Laboratory 5: Soils in Agricultural Systems

This week's lab will take place at the Dilmun Hill, the Cornell student-run organic farm. Your task will be to make measurements of soil climate characteristics in the field. Soil climate impacts plant growing success from germination to harvest. This information can be used to evaluate soil conditions and possible management tools that are important for agricultural systems. At question are how might these characteristics impact operations and be managed at Dilmun Hill?

You will also be collecting soil samples to bring back to the lab for nutrient analysis. While you will conduct sampling protocols and submission practices for lab analysis and we will submit the samples for analysis at the end of the week, the results and recommendations will be discussed and used in a later lab.

Objectives

- Examine the effect of soil management on surface and sub-surface soil temperatures
- Examine the effect of soil management on bulk density and soil water
- Explore sampling procedure for field soil testing

Readings in Text

4.5 Soil Density
4.6 Pore Space of Mineral Soils
4.7 Formation and Stabilization of Soil Aggregates
4.8 Tillage and Management of Soils
9.8 Raising the Soil pH by Liming
9.9 Alternative Ways to Ameliorate the Ill Effects of Soil Acidity
16.6 Practical Utilization of Organic Nutrient Sources
16.7 Inorganic Commercial Fertilizers
16.11 Soil Analysis

Site Background

The mission of Dilmun Hill Farm is to foster and provide integrated experiential learning opportunities and educational facilities for Cornell students, faculty, staff, and the local community in the exploration of sustainable food and agricultural systems. The goal of the farm is to demonstrate the components of a sustainable food and agriculture system by growing and distributing fruits, vegetables, ornamental crops, and other agricultural commodities using ecologically sensitive and economically sustainable practices. The Farm also promotes agricultural education by coordinating internships, independent study, and experiential learning opportunities and increases awareness about environmental and social issues relating to sustainable food systems by uniting people of different cultural, educational, and professional backgrounds.

The Student Farm began production in 1996. The entire farm is under organic production, which means no chemical fertilizers or pesticides are used. In 2003 and again in 2015 the farm became a CSA (Community Sponsored Agriculture) providing fresh organic produce to 20 members in Northside Ithaca (in 2003) and up to 60 members of the Cornell community in 2015. The farm also operates a vegetable stand in Ho Plaza. Dilmun Hill relies on Cornell student volunteers for its operation, and all volunteers receive fresh produce! For more information, visit their website:

http://www.hort.cornell.edu/department/facilities/dilmun/index.html.

The soil series for the farm is a primarily Hudson silty clay loam on the upper terrace while it is a Chenango on the lower terrace. Maintaining physical structure (i.e. aggregation) and an adequate level of soil nutrients is essential for vigorous plant growth and high yields. Soils with good porosity enhance the growth of roots and microbes by facilitating the movement of water and air into and through the soil. However, soil management practices that rely on driving heavy machinery on soil, such as occurs with tillage, can cause the particles to become more tightly packed, reducing the volume of soil pores. In compacted soils, movement of air and water are restricted and the ability of plant roots to grow is deeply reduced. Even though Dilmun Hill does not use large machinery, they still have problems with compaction and poor infiltration and drainage in several areas. As a result a variety of management strategies have been implemented at Dilmun to investigate the best management strategy for this problem. The goal for this lab is to determine how these treatments have been effective in improving the soil at the farm.

A. Analyzing Soil Physical Conditions

The soil's bulk density (D_b) is the ratio of the mass of dry soil to the volume of soil. The higher the bulk density the less pore space a soil has. Typical bulk density values depend on the soil materials and conditions. Bulk densities for organic soils, such as uncultivated forest and grasslands range from 0.1 to 1.1 Mg/m^3. In cultivated soils, values range from 0.9 to 1.8 Mg/m^3. Bulk densities higher than 1.6 Mg/m^3 inhibit root penetration. Usually values greater than 1.7 to 1.9 Mg/m^3 indicate a fragipan or a compacted glacial till layer.

