Accessible Methods for Measuring Aggregate Stability

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What are Soil Aggregates?

Pick up a handful of soil and observe it break into smaller parts in your hand. These "smaller parts" are aggregates, and they form the structure of the soil. An aggregate is made of even smaller soil particles bound together. The size and arrangement of aggregates in the soil creates pore spaces that allow for water infiltration and airflow, spaces for soil microbes and larger soil fauna to live, and channels for roots to grow.

Aggregates come in many sizes, and a diversity of stable aggregate sizes is associated with a healthy soil. However, unstable aggregates can break down. When aggregates break down, the smaller particles can be lost due to wind and water erosion. Aggregate break down also leads to the collapse of soil structure, and the small particles clog soil pores. As a result, water infiltration will decrease, compaction will increase, and it will become difficult for both roots and soil organisms to live.

Aggregates break down when they are exposed to disturbances such as wind, water, or tillage. The impact of falling water drops or the physical destruction from a plow are obvious forces that will damage aggregates. A less obvious disturbance is the act of introducing oxygen to the soil during tillage. Excess oxygen stimulates the activity of microbes that can decompose stable soil organic matter as a food source. This is troublesome, because this organic matter is an important component in building stable aggregates. Organic matter already embedded in an aggregate is not easy for microbes to break down. However, the disturbance of tillage coupled with excessive microbial decomposition can inhibit the formation of new or larger aggregates.

Even the simple uptake of water from drip irrigation can disturb aggregates. As water enters a dry aggregate, air is trapped inside the aggregate. This creates internal pressure that can destabilize the aggregate. This type of breakdown is specifically known as slaking.

Why do some aggregates hold together while others break down?

Many factors affect aggregate stability. Percentage of clay and sand, soil organic matter, glomalin produced by fungi, and other biological "glues" produced by bacteria and plants all affect the ability of soil particles to stick together. The physical structure provided by roots and fungal hyphae also provide stability.

What do we measure, and why?

Aggregate stability tests measure how well aggregates hold together during a disturbance event. These tests can predict soil risks or management needs and track changes to soil overtime. We cannot change the clay characteristics of a soil, and thus must interpret our results and set expectations with this in mind. "Good" aggregate stability in a clay loam is different from "good" aggregate stability in a sandy loam. However, we can manage for soil organic matter and biological processes that support optimum aggregate stability relative to the soil type.

Aggregate stability has long been understood to be an important component of soil quality. A method developed in 1936 remains one of the most popular laboratory tests for aggregate stability today, with modern modifications. Many techniques have been developed over the years to make aggregate stability measurements accessible in the field and in low-tech laboratory settings.

Laboratory tests provide standardization, precision, and accuracy. When resources or requirements do not allow, accessible aggregate stability tests can still be conducted by farmers, technical service providers, and home gardeners with a little legwork and scientific rumination. The following pages guide that rumination, and summarize several methods.

When choosing a method, consider the following:

Depth

Sample depth is not the same for all tests of aggregate stability. Changes to soil health are observed primarily in the top six inches of soil, thus a six-inch sampling depth is commonly recommended. However, some tests specifically focus on surface erosion and crusting and recommend a shallow sampling depth such as three inches. Some tests recommend a surface sample only. Yet other tests recommend a surface sample and a composite sample to the depth of typical disturbance.

The depth of the sample will impact the question your test answers. So, you must first establish your question. Do you care about surface aggregate stability the most? Do you care about overall aggregate stability the most? Do you feel compelled to measure them both?

Aggregate Size

Aggregates form in many sizes. A diversity of aggregate sizes is associated with good, overall soil structure. For wet aggregate stability tests, aggregates >1 mm and <2 mm are commonly measured. This aggregate size has long been associated with proper soil function. For rainfall simulations or slake tests using the cylinder method (presented below) larger aggregates are used. Some laboratory tests measure all aggregate sizes.

Wet versus Dry Samples

Many aggregate stability tests call for air dried samples. These samples will be introduced to water (ex. cylinder slake test, adapted laboratory test with sieve, rainfall simulator) to test their stability. Some tests call for field moist soil. There is a difference to interpretation.

Dry aggregates have a lower aggregate stability than moist aggregates. Measuring dry aggregates provides an interpretation of how the soil will behave under dry conditions. Depending on location and seasonal precipitation, measuring moist soil may be a better representation of how soil will behave in the field. However, dry aggregates are most often used, in part, because 1. Soils pass through sieves more easily when dry, and 2. Dry soils are easy to standardize. On any given day, a field moist soil can have a different moisture content. Because moisture content has an effect on aggregate stability, this makes it harder to compare results over time. When soils are always dry when analyzed, the data is easier to compare and interpret.

