Soils—Experimental and Field Investigation—Walk Through

Earth Science Extras
by Russ Colson

(See example investigation and report starting on page 3 below)

Assignment:

1) Collect at least two soils from different locations with different properties. These soils should be chosen to allow you to address a specific question. For example, how does sandy vs clay-rich soil affect <property of soil>? How does organic content affect <soil property>? How does long-term cultivation vs natural biome affect <soil property>?
2) Choose one particular property of the soil to investigate that might vary between the two (or more) soils sampled
3) Design an experiment to measure that property in the two soil samples. You will need to think about how to control for other variables that you need to hold constant, how to create an experiment that looks at that one variable in your different soil samples, and how to make measurements.
4) Create tables and/or graphs that clearly show your results
5) Interpret your results in terms of the original questions you asked, and in terms of the actual results that you got.
6) Write a report. Your report should identify your question and why it is important, explain your sampling method and experimental method, provide your complete results, and give your interpretations of those results along with clear reasoning for why you think those interpretations are correct given your experimental measurements.

NOTE: Expect that there will be unanticipated challenges and you will have to adjust your experimental plan to adapt. Solving unexpected problems is one of the main experimental skills that true investigation helps you practice.

Example properties you might measure:

Porosity of the soil, or its capacity to hold water. You will need to measure the amount of water that can be absorbed by the soil as a function of the total soil present (remembering that there might already be some unknown amount of water in the soil when you collect it.) -- example potential experimental problem: your sampling may disturb the soil significantly from its natural state, affecting the porosity.

Permeability of the soil, or its capacity to allow movement of water through it. You will need to measure how much water passes through a fixed thickness of soil under a constant pressure gradient, in a known amount of time. Example potential experimental problem: as with porosity, your sampling can affect the result, and how you 'pack' the soil for the experiment will have a huge effect of the result, probably a much bigger effect that the differences in your sampled soil.

Cation adsorption capacity: You will need to measure how the concentration of a cation (such as Na, Mg, or Ca) changes in water when the water passes through a set thickness of soil (or sits in the soil for some predetermined time). Example experimental challenge: You will need to find tools to measure the concentration of cations in water—there are methods/tools available for classroom and field use for measuring these parameters, also even materials for testing aquarium water might work for you. Alternatively, and less meaningful, you could use a 'cation proxy' such as food coloring, and create a set of standards with known amount of food coloring to allow you to estimate how much food coloring is left in the water after passing through the soil.

Water retention capacity: You will need to measure how quickly and/or how much water will drain from or evaporate from a saturated soil sample under some set of conditions (such as humidity for evaporation or soil thickness and time for draining). Example experimental challenges: how will you measure how much water was present and what fraction of it drained or evaporated away?

Other property: ????????

Note 1: An investigation in science is always more challenging that being told information in the classroom, and often we have a lot more experience "learning facts" about science from a 'teacher' than actually doing science. However, the investigative activity presented in this lesson actually addresses a Minnesota state high school science benchmark and so is something you should already be able to do based on your high school science experience (yes, I know that investigation is an ongoing skill that is developed over a lifetime, not in one high school class activity—that's why you're getting another chance to do it here!)
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Minnesota High School Science Benchmark: 9E.1.2.1.2 Plan and conduct an investigation of the properties of soils to model the effects of human activity on soil resources. (P: 3, CC: 2, CI: ESS3, ETS2) Emphasis is on identifying variables to test, developing a workable experimental design, and identifying limitations of the data. Examples of variables may include soil type and composition (particularly those found in Minnesota), erosion rate, water infiltration rates, nutrient profiles, soil conservation practices, or specific crop requirements.

Note 2: In my example "walk through" experiment that you can look at after at least starting your own experiment, I am going to measure water retention capacity, and address the questions 1) how does sand/clay content affect water retention capacity and 2) how does land use (agriculture vs natural biome) affect water retention.