Determining the bulk density of a soil involves taking an undisturbed (field condition) soil sample of known volume. In this lab, we will do this by inserting a cylinder of a known volume into the soil, filling the cylinder with soil, and carefully removing that exact volume. The sample is then oven dried at 105° C for two days. To calculate bulk density, the dry weight is divided by the volume of the cylinder.

$D_b = W_s / V_t$

Where:

D_b = bulk density (gm/cm^3)

W_s = weight of dry soil solids (gm)

V_t = total volume (solids and pore) (cm^3)

$V_t = \pi r^2 h$

Where:

V_t = total volume (cm^3)

r = radius of cylinder

h = height of cylinder

Determination of particle density involves measuring the oven dry weight of soil and the volume of soil particles (only solid no pore space). The volume of soil is determined by measuring the volume of water displaced by the particles.

$D_p = W_s / V_s$

Where:

W_s = weight of dry soil solids (gm)

V_s = volume of solids (cm^3)

Unlike bulk density, pore space does not affect particle density (D_p). The mineral crystal structure and the chemical composition of the soil determine particle density. Therefore, the range in most mineral soils is smaller between 2.60 to 2.75 Mg/m^3. Organic soils have a lower particle density since organic matter has a density of .8 Mg/m^3. For calculation purposes, a particle density of 2.65 Mg/m^3 is assumed for mineral surface soils with organic matter between 1 to 5 percent.

Knowing particle density, we can then calculate soil porosity from bulk density and particle density.

Soil Porosity = $1 - D_b/D_p$

Gravimetric water content

In terms of water, there are several ways to measure soil water. Gravimetric water content (θ_m) tells us the amount of water associated with a given mass of soil and is expressed in grams of water per grams of soil. This method is a direct and is the method used to calibrate all other indirect methods of measuring water content. As long as the bulk density sample is weighed before drying, the same sample can also be used to calculate θ_m. Gravimetric water content is calculated by dividing the weight of water by the weight of the dry soil. First, determine the amount of water in the soil by subtracting the initial soil weight, called the wet weight, from the oven dry soil weight.

$W_{water} = W_{wet} - W_s$

Where:

W_{water} = weight of water in soil (gm)

W_{wet} = initial soil (solid+water) weight (gm)

W_s = weight of dry soil solids (gm)

Next calculate gravimetric water content:

$\theta_m = W_{water} / W_S$

Where:

θ_m = gravimetric water content (gm/gm)

Volumetric water content

Now think about a root system and how it grows. Roots grow, or explore, certain depths, or volumes, of soil. Therefore, we find expressing water content in terms of volume of water per volume of soil, known as volumetric water content (θ_v), more useful. To calculate θ_v we first need to know the mass of soil in a given volume of soil, which is its bulk density. Then we multiply bulk density by the gravimetric water content.

$\theta_v = D_b * \theta_m$

Where: θ_v = volumetric water content (gm/cm^3)

We can then calculate the amount of pores filled with water from the soil porosity and the volumetric water content.

Soil saturation = θ_v/Soil porosity

B. Analyzing Soil Nutrient Conditions

In the previous labs, we have seen that soil conditions can vary over small distances. This kind of small-scale variability can develop naturally or be the result of management. How does a land manager account for this type of variability in sampling his or her soil? Soil samples taken at one area in a field, say in the middle, may not give accurate and representative information about the conditions throughout the field. The sample may have higher, or lower, fertility than the rest of the field.

Alternatively, the land manager could sample in a grid-like pattern (Figure 1), taking individual samples every meter or so. But the cost of analyzing each sample individually, by a soil analysis lab, would quickly become prohibitive. To get a representative sample while at the same time minimizing sampling costs, the land manager would want to collect 15 to 20 sub-samples from several locations in the field and mix thoroughly into a composite sample. Approximately one pint of this mixture should be submitted to a lab for nutrient analysis. In areas of a field known to have specific problems, such as poor drainage, a separate composite sample should be taken. Sub-samples are normally taken with a soil probe, a spade, or a soil auger to the depth of the plow layer, which constitutes the top 10 to 30 cm (6 to 12 inches) of the soil surface.

