

APBI 403 / SOIL 503

Field and Laboratory Methods in Soil Science

(Soil Physics Component)

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Soil Physics Laboratory Sessions 2019

| Date | Experiment |
|-------------|--|
| Sept. 9 | Sampling and Sample Prep – meet at UBC Farm |
| Sept. 16 | Soil texture (rapid method) |
| | Aggregate stability (with Maja) |
| Sept. 23 | Soil bulk density (core method) Soil water content (volumetric & TDR) |

1. Introduction

1.1 Laboratory Classes

Class time will use a variety of approaches designed to provide an introduction to methods commonly used for soil physical analysis, and to reinforce concepts covered in lectures. Hands-on exercises, demonstration and discussion activities will be included.

Laboratory work can involve a variety of hazards. Students are required to read section 1.3. "Some Guidelines for Lab Operations" before commencing lab work, and to have completed the student lab safety course.

1.2 Soil Physics Lab Report Objectives

In each lab period, you will be responsible for collecting data on sample(s) assigned to you. For some labs, you will be given additional analytical results (*Excel files will be posted on the course Connect site*). Written assignments for each lab are posted separately in connect.

In addition, each member of the class will be required to write final lab report on the soil physical component of this course using data provided in connect. In the write-up students will need to compare between land uses and/or soil orders (details posted in connect). The final lab report should be maximum 1500 words (approximately 4 pages), excluding all graphs and tables. Title of the report, student name, and "List of References" are not included in the word limit. Please use font size 10 or 12 (preferable) with 1.2 line spacing.

The final lab report should consist of the following sections: introduction, objective(s), material and methods, results and discussion, conclusions, and list of references.

Guidelines for weekly lab reports and final summary reports are provided in the course syllabus. Data presentations tips can also be found in the last section of the syllabus.

1.3 Some Guidelines for Lab Operations

1.3.1 Safety

1. Lab coats and solid shoes are recommended.
2. Safety glasses, masks, gloves etc. should be used where appropriate (e.g. dust from sample preparation; explosive hazards, etc.). Make sure you know where this protective equipment is located.
3. Never work alone when significant hazards are involved; especially when working with explosive or inflammable materials, and pressurized systems.
4. Never work after hours.

5. Do not use your mouth to pipette corrosive or toxic materials.
6. Do not lift Winchester bottles by the neck only; support with hand below.
7. When acids or corrosive liquids are spilled, dilute and/or neutralize, and mop up right away (use NaHCO_3 to neutralize concentrated acids).
8. All other spills should be cleaned up immediately.
9. All operations involving the risk of irritant or toxic vapor should be carried out in a fume hood with adequate ventilation.
10. Know the locations of the nearest fire extinguishers, safety shower and first aid kit.
11. If you get an electrical shock from any equipment, report it, and do not use that equipment again until it has been checked by a qualified person. Keep all electrical equipment dry.
12. Broken and chipped glassware is a hazard. Report breakages and dispose of broken glass only in the labeled receptacle provided for this purpose.
13. Exercise caution in moving around the lab, especially in crowded areas (e.g. near a sink or fume hood).
14. Report ALL ACCIDENTS. Even apparently minor ones can develop serious side effects later on. In the case of an eye injury in particular, immediate treatment is essential.
15. In case of fire, clear the area of personnel and call the fire department at 911. If no phone is available, pull the nearest alarm.
16. Never eat or drink in the lab.
17. In general, make sure you understand the hazards involved before starting any lab operations. If in doubt, ask!

1.3.2 Class Lab Exercises

1. Adequate preparation is essential for good analytical work. Understand the principles of a procedure before starting (i.e. read up on each exercise before entering the lab).
2. Record all your observations and results in an organized manner.
3. Tabulate results where possible (plan this ahead). Efficient systems of recording and manipulating data will avoid confusion and save time.
4. While students are expected to develop some ability to solve their own analytical problems, do not hesitate to ask questions.

2. Sampling and sample preparation for mineral soils

Soil physical properties such as bulk density, structure, pore space, soil temperature and soil moisture vary both spatially and temporally. Spatial variation can occur horizontally and/or vertically. Parameters which have significant temporal variability are those impacted by climatic conditions (e.g. soil moisture) and/or human impact (e.g. compaction impacting soil bulk density). Soil physical properties are influenced by both inherent characteristics (e.g. texture), and by management (e.g. bulk density).

2.1 Field sampling

Sampling for mineral soils will take place at the UBC Farm, on both agricultural and forest sites. The sampling design needs to consider the research question to be investigated: in this case a comparison between soil physical properties on agricultural and forest sites at the UBC Farm.