Air dried samples are not moisture free. Soil texture, soil organic matter, and mineralogy will all affect the true water content of an air-dried sample. To increase quality of non-laboratory methods, dry a weighed subsample of the soil in an oven at 170°F, or whatever your lowest oven setting allows (a microwave is not recommended, as this could impact the results for this test). If 5 g is placed in the oven and it weighs 4.5 g when it comes out, 0.5 g of the initial weight was water. That means the air dried soil was still 10% moisture. Use this information to adjust the results and interpretations of the chosen aggregate stability test. However, avoid analyzing soil that has been in the oven. High temperatures can change the chemistry of the aggregates, and therefore change the aggregate stability. Ovens used in laboratories can be set at temperatures much lower than readily available home ovens.

There is a specific method for dry aggregate stability where dry samples are sieved and never rewetted. This method is used to predict the risk of soil erosion. However, this method requires additional information including the percentage of sand, silt and clay, soil organic matter, and calcium carbonate. This method is appropriate for research purposes but has not been adapted for in-field assessments or into a simplified non-laboratory technique.

Ease of Repetition

Ideally, all samples are measured in duplicate. This means if one sample is collected from an area of a field, it is measured with the same method twice. The results are averaged into one number to create a final data point. If the two results are very different from one another, there is likely a mistake. Repeat the method a third time. Average the two results that are most similar. If all three results are not similar, the sample may have been poorly collected/handled or the method is not being done properly.

When selecting a test, consider the difficulty and time required to perform the test and how many samples must be measured. A simpler test conducted in duplicate may be more valuable than a complicated or time consuming test run only once per sample.

When interpreting results, consider the following:

Soil Texture

Soil is composed of sand, silt, and clay. Silt and clay form aggregates better than sand. When making comparisons between soils, texture must always be considered. The potential aggregate stability for a sandy soil is not same as the potential aggregate stability for a clay soil. Texture information can be found in the USDA-NRCS web soil survey, or it can be measured with a simple at home test or in the laboratory for increased precision.

Soil Fertility and Soil Organic Matter

Soil organic matter and cations (molecules with a positive charge) will affect aggregate stability. Generally speaking, as soil organic matter increases, aggregate stability will increase. Maintaining soil fertility will also support aggregate stability; calcium and magnesium form bonds with clay and help hold aggregates together.

Clay Mineralogy

Mineralogy is the study of the chemical and physical properties of minerals. A major effect of mineralogy is that some clay swells, and some clay does not. Whether or not clay swells impacts aggregate stability. Well-defined mineralogy is helpful information, but mixed mineralogy – such as that found in many New England soils – can preclude clear expectations.

The mineralogy classification of clay is found in the Official Soil Series Description; it is the second term in the family, or taxonomic class statement. Ex.) TAXONOMIC CLASS: Coarse-loamy, mixed, active, mesic Oxyaquic Dystrudepts. In this example, mixed means there are mixed clay minerals. This is as opposed to a clear definition such as smectitic, which refers to clay made of smectite minerals prone to swelling.

The effect of mineralogy of soil aggregate stability is an important field of study but it is quite technical. When results are unexpected, or comparisons are being made between fields, further investigation into the effects of mineralogy may be of interest.

When collecting a sample, consider the following:

Sample Area

Soil fertility samples can be taken on up to 20 acres. Soil health can be more variable than fertility and each soil health sample should cover a smaller area. Choose an area of a field that represents typical management and growing conditions not more than 2 acres in size. Collect samples appropriate for the depth of the method. Use a shovel, not a soil probe, to minimize destruction of aggregates during sampling. The number of samples needed is relative to the method.

Sample Handling

Aggregates break down with physical disturbance. This includes the force of a shovel, the plop into a bucket, the bucket bouncing around in the trunk, the samples being dumped onto a table to dry, etc. Samples for aggregate stability should be treated with extra care.

Once samples are in storage, aggregate stability can increase slowly with time. For this reason, samples should not be stored long term.

Sample Storage

If the sample will be used for a dry analysis, airdry the soil. If possible, complete the analysis immediately after airdrying the soil, rather than collecting the soil and storing it for later analysis. The more the soil is moved, the more it will break down and alter the results. If the sample will be analyzed at field moisture, keep the sample in an airtight bag until it is analyzed to prevent changes to the moisture content.