When should soil sampling be done? For nutrient analysis, samples ideally should be collected just prior to seeding a crop; however, this is not often practical because of the time required for analysis. Thus, samples for a soil test are usually taken in the previous fall, for spring planted crops. The land manager receives the soil test report from a soil testing lab over the winter. The soil test report will provide recommendations for fertilizer and lime application rates for selected crops grown on that soil. With this information, the land manager can make plans for how much fertilizer and lime to apply to spring crops.

The purpose of soil testing is to determine the nutrient supplying ability of the soil, as well as soil pH and organic matter levels. Not all nutrients found in the soil are equally available to plants. The soil test is designed to measure the fraction of total soil nutrient supply accessible to plant roots. To do this, analytical laboratories use chemicals that extract nutrients from the same “pool” used by the plant, effectively mimicking the ability of the plant to acquire nutrients from the soil.

There is no universal method for soil testing. Soil testing labs vary in their methodology based on the soil, climate, crop and economic factors of a particular region. These variations often result in differences in test results and make comparisons between labs difficult. Therefore it is important to choose a lab that has local field calibrations and offers a correlated soil test based on field laboratory research. Background information on the field should be submitted along with the sample.

Proper interpretation of nutrient analysis results is essential for determining crop fertilizer rates. In a soil test report, such as the one provided in this lab, soil nutrient levels are quantified in terms of elemental nutrients per unit area. Commercial fertilizers, on the other hand, are quantified in terms of a single compound for nitrogen (N) and as soluble salts for phosphorus (P_2O_5) and potassium (K_2O). The fertilizer bag will contain three numbers, such as 10-20-20. The first number indicates that the fertilizer contains 10 percent nitrogen. The second number indicates 20 percent P_2O_5 and the third 20 percent K_2O. Therefore, calculations are required to convert the recommended P and K rates to their fertilizer forms.

Elemental P * 2.29 = P_2O_5

Elemental K * 1.2 = K_2O

Fortunately Cornell Nutrient Analysis Laboratory gives their recommendations in the fertilizer form (N – P_2O_5 – K_2O) so you don’t have to do these conversions.

Most liming materials contain calcium carbonate, oxide, or hydroxide and/or magnesium. Lime requirements are based on a 100 percent effective calcium carbonate equivalent or effective neutralizing value (ENV). The ENV depends on the fitness of the material (the finer the lime, the quicker the reaction with the soil) and the chemical nature of the lime. One atom or molecule of Ca, Mg, CaO,

MgO, $MgCO_3$ and $CaCO_3$ will neutralize the same amount of acidity. Therefore, to make comparisons between different liming materials we need to compare their molecular masses. For example, the moleculat mass of calcium carbonate ($CaCO_3$) equals 100 and the molecular mass of pure burned lime (CaO) equals 56.

$CaCO_3/CaO = 100/56 = 1.786$

Therefore, 1 kilogram of pure burned lime will neutralize as much acidity as 1.786 kilograms of pure limestone.

In additions to the type of nutrient additions, the method of application is important. There are ways to incorporate fertilizer and lime into the soil. With broadcasting, the nutrients are applied uniformly

before planting and incorporated by tilling or cultivating, or in the case of potting mixes, blended right into the mix. With banding, fertilizer and lime are applied in a localized zone, usually to one or both sides of the seeds. Broadcasting requires more fertilizer than banding and has a higher rate of leaching. However, there is less of a risk of fertilizer salt injury than with banding. To avoid this type of injury no more than 80 lbs/acre of N and K_2O should be applied in a fertilizer band at one time. Despite the risks involved, growers prefer to band fertilizer in the field because of the reduced cost. In greenhouses, broadcasting and applying fertilizer in a soluble form is favored. However, since liming materials have a low solubility in water, they must be applied by broadcasting or banding.