For details on sampling see: <http://soilweb.landfood.ubc.ca/labmodules/plant-nutrients/soil-sampling> or <https://www.youtube.com/watch?v=tuqoOVUm05I>

2.1.1 Sampling Agricultural Fields

1. On agricultural fields, we will use a stratified random sampling design. A minimum of four replicates (agricultural fields) will be sampled, one replicate per pair of students.
2. Before sampling, make a sketch your field location and sampling design, noting the name of your site (e.g. D4-1)
3. When sampling mineral soils, the overlaying litter layer is 1st removed. If live vegetation is present, samples are taken “through” or between the vegetation.
4. Within each replicate, random Ap horizon samples will be collected (minimum of 6) using a soil corer or trowel, and samples mixed to generate one composite sample (approximately 500 g) for each replication. Make sure to note the depth of these samples (e.g. 5-15 cm)
5. A small pit will be dug (at a random location) within each agricultural site and a B horizon sample collected. Make sure to note the depth of this sample (e.g. 30-40 cm).
6. Carefully label your sample bags noting the replicate and the horizon for each sample. To simplify labelling we will use the following system:

AGR 1 – A (for agricultural field replicate 1, A horizon), AGR 1 – B (for agricultural field replicate 1, B horizon), AGR 2 – A etc.

You need to carefully record detailed information about your site in your field notes. Specifically the field (e.g. D4-1), horizon, depth of sample and any general observations. Taking a few photos of sampling at your site is also recommended.

2.1.2 Sampling Forest Soils

1. In the forest site, we will use a random sampling design. A minimum of four replicates (forest sites) will be sampled, one replicate per pair of students.
2. Before sampling, make a sketch your site location relative to know landmarks (e.g. Indigenous garden, Yurt etc.), and relative to other sampling locations (i.e. other student pairs).
3. When sampling mineral soils in forest sites, the overlaying litter layer (LFH) is 1st removed. Where live vegetation is present, samples are between the vegetation.
4. A pit will be dug at each site to sample at depth. Note that the depth of each pit may vary between sites. Try to dig down to the top of the C horizon (approximately 0.7 m) to facilitate the identification of soil horizons.
5. At each site samples will be taken at two depths: The Ah and B horizon. Note, that sampling the Ah horizon in forest soils can be challenging, in part as the LFH in moder or mull humus forms may not have an abrupt boundary with the Ah (mineral) horizon.
6. Carefully label your sample bags noting the replicate and the horizon for each sample. To simplify labelling we will use the following system:

FOR 1 – A (for forest site replicate 1, A horizon), FOR 1 – B (for forest site replicate 1, B horizon), FOR 2 – A etc.

You need to carefully record detailed information about your site in your field notes. Specifically the site (e.g. FOR 1), horizon, depth of sample and any general observations (e.g. abundance of roots, stoniness etc.). Taking a few photos of sampling at your site is also recommended.

2.2 Sample preparation

Samples will be taken back to MacMillan and spread out to air dry in the basement of the Soil lab in room 48.

1. Air dry samples on the drying racks

After samples are air dried:

2. On a clean surface (e.g. parchment paper); any large clods should be broken by hand.
3. Samples need to be crushed and sieved to remove coarse fragments (> 2mm). We will crush any aggregates using a wooden rolling pin, and hand sieve (2 mm mesh).
4. Any remaining aggregates should be crushed and sieved.
5. Store the fine fraction in a plastic container with lid – label your container. These samples will be used for some soil physical analysis (e.g. texture).
6. Discard any rocks or excess soil in the APBI 403 Waste container provided