Three Common Tests

The following is a summary of three methods. Additional thoughts, guidelines, and details are added here. Strong similarities in language compared to the original method summaries may be present. Scientific credit for the methodologies should be attributed to the original sources, not this fact sheet.

Cylinder Slake Test (NRCS)

- When to use:
  - On-farm demonstrations
  - Quick assessments
  - Cheap, easy assessment over time with thoughtful data collection
- Soil depth:
  - Soil surface
- Soil moisture:
  - Air dry
- Aggregate size
  - Large, “golf ball size” aggregates are collected from the field. The size of the mesh will determine the size of the particles that easily, visually breakdown. 5mm is the standard mesh size.

- Exercise caution when:
  - Making comparisons between farms or fields. This test is a great visual aid and requires no true data collection. This test can help compare the current field condition to the "potential" condition. The "potential" is a sample collected from an undisturbed area, such as a fence line. This test can also be used to see differences over time. For example, if a farm changes to no-till and wants to observe the before and after with several years of management in between.
- Method
  - Collect a large soil aggregate, approximately the size of a golf ball, from the soil surface. Allow the soil to air dry.
  - Place a wire mesh "basket" into a glass jar filled with water.
    - A 5 mm wire mesh is most commonly used with little exception. A smaller mesh can be used if that is what is handy, you just have to be consistent. Do not compare the results from a 5 mm mesh to a 3 mm mesh, for example. If particle size is important to the question being asked, choose a different method.
  - Gently place the aggregate on the mesh. It should be completely submerged. Note the time or start a stopwatch.
    - For the simplest test: wait five minutes. How cloudy is the water? Estimate how much of the soil clod has disintegrated. If using this as a comparison, which sample is more intact? More intact = better*
      - *Break open the soil aggregate if possible. If the aggregate is dry in the middle, this indicates a very degraded soil. In this case, more intact ≠ better.
    - For a numerical test: estimate the rate of breakdown. What percent of the aggregate is lost overtime? A ranking scale for the slake cylinder test is not available. You can create your own ranking scale to create numerical data as long as you are consistent and logical. *The proposed table below is adapted from the USDA qualitative slake test method for demonstrative purposes.*
      - When creating a ranking scale, handle the information carefully and communicate the scale if sharing results with others. It will be confusing if multiple sources of information are ranking a "3" with different criteria.

Rank	Criteria
0	The soil immediately disintegrates and falls through the mesh.
1	50% or more of the soil falls through the mesh within the first five seconds.
2	50% or more of the soil falls through the mesh within 5 – 30 seconds.
3	50% or more of the soil falls through the mesh within 30 seconds to 5 minutes.
4	10 – 25% of soil remains in the basket at 5-minute mark.
5	25-75% remains in the basket at 5-minute mark.
6	75 – 100% remains in the basket at 5-minute mark.

Wet Sieving (USDA ARS)

- When to use:
  - Laboratory-adjacent method
  - High quality demonstration
  - Northeast SARE Farmer Grants
  - Inexpensive quantitative method
  - Farm trials
  - Increased precision farm monitoring over time
  - Preliminary data collection (i.e., research not-yet-funded)
- Soil depth:
  - 0-3 inches for pastures, hayfields, and long term (≥10 year) no till
  - 0-6 inches for conventional management, reduced tillage, and big picture changes over time.
  - 0-3 inches AND 3-6 inches (as separate measurements and averaged measurements) for transitioning fields over time. *This level of detail is not needed for general on-farm assessments. However, this approach would be valuable for farmer grants through SARE and would contribute good data to the scientific community.*
- Soil Moisture
  - Air dry
    - Must correct with oven adjusted moisture content
- Aggregate size
  - 1-2 mm particle size is widely used. This particle size has been shown to be a good indicator of overall soil structure. These smaller aggregates may not be significantly negatively affected by field management in the short term.
  - 2 mm – 5 mm aggregates are readily affected by field management. These aggregates will break down with physical disturbance. Larger aggregates could be measured if the desire is to compare changes or differences between field management.
  - Both aggregate sizes could be measured using two sieves for a more comprehensive assessment.
- Exercise caution when:
  - Results seem "funny". Spilling soil, a coffee filter that weighs more or less than all the others, or incompletely drying the sample in the microwave will all alter the results.
- Method
  - Collect a soil sample from the field, following the protocols noted above *(Section titled* "When collecting a sample, consider the following").
  - Air dry the sample
  - Determine the average weight of a dry coffee filter on your scale.
  - Gently shake the sample so it passes through a 2 mm sieve stacked on top of a 1 mm sieve. Each sample should be shaken the same number of times and with the same force. Place a collection pan or other vessel below the 1 mm sieve; soil <1 mm is not used, but failure to contain this soil will result in a mess.
  - Weigh 3 g of the 1-2 mm particle size in a tared coffee filter. Set aside.
  - Place a 0.5 mm sieve in a shallow container, such as a dishpan. Fill with water until it covers approximately 1 inch above the sieve mesh (NOT 1 inch above the sieve rim).
  - Gently pour the dry soil into the sieve. Allow to sit, undisturbed, for 12 hours.