C. Soil Temperature

Soil temperature affects the rate of seed germination, seedling emergence and growth, root development, and most microbial processes. Plants and microorganisms, just like humans, thrive at certain temperatures. If the temperature is too high or too low many biological processes won't take place. The microclimate for a seed, plant, or microorganism can be impacted by different soil management practices. For example, ridging or mounding a soil increases the soil surface area and can expose the soil to more radiation, resulting in warmer temperatures. Mulches and other crop residues insulate the soil, keeping soil surfaces cooler during hot weather and warmer during cold periods. In the Northern Hemisphere, southern exposed fields, greenhouses, and cold frames receive more sunlight and become warmer than those that are northern facing. Understanding how soil and land characteristics influence soil temperature enables us to make better decisions in growing crops, planting trees, or managing compost.

There are different kinds of instruments used to measure soil temperature. Some require manual readings where as others can be connected to a data logger. A bimetallic thermometer has a bonded strip of two different metals, shaped into a coil that is enclosed by a metallic sheath. One end of the strip is fixed and the other end is attached to a needle on the dial. A change in temperature along the coil region results in a distortion of the bonded strip causing a rotational motion on the dial, which provides the temperature readout. They tend to have a slow response time.

Infrared thermometers measure the amount of longwave (infrared) radiation emitted by the surface and convert the intensity of that signal to surface temperature. The object being measured does not need to be touched to obtain a temperature reading and the thermometer integrates over a larger surface area.

Exercise A. Soil Physical Properties

Materials

- Core Soil Sampler
- 2 sleeve liners
- 2 soil cans
- measuring tape
- spatula
- moisture meter
- hand-held penetrometer

Steps (field exercise)

1. You will sample different beds under different management practices for bulk density, water content, soil moisture tension, and compaction.

2. Insert sleeve liner in Core Soil Sampler and take sample in the beds. You will collecting two samples at a 0-5 cm and 30 to 35 cm depths (unless you reach an impenetrable contact at which point you will collect the 5 centimeters above that contact).

3. Remove liner from Sampler and trim excess soil from top and bottom with spatula. Only remove excess soil. The entire volume of the liner must be filled with soil. Repeat procedure if necessary. Place liners in designated soil cans.

4. Carefully empty contents of the first liner into the labelled soil can. Use knife if necessary. It is important that all soil from the sleeve liner goes into the soil can. Your calculations depend on this accuracy. Close soil can when done in order to avoid evaporation. You will weigh your samples in the soil lab at the end of the class. Do the same with the other liners.

5. Measure height (cm) and radius (cm) of each liner and calculate volume. Record in Table 1.

6. Measure soil water with the moisture meter and record in Table 1.

7. Measure soil compaction with penetrometer. Record in Table 1.

Steps (lab exercise)

1. At the end of class, bring labelled cans back to soils lab. Weigh samples and record weights (table 1).

2. Open can, place lid on bottom and insert cans in 105° C oven. The samples will take 48 hours to dry.

3. After 48 hours reweigh soil cans and record weights (table 1).

4. Empty soil into marked bucket, weigh empty cans, and record weights (table 1). Wipe out cans and place in marked bucket.

5. Calculate wet soil weight by subtracting the weight of the can. Record (table 1).

6. Calculate dry soil weight by subtracting the weight of the can. Record (table 1).

7. Calculate soil water weight by subtracting dry soil weight from wet soil weight. Record (table 1).

8. Calculate bulk density by dividing dry soil weight by volume of liner. Record (table 1).

9. Calculate gravimetric water content by dividing water weight by dry soil weight (table 1).

10. Calculate volumetric water content by multiplying bulk density by gravimetric water content. Record (table 1).

Table 1. Soil Water/Bulk Density results

	0 – 5 cm	30–35 cm (or contact)
Group and treatment		
Soil can identification code		
Height (h) of sample liner (cm)		
Radius (r) of sample liner (cm)		
Volume (V_t) of liner (cm^3) = $\pi r^2 h$		
Weight (gm) of wet soil + can		
Weight (gm) of dry soil + can		
Weight (gm) of soil can		
Weight of wet soil (W_{wet})		
Weight of dry soil (W_s)		
Weight of soil water (W_{water})		
Bulk density (D_b)		
Gravimetric water (θ_m)		
Volumetric water (θ_v)		
Soil water (moisture meter)		
Soil compaction (penetrometer)		