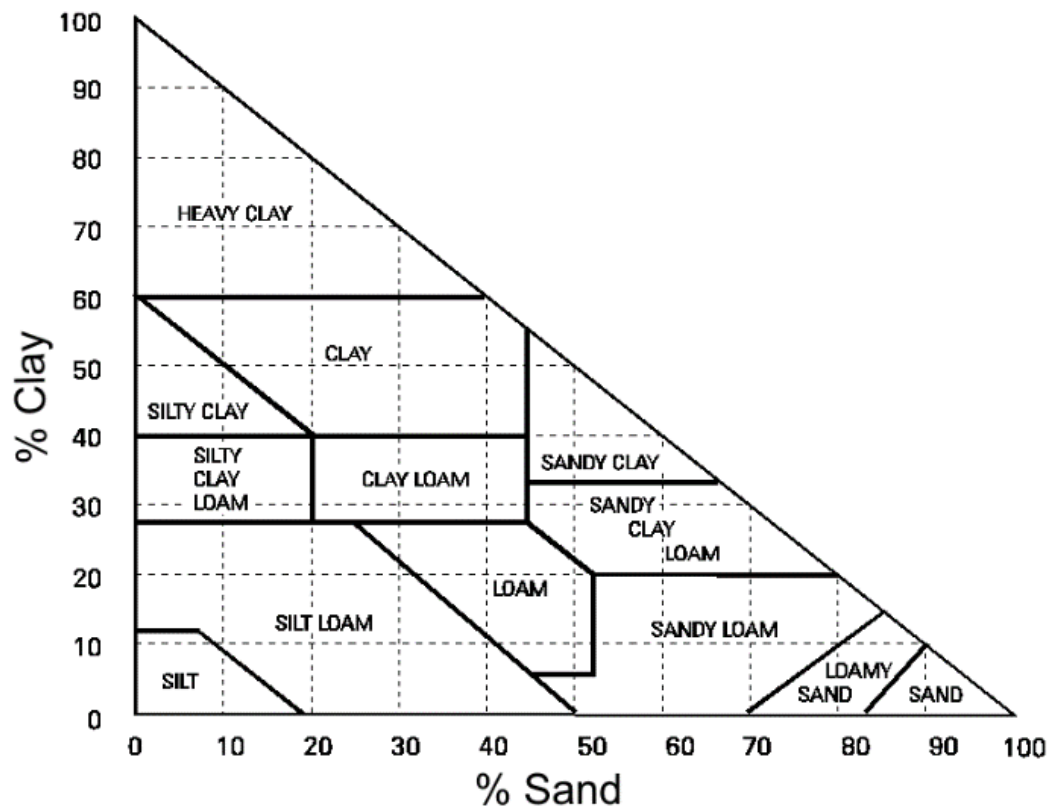
For details on sample preparation see: <http://labmodules.soilweb.ca/trace-elements-sample-prep/> or <https://www.youtube.com/watch?v=A11v-jARhLM>

3. Determination of Soil Texture (particle size)

The determination of soil texture is a common soil analysis, and an important indicator of soil properties. Soil texture is designated on the basis of the mass ratios of the 3 size fractions by weight of sand, silt and clay. Particle size is expressed as the percentage of sand, silt and clay in the sample. The Canadian classification of particle size is as follows:

| Name of separate | Diameter, mm |
|------------------|--------------|
| very coarse sand | 1.0 - 2.0 |
| coarse sand | 0.5 - 1.0 |
| medium sand | 0.25 - 0.5 |
| fine sand | 0.10 – 0.25 |
| very fine sand | 0.05 - 0.10 |
| Silt | 0.002 - 0.05 |
| Clay | <0.002 |
| fine clay | <0.0002 |

Soil texture is then determined by the relative % of sand and clay in a soil (the remainder being silt), according to the following figure:



A variety of techniques are available for determining soil particle size distribution, but most of them are based on sieving or sedimentation techniques. The sample is 1st dispersed into the individual primary particles, followed by fractionation and quantification of each particle-size class by sieving or sedimentation. For diameters < 0.05 mm, sieving is inefficient and difficult, and sedimentation in water is the preferred procedure. Hydrometer and pipette methods are sedimentation procedures (standard methods), are time consuming and require specialized equipment (e.g. hydrometer, sedimentation cylinders, pipettes etc.), and the technology is not immediately accessible to agricultural consultants, conservationists or producer groups. An alternative “**simplified method for soil particle size analysis determination**” has been developed by Kettler et al. 2001. This method combines sieving and sedimentation, and has been shown to correlate very well with standard methods.

3.1 Reagents

1. 3% by weight aqueous HMP (hexametaphosphate)

3.2 Desiccant

1. Magnesium perchlorate ($Mg(ClO_4)_2 \cdot 6H_2O$) or calcium sulfate ($CaSO_4$)

3.3 Procedure – Pre lab

1. Check to see if any of your classmates have already made up sufficient HMP (hexametaphosphate), if not

To make up 3% by weight aqueous HMP:

- Weigh 15 g Calgon (HMP) into 500 mL distilled water in a large beaker
 - Stir until dissolved
2. Weigh out 15 g air dry soil (< 2mm fraction) into 100 ml bottle.
 3. Label your bottle using your abbreviated sampling code (e.g. AGR 1-A, AGR 1 – B, FOR 1 – A, FOR 1 - B etc.)
 4. Add 3:1 HMP (45 ml) to soil (15 g) ratio, and place your sample on the shaker (prior to 10:30 am the day of your lab)
 5. Shake the sample for 2 hours on a reciprocating shaker at 120 reciprocations per minute (Sandra will start the shaker 2 hours prior to the lab)

Note there should be 2 samples per each 2 person student team using the soil samples collected the previous week; 1 sample for each horizon (A and B) at your site.