- Keep the soil underwater while moving up and down 20 times in 1 minutes.
- Rinse the soil from the sieve into a funnel over a large glass jar.
- Pour the jar with the soil and water into a funnel with a coffee filter placed inside.
- Place the coffee filter in the microwave for approximately 3 minutes to evaporate the moisture or dry in an oven at 170°F.
- Weigh the filter plus soil. Apply the following:
- Rinse the sample in the sieve under a faucet to remove all silt and clay. Transfer remaining material (large organic matter, sand, small rocks) to a coffee filter and dry in the microwave.
- Weigh.
  - Final weight – filter weight – rock/sand/debris weight = water stable aggregates weight
  - Weight of soil added (3 g) – rock/sand/debris weight = true amount of soil added.
  - Water stable aggregates weight/true amount of added soil = percent wet aggregate stability

FILTER WEIGHT (g): __________

WEIGHT OF SOIL ADDED (g) __________

FINAL WEIGHT AFTER WET SIEVE AND DRYING (g): __________

ROCK/SAND/DEBRIS WEIGHT (g): __________

1. FINAL WEIGHT – FILTER WEIGHT – ROCK/SAND/DEBRIS WEIGHT = _____________ g

2. WEIGHT OF SOIL ADDED – ROCK/SAND/DEBRIS WEIGHT = ______________ g

3. (#1 ÷ #2) x 100 = ___________ percent of water stable aggregates

Drop Method (McCalla, 1944)

- When to use:
  - Interest in the effect of rainfall or overhead irrigation.
  - Useful when making comparisons. Not useful as a stand-alone assessment.
  - Might be used in combination with the slake cylinder test or the wet sieve test.
  - Precise measurement using laboratory-adjacent equipment is feasible and desired.
- Soil depth:
  - Soil surface in no till or perennial systems. Top 3 inches in disturbed systems. *Note, the original 1944 method assesses subsoil, but these soil aggregates will not receive the full force of a falling raindrop. If the desire is to collect data on aggregate stability at different depths or to 6 inches deep, this method could still be used. See the caution section below.*
- Soil moisture:
  - Air dry
- Aggregate size
  - 0.15 g aggregate
- Exercise caution when:
  - There is difficulty maintaining a consistent drop size from the pipette.
  - Assessing soils with high levels of soil organic matter. High amounts of soil organic matter can result in the aggregate breaking in half, but not disintegrating. "High" is relative to soil texture.
  - Measuring aggregates deeper in the soil where they will not receive rainfall. This does allow for comparisons using the same method with consistent force, but the deep aggregates will not be subject to the force of falling raindrops so the implication of the results must be carefully interpreted. It is better to use the wet aggregate stability test if deeper aggregates are of interest.
- Method
  - Place an air-dried aggregate weighing 0.15 g on a 1 mm sieve. A piece of malleable mesh or screen material can also be secured over a jar with a rubber band and used in place of a proper sieve.
  - Adjust the burette pipette so that distilled water forms 4 – 5 mm drops that fall at a rate of 1 drop every 5 seconds.
  - Position the burette pipette so that is 30 cm above the aggregate.
  - Allow the water drops to strike the aggregate.
  - Record the number of drops required to break down the aggregate and wash it through the sieve/screen. Record this number.
  - Repeat the test 30 times per sample. Average all results.

# of drops required to breakdown an aggregate.

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References are supplied in text.

This document was originally created to accompany a workshop where participants practiced using these methods. For support using this resource to create a workshop of your own, please reach out to Sam Corcoran, sglazecorcor@umass.edu