Note 3: Your report, including all the elements listed above, should be submitted in pdf format. Your report should additionally include pictures of your field sampling and experimental set up, and you must be seen and identifiable in at least one of the pictures.

Example Investigation and Report

Investigation of the effects of soil texture (sandiness) and land use (crops vs native grass) on soil capacity to retain water

By Russ Colson

Abstract: The capacity of soil to retain water, that is, limit the water that is lost either to downward migration under gravity or upward loss due to evaporation and capillary action, is an important consideration in both agriculture as well as native landscape restoration or preservation. This study examines the effects of two variables—soil sandiness and land use—on a soil's capacity to retain water. Results show that more clay-rich soil can retain water better than sandy soil and that soil established with natural grass retains water better than soil used for crop farming. The interpretation is that both fine-grained clay minerals and organic matter are important factors in retaining moisture. The higher water retention of native grasses, compared to cultivated fields, may have implications for net carbon footprint of various land uses.

Sampling Strategy:

To examine the effect of soil texture (sandiness) on water retention capacity of soil, I collected a soil sample (Soil 1) from the former Glacial Lake Agassiz lake bed in the Red River Valley of northwest Minnesota, a soil established on a clay-silt parent sediment (Sherrack Formation) and almost devoid of sand. This sample was taken from the upper 2 inches of a field under cultivation for at least 30 years, planted to sugar beets at the time of collection (August 2022). The sample location was Lat 46.876392; Long.-96.610722 as determined using a Galaxy J7 Skypro phone with Google Maps. A second sample (Soil 2) was collected from the area of the former beaches of Glacial Lake Agassiz where sand dune fields were once established along the shoreline of the lake. This sample came from native prairie, with abundant native grasses and horsetails. Due to the density of roots in the soils, sampling was difficult and the sample taken was from a recent pocket gopher mound. This sample was collected at Lat. 46.854832; Long. -96.444156, measured as for Soil 1.

Collecting Soil sample 3.

To examine the effect of land use, I collected two samples within about a hundred yards of each other, on land of the same slope occupying the flat top of a hill in glacial till outside the Red River Valley. Given the similar location, similar parent material, and similar slope, the two soils are expected to differ only in that one of them (Soil 3) was taken from ground with native grass (mainly big blue stem) established for at least 25 years, and the other (Soil 4) came from soil under cultivation for at least 30 years, presently planted to wheat. Both samples came from the upper 2 inches of the soil, collected in early September 2022, after wheat harvest. Soil 3 was collected from

Lat. 47.023351; Long. -96.318970 and Soil 4 from Lat. 47.023351; Long. -96.318970, measured as for Soil 1.

Experimental Methods:
Each soil sample was saturated with water by adding water in increments to soil held in a glass cup and stirred with a chopstick, until the sediment, when at rest, retained just the beginning of water accumulation at the surface. In some cases where too much water was added, resulting in pooling of water at the surface, additional soil was added to bring to just-saturation.


Scale, cup, chopstick and soil during measuring

The original plan was to cover the top of the glass cup containing the saturated soil with a thin coffee filter, and upend the cup, measuring how much water drained through in either 10 minutes or 20 minutes. This was done initially by allowing the water to drip into an empty bowl, wiping out the water with a paper towel whose mass was known, and then measuring the change in mass of the paper towel due to the presence of the extra water. Mass measurements were made with a top-loading food scale purchased at Walmart with a minimum measurement increment of 1gram. Later, the cup was simply upended on top of the paper towel and allowed to drain directly into it, with the water then measured in a similar fashion.


Failed effort to drain water from upside down cup through a coffee filter.

This experimental approach proved to be ineffective because the drip rate of water through the coffee filter was much too slow and the total water drained in 10-20 minutes was only a few percent of the water present in the saturated soil. This made distinguishing differences in the water retention between the different soils difficult (even putting plain water with no soil at all in the cup resulted in only a very slow drip through the coffee filter).