Procedure – During lab

6. Wet sieve the soil slurry through a 0.05 mm sieve to separate the sand and silt/clay fractions. Rinse the silt and clay through the sieve into a 600 or 800 ml beaker. Use a water bottle to rinse the sand fraction off the sieve into a 500 ml beaker. Label your beakers, pre-weigh and record their weights.
7. Oven-dry the sand fraction @ 55 °C to constant weight (this may take 1-2 days depending on how much water you use) and record.
8. The silt and clay solution is stirred thoroughly to suspend all particles, and then allowed to settle undisturbed at room temperature (18-24 °C) for at least 90 minutes but < 6 hours. After the sedimentation period, decant off the suspended clay fraction (and discard). Dry the settled silt fraction in the beaker at 105 °C to constant weight.

Note: organic soils require pre-treatment with H₂O₂ (hydrogen peroxide) to oxidize the organic matter.

9. Share your results with other student groups: agricultural soil and/or forest.

3.4 Calculations

The % sand and % silt are calculated based on their fraction of the original mass:

$$\text{Sand \%} = \left(\frac{\text{oven dry sand mass}}{\text{original sample mass}} \right) \times 100\%$$

$$\text{Silt \%} = \left(\frac{\text{oven dry silt mass}}{\text{original sample mass}} \right) \times 100\%$$

The % clay is determined by calculating the difference of 100% minus the sum of the % sand and % silt:

$$\text{Clay (\%)} = 100 = (\text{Sand (\%)} + \text{Silt (\%)})$$

3.5 Reference

Kettle TA, Doran JW, Gilbert TL. 2001. Simplified method for soil particle-size determination to accompany soil-quality analyses. *Soil Sci. Soc. Am. J.* 65:849-852.

Data required for calculation of % sand, silt and clay

Soil: bare agricultural soil turf grass sample forest soil

| Sample | Weight of 800 ml beaker (tare g) | Weight of 500 ml beaker (tare g) | Weight of air dry soil (g) | Weight of oven dry sand (g) | Weight of oven dry silt (g) |
|--------|---|---|-------------------------------------|--------------------------------------|--------------------------------------|
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4. Determination of Soil Aggregate Stability

Under natural conditions in most soils, a high proportion of soil particles are arranged into secondary units called **aggregates**. **Soil structure** describes the arrangement of the solid soil particles into aggregates. Soil structure has an important influence on many factors affecting plant growth. The permeability of the soil to air and water depends on (1) the total porosity, and (2) pore size distribution. Both of these are closely associated with aggregation and subject to change when aggregation changes. Since aggregates vary greatly in size and shape (granular, blocky, platy, prism-like, wedge) as well as their ability to resist disintegration, these are characteristics that are frequently determined.

Aggregate stability is ability of soil aggregates to withstand external pressure. The method of determining aggregate stability that will be used in this exercise is a modified version of the one described by Kemper and Rosenau (1986). The method consists of placing a sample of soil on a set of sieves that is oscillated vertically under water at a prescribed rate, stroke, and time. The amount of soil remaining on each sieve is determined. A correction is usually made for the primary particles and chunks of organic matter present in the size classes of aggregates.

Considerable variation of opinion exists as to the method of pre-treatment of the sample. Rapid wetting or direct immersion into water increases the breakdown of aggregates due to the effects of entrapped air. Spraying the soil with a fine spray or mist or wetting under vacuum have been suggested to avoid slaking (i.e., disintegration).

4.1 Procedure

1. The soil is sampled with a trowel. Samples are stored in rigid-wall plastic containers at 4°C (i.e., in the fridge) to prevent drying, physical disturbance, and microbial activity. Ideally, samples should not be stored for too long and should be analyzed as soon as possible after sampling.
2. Place entire sample onto set of two large sieves with openings of 6 mm (on top) and 2 mm (on bottom). Remove rocks, large pieces of roots, etc. and gently break apart by hand large clumps of soil. If samples are very wet, and appear unlikely to move through the sieves upon agitation, leave them to air-dry overnight.
3. Sieve the sample. Use the soil that remains on the 2 mm-sieve, as this is the proportion that has an average aggregate diameter of ~4 mm.