Exercise B. Soil Temperature

Materials

- Bimetallic thermometer
- Infrared thermometer

1. First measure air temperature with the bimetallic thermometer and record in Table 3. Thermometers are in ° C.

2. Again using the bimetallic thermometer, you will measure soil temperature at two depths, 5-cm depth (note indentation on thermometer) and 12-cm (insert entire thermometer) in two different locations in the bed using these thermometers. The first location will be under plant cover or mulch while second will be under bare soil. Record these temperatures in Table 2.

3. Measure the surface temperature of these beds using the infrared thermometer. Note how the temperature changes as you move the infrared thermometer away from the surface. The further away you hold the infrared thermometer, the larger the ground diameter of the temperature reading. At each bed location take several measurements of the soil surface, holding the infrared thermometer approximately 15 cm from the surface (measures 0.32 cm diameter) and then holding the infrared thermometer about 90 cm from the surface (measures 115 cm diameter). Record data in Table 2.

Table 2. Temperature

Treatment: Air Temperature:

With Bed Treatment:	Regular thermometer		Infrared thermometer	
	5cm depth	12cm depth	surface (@15cm)	surface (@90cm)
Bare Soil				
Veg or mulch				

Assignment:

Write a report that presents:

1) your results (moisture, density and temperature),
2) explains those results and
3) include a brief discussion on what you might suggest for improved performance based on your sample plot as well as your observation and the discussion presented about Dilmun's practices, soils, history and landscape.

Exercise C. Soil Nutrient Conditions (Soil Sampling)

This exercise is collecting samples for a later lab and will not be required to be included in the lab 5 lab report.

Materials:

- soil probe
- bucket
- ruler
- tape
- sampling bag
- Cornell Nutrient Analysis Lab submission sheet

Step One (field exercise)

1. Observe plot and design a representative sampling scheme for your site. Make sure to note your design in your lab notebook and why you chose that particular pattern.

2. Measure 20 cm on a soil probe and mark with tape

3. Take 15 to 20 samples to a 20 cm depth. Place soil samples in bucket.

4. Mix soil thoroughly, take a sub sample, and place soil in the sampling bag. You will submit this sample along with the submission sheet.

5. Complete submission sheet with field history of your sample. Give sample and sheet to your TA. Make sure to record your sample has the ID number below. You will need this number to get your results back from the lab. This will be accomplished in the lab at the end of the field component of the day.

Step Two (lab exercise) – this will be completed in a later lab, but has been included her for you information.

1. Examine the nutrient analysis sheets from one of the Dilmun Hill plots.

2. Find recommended lime and fertilizer rates for growing corn (grain) in this soil for this year (1st year corn:grain) and record in Table 3.

3. Choose fertilizer materials from information provided in the lab, and using their nutrient contents, calculate the amount of these fertilizers needed per acre for this soil. Record in Table 2 the lbs/acre needed to meet recommendations.

4. Calculate the amount of lime needed per acre for this soil and record in Table 2. Remember your recommendation is based on 100% effective neutralizing value of $CaCO_3$. Therefore, you need to divide the recommended rate of lime by the ENV of hydrated lime.

Rate to use = recommended rate/ENV of lime source

5. Repeat steps 1 through 6 with the nutrient analysis sheet from the second Dilmun Hill plot. Record in Table 2.

Table 3. Fertilizer and Lime Requirements Nutrients	Recommendations (lbs/acre)	Fertilizer chosen and analysis (%)	Fertilizer and lime to be added (lbs/acre)
N			
P_2O_5			
K_2O			
Lime			

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