remove the sample and weigh it. Oven-dry and re-weigh.

Calculations:

Calculate the bulk density of the soil from the dry weight and the measured volume. Assume the particle density to be $2.65 \text{ g}\cdot\text{cm}^{-3}$, and calculate the % pore space.

Do the rest of the calculations as follows:

1. Calculate the bulk density: $D_b = \text{oven dry weight (g)} / \text{volume } V_b \text{ in cm}^3$. Assume that the volume is equal to the volume bounded by the ring.
2. Calculate total porosity. Particle density = $2.65 \text{ g}\cdot\text{cm}^{-3}$

$$\text{Porosity} = 1 - \frac{\text{Bulk Density}}{\text{Particle Density}}$$

3. Note that for each suction applied (h_f), $V_f - V_i$ is water that was pulled out of the soil. However, there may be some error due to water contributed from the glass plate as well as due to collapse of the flexible tube. Assuming that this error is spread equally over all suction increments (an assumption almost certainly not valid), we can correct the volume of water pulled from the soil for each increment by multiplying by a correction factor, F_c . F_c is determined as follows: add up all the suction volumes and call the result V_{cum}

$$V_{cum} = \sum (V_f - V_i)_1 + (V_f - V_i)_2 \dots (V_f - V_i)_x$$

Determine the amount of water (apparent) remaining in the soil as follows:

$$V_{remap} = (\%PS * V_b) - V_{cum}$$

$$F_c = \text{volume water actually remaining} / V_{remap}$$

The volume actually remaining is determined by the weight loss of the sample upon drying.

Each of the suction volumes ($V_f - V_i$) should now be multiplied by F_c .

4. Arrange a table with the following information:
 - a. suction applied (cm of water)
 - b. suction applied (atmospheres)
 - c. cumulative (corrected) volumes of water pulled from the soil.

- d. cumulative %age water (by volume) remaining in the soil
(volume of water/total soil volume)
 - e. cumulative %age water (by weight) remaining in the soil
(= % water by volume / Db)
5. Make a graph of suction (in cm and atm) vs cumulative % water (by weight) remaining in the soil.

V. Pressure Plate Determination of a Suction-moisture Curve

Theory

A saturated soil, when subjected to increased vapor pressure, will lose a portion of its water. If the original mass and volume of the soil are known, the amount of water remaining in the soil after a given pressure has been applied can be measured. By repeated measures of the water content at different pressures, the suction-moisture curve can be derived.

Method

1. Assembly and use of the pressure plate apparatus will be demonstrated by the TA.
2. Grind 50 grams of oven dried soil to pass a 2 mm sieve.
3. Place a numbered retainer ring on the surface of the ceramic plate and fill it with soil (remember your number).
4. When ALL samples are in place - cover the ceramic plate with water.
5. Allow to stand for 24 hours. (This gets the soil saturated).
6. After 24 hours apply pressure (See Table 1).
7. Let stand until equilibrium is established (see Table 1).
8. After equilibrium is established remove samples.
9. Record sample weight, oven dry for 24 hours at 105°C and reweigh - calculate grams H₂O/100 grams soil.
10. Repeat steps 1-9 for a different set of samples (using same soils) using a new pressure setting (Table 1).

Calculations: Graph the Suction-Moisture Curve for each soil.

Things to Think About:

What assumptions have we made? How will they affect our results? Are the curves for our two soils similar or different? Why?

References:

Brady, Chapter 7.
Black, Part I, pp. 131-137.

TABLE 1. Pressures and Equilibrium Times

Ceramic Plate	Pressure	Time to Equilibrium
1 bar	0.8 bar	24 hours
15 bar	3.0 bar	72 hours
15 bar	7.0 bar	48 hours
15 bar	11.0 bar	48 hours
15 bar	14.5 bar	24 hours

SOIL CHEMISTRY

The chemistry of the soil can refer to many different portions: the chemistry of clay, mineralogy, the chemistry of plant nutrients, the surface chemistry of colloidal materials interacting with the soil solution, etc. In this set of exercises, it is the latter that we will examine. Some of the tasks will be demonstrations, while others will be hands-on experiments and determinations.