4. For water content determination, weigh out about 5 g of soil sample (that remained on the 2 mm-sieve) into aluminum tin, record tin #, tin weight, and tin+soil weight. Put these samples in oven at 105°C for 12 hrs of drying.
5. Assemble 6 sets of sieves in the following order: 2-mm (top), 1-mm (middle) and 0.25-mm (bottom).
6. Weigh out about 15 g of soil sample (that remained on the 2 mm-sieve) into a tarred aluminum tin and record soil weight. Transfer soil to the top sieve of the set, and record sieve nest #.
7. Put top sieve with soil into the steamer, and leave for ~15 min, or until the sample glistens. Depending on the starting water content, this step might take much longer than 15 min.
8. Place top sieves back on their respective sieve sets. Install the sets of sieves into sieve holder (max 6 sets at one time) and lower into basin of water, ensuring water covers top of the soil when the oscillating mechanism is at the top of its stroke. Oscillate the sieves for 10 min.
9. Remove sieve sets out of the water and let drain for a few minutes.
10. Place sets of sieves in the oven at 105°C for a minimum of 12 hours.
11. After drying in the oven, brush the dry soil from the sieves into soil moisture tins, weigh the dry samples, and record dry weights for:
 - Ws4 = top sieve
 - Ws1.5 = middle sieve
 - Ws0.625 = bottom sieve
12. Use mortar and pestle to grind down aggregates collected from each sieve. Re-sieve each sample through sieve on which it was collected, brush the coarse fragments from the sieve, and weight them for coarse fragment corrections.
NOTE: during this step, work with one sieve at a time (i.e., do not stack sieves on the top of each other when sieving for coarse fragments).

4.2 Calculations

van Bavel (1949) proposed that equal weights of aggregates be assigned an importance of weighing factor that is proportional to the size of aggregates. The parameter, mean weight diameter (MWD), is equal to the sum of products of (1) the mean diameter (D_i) of each size fraction and (2) the proportion of total weight (S_i) occurring in the corresponding size fraction, where the summation is carried out over all four size fractions, including the one that passes through the finest sieve:

$$(MWD = \sum_{i=1}^4 D_i S_i)$$

When sample does NOT have any coarse fragments, calculate as follows:

Weight of sample left on top (i.e., 2-mm) sieve

$$S_4 = \frac{W_{S_4}}{\left(\frac{W_S}{1 + \theta}\right)}$$

Weight of sample left on middle (i.e., 1-mm) sieve

$$S_{1.5} = \frac{W_{S_{1.5}}}{\left(\frac{W_S}{1 + \theta}\right)}$$

Weight of sample left on bottom (i.e., 0.25-mm) sieve

$$S_{0.625} = \frac{W_{S_{0.625}}}{\left(\frac{W_S}{1 + \theta}\right)}$$

Weight of sample that passed through the bottom (i.e., 0.25-mm) sieve

$$S_{<0.25} = 1 - (S_4 + S_{1.5} + S_{0.625})$$

Mean weight diameter (MWD)

$$MWD (mm) = (S_4 * 4) + (S_{1.5} * 1.5) + (S_{0.625} * 0.625) + (S_{<0.25} * 0.125)$$

Soil water content at the time of analysis

$$\theta = \frac{W_{S_{wet}} - W_{S_{dry}}}{W_{S_{dry}}}$$

When sample does have coarse fragments, calculate as follows:

Total weight of coarse fragments: $W_c = (W_{cf\ 4} + W_{cf\ 1.5} + W_{cf\ 0.625})$

Weight of sample left on top (i.e., 2-mm) sieve

$$S_4 = \frac{W_{s4} - W_{cf4}}{\frac{W_s}{1 + \theta} - W_c}$$

Weight of sample left on middle (i.e., 1-mm) sieve

$$S_{1.5} = \frac{W_{s1.5} - W_{cf1.5}}{\frac{W_s}{1 + \theta} - W_c}$$

Weight of sample left on bottom (i.e., 0.25-mm) sieve

$$S_{0.625} = \frac{W_{s0.625} - W_{cf0.625}}{\frac{W_s}{1 + \theta} - W_c}$$

Weight of sample that passed through the bottom (i.e., 0.25-mm) sieve

$$S_{0.125} = 1 - (S_4 + S_{1.5} + S_{0.625})$$

Mean weight diameter (MWD)

$$MWD (mm) = (S_4 \times 4) + (S_{1.5} \times 1.5) + (S_{0.625} \times 0.625) + (S_{0.125} \times 0.125)$$