Instead of measuring the ‘drain rate’ as described above, I was able to measure the ‘evaporation rate’ by placing the saturated soil samples on parchment paper on a cookie sheet in an oven heated to 170ºF. The ‘thickness” of the saturated soil samples was kept as constant as possible (estimated visually and qualitatively) so that differences in water transport distance or surface area of the sample did not become more important variables than those I was trying to measure. This thickness was about 0.6 to 0.9 cm after drying was complete—Soil 1, with its abundance of expandable clays, was close to 0.6 cm and the others 0.8-0.9cm.

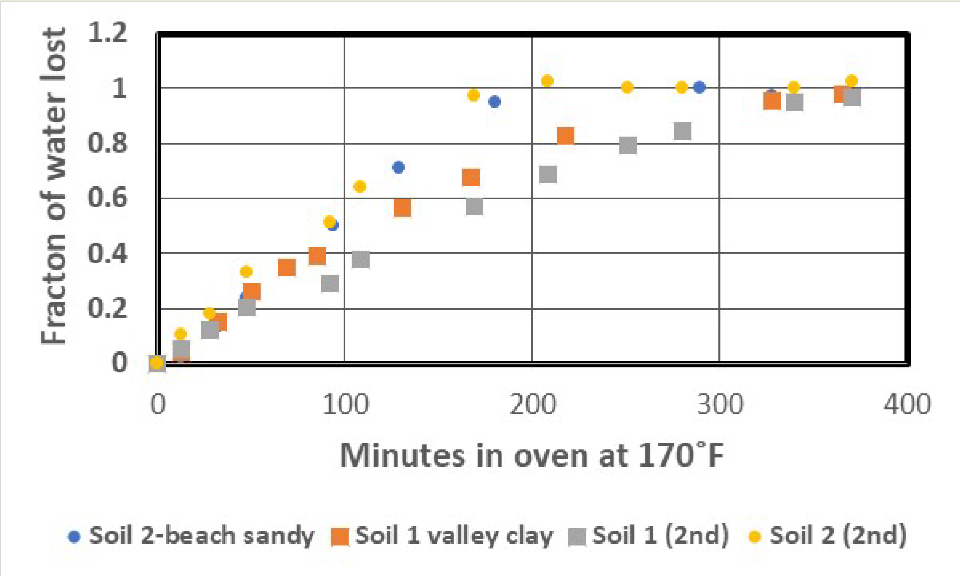
Drying saturated soil samples in oven at 170˚F.

Water loss rate was measured by periodically taking the experimental samples from the oven and measuring mass with the top-loading food scale. Most water was lost within about 6 hours for all samples, but samples were left in longer, and then finally heated for another 2 hours at 200ºF, to determine the total water present in the samples (some water would have been present in the samples when collected and so the water added to saturate the soils cannot be taken as the total water present).

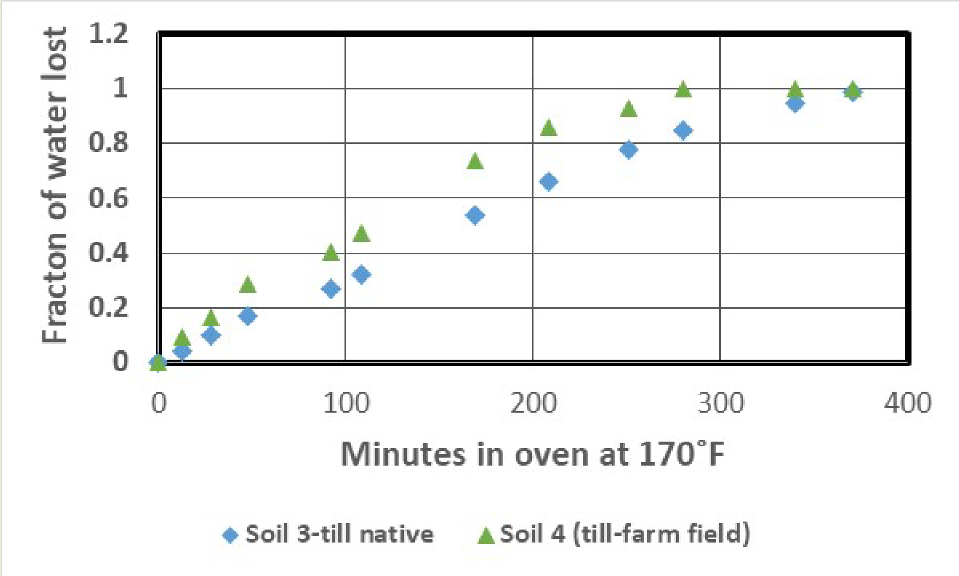
Soils 1 and 2 were measured twice each by this method to establish an estimate of experimental uncertainty. Soils 3 and 4 were measured only once each.