The surface of soil colloids has a net negative charge due to unshared oxygens and hydroxyls, and isomorphous substitution of one cation for another in the tetrahedral or octahedral layers of clay crystals. Charges that are related to protons by equation such as:



are termed **pH dependent**, because shifts in pH cause a greater or lesser number of the charges to be blocked by protons. Charges arising from isomorphous substitution are referred to as **permanent charges**, because they are unaffected by pH.

The net negative charge of the colloids is balanced by cations from the soil solution. The ability of cations to move closer to or further from the colloid surface is referred to as **cation exchange** and the amount of negative charge capable of participating in cations exchange is termed **cation exchange capacity (CEC)**. CEC is expressed in units of milliequivalents per 100 grams of soil. Remember that an equivalent is 6.02×10^{23} charges, and 1 meq = .001 equivalent.

I. Soil pH

The term pH refers to the negative logarithm of the hydrogen ion activity. For our purposes we will assume that the activity coefficient is 1 so that concentration and activity are identical. Thus, $\text{pH} = -\log[\text{H}^+]$. When we measure pH in soil, we want to determine the concentration of protons in the soil solution, but invariably, some portion of the reserve acidity (those protons and protogenic species like Al^{3+} that are bound to colloids) are included in the determination. Soil pH, nevertheless, does accurately approximate the proton condition in the soil solution and is useful for determining a number of related properties of the soil, including nutrient availability, buffer capacity etc.

Procedure:

Colorimetric

Take a small crumb of soil and place it in the large well of a soil pH plate. Add a few drops of indicator dye to just saturate the soil. Too much will ruin the assay. Using a glass rod or the point of a knife, etc., draw some of the fluid out of the soil crumb. Compare the color of the dye with the chips on the appropriate chart. If the color does not match any color on the chart, begin again with a new crumb and a dye that covers the appropriate higher or lower pH range (you will be able to tell which just by looking at the dye/chart relationship).

Potentiometric

Place some soil in the bottom of each of 3 beakers and cover it with one of the following solutions: Deionized water, 0.1N CaCl_2 , 0.1N KCl (Use about 2 volumes of solution per volume of soil in the beaker). Insert the electrode into the solution **after the soil has settled**. When the meter stabilizes, read and record the pH on the data sheet.

II. Cation Exchange Capacity:

Calculations involving C.E.C.

To convert meq/100 g of an element to parts per million one needs only to multiply meq/100 g by 10 times the equivalent weight of the element.

Example 1: If a soil contains 5 meq/100 g of sodium (atomic wt. = 23, valence = +1) the soil has $5 \text{ meq/100 g} \times 23 \text{ mg/meq} \times 1 = 1150 \text{ ppm Na}$

Example 2: If a soil contains 5 meq/100 g of calcium (atomic wt 40 valence + 2) then the soil contains $5 \text{ meq/100 g of } 40/2 \text{ mg/meq} \times 10 = 1000 \text{ ppm Ca}$

Calculate the ppm, lb/A.F.S. and kg/hectare of H^+ for a soil which has 1 meq/100 g of H^+ .

Answer: 10 ppm, 20 lb/A.F.S. and 22.4 kg/hectare.

Determination of Reserve Acidity and % Proton Saturation (%HS)

Two terms which are commonly encountered when one speaks of C.E.C are percent hydrogen saturation (%HS) and percent base saturation (%BS). %HS is the portion of the exchange complex which is occupied by hydrogen ions and % BS is the portion of the exchange complex occupied by cations other than hydrogen. %HS is calculated in the following way:

$$\%HS = \frac{\text{meq} / 100\text{g of H}^+ \times 100}{\text{CEC}}$$

$$\%BS = 100 - \%HS$$

Procedure:

- Place 10.0 g of soil into a clean Erlenmeyer flask.
- Measure out 100 meq of calcium acetate (CaOAc) and 20 mL of water into separate containers.
- Add half of the CaOAc to the soil and shake for five minutes.
- Rinse the filter flask and filter funnel thoroughly with distilled water.
- Attach the flask to the suction hose and place the funnel firmly in the top of the flask.
- Place a piece of filter paper in the funnel and center it.
- Turn on the water aspirator to create a vacuum.
- Wet the filter paper with distilled water from the squeeze bottle on your bench. The filter paper should seal to the bottom of the funnel.
- Making sure the water for the aspirator is running full force, swirl the flask containing the soil solution gently, pour all the soil and the solution onto the filter paper in the filter funnel.
- Transfer the remaining CaOAc to the flask which contained the soil.
- Quantitatively transfer all the remaining soil and solution to the filter. Extra water from a wash bottle can be used to rinse out any remaining soil.
- Add the 20 mL of water to the filter and allow to filter through completely.
- Disconnect the suction hose from the filter flask before turning off the water aspirator.
- Quantitatively transfer the solution from the filter flask to a 250-mL Erlenmeyer flask.
- Add 5 drops of phenolphthalein indicator solution to the filtered solution and titrate with a standardized NaOH.
- Record the volume and normality of the NaOH used on the data sheet.

- Calculate the exchangeable hydro-gen in your sample using the following equations:

$$\text{meq NaOH} = \text{mL NaOH} \times \text{Normality of NaOH}$$

$$(\text{N.B., eq/L} = \text{meq/mL})$$

$$\text{meq NaOH} = \text{meqH}^+ \text{ per unit weight of soil}$$

$$\text{meqH}^+ \text{ per 100 g of soil} = \frac{\text{meq H}^+ \text{ per 10 g soil} \times 100}{\text{weight of soil}}$$

- Record your answers on the data sheet.

Determination of Cation Exchange Capacity:

Procedure:

- Place 10.0 g of soil into an Erlenmeyer flask.
- Measure out 50 mL of 1N HCl and 150 mL of distilled water onto separate containers.
- Add about half of the HCl to the soil, swirl gently for a period of 10 minutes. The HCl displaces all the cations on the soil and replaces them with H⁺ ions.
- Prepare the filter flask as described previously.
- Swirl the flask containing the soil solution vigorously and pour all of the soil and solution onto the filter paper in the funnel.
- Transfer the remaining HCl to the flask which contained the soil. Swirl and quantitatively transfer all of the remaining soil and solution to the filter. A small amount of excess water can be used to transfer any soil remaining in the flask to the filter.
- After the HCl has filtered through completely wash the sides of the funnel with a few mL of distilled water from a wash bottle and allow to filter completely.
- Add 15 to 20 mL of the distilled water, which you measured previously, and allow it to filter completely.
- Repeat step (h) until the 150 mL of water is used. Make sure that all of the water from the previous addition has filtered through before proceeding.
- Disconnect the suction hose and turn off the aspirator.
- Lift off the top section of the filter funnel, which contains the filtered soil, and set it aside in a safe place.
- Discard the solution in the filter flask and rinse the filter flask and the bottom section of the filter funnel thoroughly with distilled water.
- Measure out 100 mL of 1N CaOAc and 20 mL of distilled water into clean containers.
- Reassemble the filter funnel and reconnect the suction hose and turn on the aspirator water.
- Add 15 to 20 mL of the CaOAc you measured out and allow it to filter completely.

- p) Repeat step (o) until you have used all the CaOAc, this slow washing replaces all of the H⁺ ions with Ca²⁺ ions.
- r) Add the 20 mL of distilled water and allow it to filter completely.
- s) Quantitatively transfer the solution to a clean 250-mL Erlenmeyer flask.
- t) Titrates the solution as in part one after adding 5 drops of phenolphthalein indicator solution.
- u) Record the mL of NaOH used on the data sheet.
- v) Because we replaced all the cations with H⁺ ions, we calculate the CEC of the soil exactly the same way we calculated exchangeable hydrogen. Do these calculations and record your results on the data sheet.
- w) Calculate the hydrogen saturation and base saturation of your soil.

DATA TABLE, SOIL CHEMISTRY

SOIL SAMPLE	pH IN:		
	WATER	0.01N CaCl	0.1N KCl