Soil water content at the time of analysis

$$\theta = \frac{W_{S_{wet}} - W_{S_{dry}}}{W_{S_{dry}}}$$

4.3 Materials

- A mechanical wet sieving machine that will raise and lower a sieve holder through a distance of 2.5 cm, 40 times each minute.
- A tub, filled with water
- Steamer or humidifier
- Oven (set to 105°C)
- Set of 6 mm- and 2 mm-sieves
- Twelve sets of sieves, nested into sets of 2 mm, 1 mm, and 0.25 mm sieves
- Sieve brush
- Spoon/scoop
- Small aluminum tins

4.4 References

Angers, D.A., and G.R. Mehuys. 1993. Aggregate stability to water. p. 651-6657 in M.R. Carter, Ed. Soil sampling and methods of analysis. Canadian Society of Soil Science, Lewis Publishers, Boca Raton, FL.

Kemper, W.D., and R.C. Rosenau. 1986. Aggregate stability and size distribution. p. 425-442 in A. Klute, Ed. Methods of soil analysis. Part 1, 2nd ed. American Society of Agronomy, Madison, WI.

Nimmo, J.R., and K.S. Perkins. 2002. Aggregate stability and size distribution. p. 317–328. In J.H. Dane and G.C. Topp (eds.) Methods of soil analysis. Part 4. SSSA Book Ser. 5, Madison, WI.

van Bavel, C.H.M. 1949. Mean weight diameter of soil aggregates as a statistical index of aggregation. Soil Science Society of America Proceedings 14: 20-23.

Data sheet – aggregate stability

| Sample # | Sample ID | Sieve # | Soil Weights (g) | | | | Water Content – θ (g) | | | | Coarse Fragment Corrections (g) | | |
|----------|-----------|---------|------------------|-----------|-------------|---------------|------------------------------|---------|-----------------------|-----------------------|---------------------------------|--------|----------|
| | | | Ws (moist) | Ws4 (dry) | Ws1.5 (dry) | Ws0.625 (dry) | Tin # | Tin (g) | Tin+Ws θ (wet) | Tin+Ws θ (dry) | Wcf4 | Wcf1.5 | Wcf0.625 |
| 1 | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | |
| 6 | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | |

5. Soil bulk density

The combined influence of soil texture and structure is described by soil bulk density. For mineral soils, most soil bulk densities fall between 1.0 and 1.6 g cm⁻³. As the soil bulk density increases, pore space decreases, and root penetration may be restricted in soils with bulk densities > 1.6 g cm⁻³. Lower bulk densities are desirable for plant growth and soils with low bulk density have greater infiltration rates.

5.1 Symbols, constants and units

| Symbol | Name | units | notes |
|------------|------------------------------|--|--|
| ρ_b | soil bulk density | g cm ⁻³ | Equation 2 |
| ρ_s | particle density | g cm ⁻³ | = 2.65 g cm ⁻³ mineral soil |
| ρ_w | density water | kg m ⁻³ g cm ⁻³ | 1,000 kg m ⁻³ 1 g cm ⁻³ |
| M_d | oven dry mass of soil | g | measured |
| M_w | wet mass of soil | g | measured |
| V_c | volume core | cm ⁻³ | measured |
| V_s | volume solids | cm ⁻³ | |
| Φ | porosity | cm ³ cm ⁻³ | Equation 3 |
| Θ_m | gravimetric moisture content | g water / g soil | Equation 1 |

5.2 Core method

5.2.1 Field and Laboratory Procedures

1. Obtaining an undisturbed soil sample of known volume

Site: UBC farm bare agricultural field

Sampling design: stratified random grid, each student pair samples 2 profiles within 1 grid. Samples are taken from 5-10 cm, 15-20 cm (Ap horizon) and approximately 25-30 cm below the surface (B-horizon). For each location and depth, an undisturbed soil core is extracted with a core of fixed volume, and all the soil from the core is placed in a sealed moisture tin. In this manner both bulk density and soil moisture

can be measured from the same sample. Carefully note the label of your soil moisture tin and lid.

2. Determining sample mass (M_s)

Weight all “filled” soil moisture tins with their lids on as collected in the field immediately following their collection using a digital balance. Place moisture tins (with lids placed under the tin) in a forced-air drying oven and dry to constant weight at 105 °C (24 to 48 hours).

3. Remove the tin from the oven, cool to room temperature in a desiccator containing active desiccant, and re-weigh.
4. Discard the soil, clean tins, and weight tare (tin + lid) (g).