Experimental Results:

The results of the water-evaporation experiments for the clay-rich and sand-rich soils are shown in the figure at right. Two measurements were made for each, demonstrating the reproducibility of the measurements. The rate of evaporation are not distinguishable at less than about 90 minutes evaporation (about 35% of the water evaporated), but at greater times and percent evaporation the sandy soil clearly deviates to the upside, meaning that it is losing water at a higher rate.



The results of the water-evaporation experiments for the native grass vs cultivated field (in glacial till) soils are shown below. Each was only measured once. There is a clear deviation to the upside for the cultivated field soil apparent from the beginning of evaporation, demonstrating that the cultivated field soil loses water at a higher rate.



In addition to rate of water loss with evaporation, these experiments allow comparison of the amount of water that each soil can absorb at saturation. These results are shown in the table below, with the water capacity shown as the ratio of water present at saturation divided by the dry soil mass. Not only does the native grass soil lose water at a lower rate, but its capacity to absorb water is much higher to begin with. The clay-rich valley soil (with its abundance of expandable clays) has the second highest capacity to absorb water, and the cultivated till soil and the sandy soil come in third and fourth.

Water capacity at saturation

Sample	Mass water/dry mass
Soil 1 1st	0.43
Soil 1 2nd	0.48
Soil 2 1st	0.29
Soil 2 2nd	0.31
Soil 3	0.62
Soil 4	0.36

Interpretations:

The higher rate of evaporation observed for the clay-rich Soil 1 versus the sandy Soil 2 is consistent with both stronger adsorption bonding of water molecules to the clay particles and with lower permeabilities in the clay rich soil, which would make it more difficult for water to migrate to the surface where evaporation occurs. Both of these properties would tend to limit water loss to evaporation.

The seeming similarity of evaporation rate up through about 35% water loss is not obviously explained by the greater permeability and lower absorption of the sandy soil, which would tend to produce greater loss from the onset of evaporation. It's possible that this effect is due to the fact that not only is Soil 2 sandier (which might reasonably result in higher evaporation rates) but it is also established in native grassland (which, as we will examine below, is consistent with lower evaporation rates). For example, it's possible that the higher organic content of the sandy loam (abundant small, tangled rootlets were abundant in the sample and much of the non-sand fraction appears, visually, to be organic matter), clings to the water even more strongly than clay, up to a certain point. Once drying reaches 35%, the organic matter may not have as big an effect and the greater permeability and lower absorption strength of the sand allows the water to escape more easily.

The higher rate of evaporation observed for the cultivated field Soil 3 (established in glacial till—a mix of clay, silt, sand, and gravel) compared to the native grassland Soil 4 (also established in glacial till in closer proximity to Soil 3) is consistent with higher organic contents of the native grass soil holding more tightly to the water. Abundant organic matter, including tangles of fine rootlets were visually apparent in Soil 3.

Combined with the higher water capacity of Soil 3 (see table above), the greater water retention capacity of the native grass soil means that cultivated soils, even if well maintained and fertilized regularly, may not have the overall productivity of a native grass soil. This has implications for carbon footprint, since the more productive native soil might remove more CO_2 form the air, as well as overall productivity of the land.