5.2.2 Calculations – core method

1. Soil moisture content – mass basis

The results are reported as % soil water on a dry-mass basis with the conditions specified (i.e. at 105°C for 24-48 hours), and calculated as:

$$\Theta_m = \frac{M_w - M_d}{M_d} \quad [1]$$

2. Soil bulk density

$$\rho_b = \frac{M_d}{V_c} \quad [2]$$

3. Porosity

$$\Phi = 1 - \frac{\rho_b}{\rho_s} \quad [3]$$

where ρ_s is assumed = 2.65 g cm⁻³

5.3 Excavation method

5.3.1 Field Procedures

1. Obtaining disturbed soil sample of known volume

Site: UBC farm - forest site

Sampling design: stratified random, each student pair samples 1 profile within the forest site. Mineral soil samples are taken from approximately 0-20 cm (AB horizon), and 30-50 cm (BC-horizon) below the surface. For each location and depth:

1.1 Excavate a disturbed mineral soil sample

- 1st remove the forest floor to expose an area of mineral soil big enough for the sampling template; fix the plate to the soil (be careful not to compress the soil)
- use a knife to cut around the circle of the plate outlining the hole to be dug-
- use spoon or small trowel to remove the soil (a flat head screwdriver is useful to delineate the lower edges; scissor may be used to cut fine roots)
- use a ruler to check your depth (20 cm)
- when excavated, label your soil sample (team, location, depth)

1.2 Determining the volume of your hole

- line the hole with a plastic bag (pre-check that it has no leaks)
- use your fingers to place the bag in contact with the soil walls
- fill a 500 or 1000 ml graduated cylinder with water– i.e. known volume
- pour water into the hole until the level is even with the bottom of the template (remove any trapped air if required)
- read and record volume of remnant water and calculate the volume
- slowly remove the bag and verify that the bag has no wholes and that the soil is dry

2. Sampling for soil moisture

- collect a mineral soil sample from the side of your excavation at approximately ½ depth
- place soil in soil moisture tin, seal, and note the label of your soil moisture tin and lid

5.3.2 Lab Procedures – excavation method

1. Bulk density – excavation method

1.1 Separate coarse and fine fractions

- spread the soil collected in the field on parchment paper to air dry (24-48 hours)
- carefully transfer the air dry sample to a 2 mm sieve with bottom, cover with lid and shake gently until all fine materials have passed through the sieve
- use mortar and pestle to crush any soil aggregates

1.2. Determining sample mass (Ms) for excavation method

- collect coarse material into a tared aluminum foil pan, weight and record weight and pan label
- collect fine fraction into tared aluminum foil pan, weight and record pan label
- place fine fraction into a forced-air drying oven and dry to constant weight at 105 °C (24 to 48 hours); cool in desiccator and re-weight
- discard the soil, clean aluminum foil pan, and weight tare of the pan (g) if not previously tared.

2. Soil moisture

2.1 Determining sample mass (Ms)

- Weight all “filled” soil moisture tins with their lids on as collected in the field immediately following their collection using a digital balance. Place moisture tins (with lids placed under the tin) in a forced-air drying oven and dry to constant weight at 105 °C (24 to 48 hours).
- Remove the tin from the oven, cool to room temperature in a desiccator containing active desiccant, and re-weigh.
- Discard the soil, clean tins, and weight tare (tin + lid) (g).

5.3.3 Calculations

1. Soil moisture content – mass basis

The results are reported as % soil water on a dry-mass basis with the conditions specified (i.e. at 105°C for 24-48 hours), and calculated as:

$$\Theta_m = \frac{M_w - M_d}{M_d} \quad [4]$$

2. Soil bulk density

Mass of fine material (<2.00 mm), oven dried = M_{fine} (g)

Mass coarse mineral = M_{coarse} (g)

Total volume = V_t (mL) = V_t (cm³)

Assume particle density of mineral (ρ_s) = 2.65 g cm⁻³

$$V_{\text{coarse}} (\text{cm}^3) = \frac{M_{\text{coarse}} (\text{g})}{\rho_s (\text{g cm}^{-3})}$$

$$V_{\text{total}} (\text{cm}^3) = V_{\text{total}} (\text{ml}) \times \frac{1 \text{ cm}^3}{1 (\text{ml})}$$

$$V_{\text{fine}} (\text{cm}^3) = V_{\text{total}} (\text{cm}^3) - V_{\text{coarse}} (\text{cm}^3)$$

$$\rho_b (\text{g cm}^{-3}) = \frac{M_{\text{fine}} (\text{g})}{V_{\text{fine}} (\text{cm}^3)} \quad [5]$$

3. Porosity

$$\Phi = 1 - \frac{\rho_b}{\rho_s}$$

[6]

where ρ_s is assumed = 2.65 g cm⁻³

5.4 References

Grossman R.B. Reinsch T.G. 2002. Bulk density and linear extensibility. *In* Dane J.H. and Topp G.C. (eds) *Methods of soil analysis. Part 4. Physical methods.* SSSA, Madison WI 201-228.

<http://soilweb.landfood.ubc.ca/labmodules/water/gravimetric-water-content>

<http://soilweb.landfood.ubc.ca/labmodules/compaction/soil-bulk-density>

Data required for calculation of % soil water content on an oven-dry mass basis

| Profile | Depth (cm) | Tin # | Weight of wet soil + tare (g) | Weight of dry soil +tare (g) | Weight (tare) of tin (g) | Weight of wet soil (g) | Weight of dry soil (g) | % Soil water content |
|---------|------------|-------|-------------------------------|------------------------------|--------------------------|------------------------|------------------------|----------------------|
| 1 | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| 2 | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

6. Soil volumetric water content – TDR method

Soil water content affects the growth of plants and soil organisms, soil strength and soil-water budgets; consequently determining soil water content is one of the most commonly performed types of soil analysis. Soil water content is expressed as the ratio of the mass of water present in the sample to the mass of the sample after it has been dried at 105°C to a constant mass; or on a volumetric basis (volume of water per unit bulk volume of dry soil). The gravimetric method is a direct measurement of the soil water content, while indirect methods relate soil property(s) to the soil water content. Time-domain reflectometry (TDR) is one indirect method based on electromagnetic measurements. Indirect measurements may be advantageous because they can be done in the field, are non-destructive and permit continuous monitoring through connection to data logger.

6.1 Symbols, constants and units

| Symbol | Name | units | notes |
|------------|------------------------------|--|------------|
| M_d | oven dry mass of soil | g | measured |
| M_w | wet mass of soil | g | measured |
| V_c | volume core | cm^3 | measured |
| Θ_m | gravimetric moisture content | g water / g soil | measured |
| Θ_v | volumetric moisture content | cm^3 water / cm^3 soil | Equation 1 |
| Θ_s | saturated moisture content | % | |
| Φ_a | air filled porosity | cm^3 air / cm^3 soil | Equation 2 |
| | % saturation | % | Equation 3 |

6.2 Field and Laboratory Procedures

1. Sampling and gravimetric moisture content as per section 4.2
2. Additionally, take field measurements of volumetric moisture content using the TDR. As the TDR measures moisture content along the length of the probes, insert the TDR horizontally at each measurement depth (1.5, 10, 20 and 30 cm below the surface). Note inserting the TDR vertically gives you a depth integrated soil moisture measurement. Record θ_v for each depth in your soil profile(s).

Note: do not force the TDR into compact soil; simply report no data.

6.3 Calculations

A. Soil moisture content – volumetric basis

The conversion from gravimetric to volumetric moisture content is given by:

$$\Theta_v = \Theta_m \times \frac{\rho_b}{\rho_w} \quad [1]$$

B. Air filled porosity

$$\Phi_a = \Theta_{sat} - \Theta \quad [2]$$

C. Percent saturation

$$\text{Percent saturation} = \Theta / \Theta_{sat} \times 100 (\%) \quad [3]$$

6.4 References

Topp, G.C. Davis J.L. Annan A.P. 1980. Electromagnetic determination of soil water content: measurement in coaxial transmission lines. Water Resources Research 16: 574-582.

<http://soilweb.landfood.ubc.ca/labmodules/water/time-domain-reflectometry>

Data required for calculation of % soil water content on volumetric basis

| Profile | Depth* (cm) | TDR reading (%) | θ_m^{**} (g/g) | ρ_b^{**} (g cm ⁻³) | θ_v (cm ³ /cm ³) |
|---------|----------------|-----------------------|--------------------------|--|---|
| 1 | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| 2 | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

*attempt to match depths for TDR readings to sampling depths in section 4.3

**values from section 4.3

7. General References – Soil Physical Properties

Carter, R. (ed). 1993. Soil Sampling and Methods of Analysis. Lewis Publishers. 823 pp.

Dane J.H Clark G.C. (eds). 2002 Methods of soil analysis. Part 4. Physical methods. SSSA book series Vol. 5. Madison WI.

Jury W. Horton R. 2004. Soil Physics. John Wiley & Sons, New Jersey. 370 pp.