NCF-Envirothon 2027 Maryland

Current Issues Part A Study Resources

Key Topic 5: Assessment Tools

Learning Objectives

14. Compare and contrast soil health assessment tools and field methods.
15. Be able to conduct soil health assessments with tools, such as the soil health card, to evaluate soil condition and guide management decisions.
16. Evaluate the effectiveness of demonstration models to educate about soil health indicators.

Resource Title	Sources	Page
How Good Are Your Soils? Field and Laboratory Evaluation…., *Chapter 23*	*Magdoff, F., & Van Es, H. (2021). Building Soils For Better Crops Sustainable Soil Management, 4th edition (Chapter 23).*	150
In- Field Indicators of Healthy Soils	*USDA NRCS. (n.d.). In-Field Indicators of Healthy Soils.*	162
Maryland Soil Health Card	*Maryland Department of Agriculture. (n.d.). MARYLAND SOIL HEALTH CARD.*	164
Full Scale Rainfall Simulator Instructor Guide, *Version 2*	*U.S.D.A. NRCS, Soil Health Division. 2025. Full-Scale Rainfall Simulator Instructor Guide, Version 2. Soil Health Division Technical Note 470-13.*	178
Soil Health Minute: Rainfall Simulator - *VIDEO*	*NDSU Soil Health, YouTube*	203
Soil Health Monitoring: Like Maintaining Your Equipment	*Soil Health Institute. (n.d.). Soil health monitoring: like maintaining your equipment. In Farmers for Soil Health.*	204
What You're Missing if You're Only Testing for Fertility	*Soil Health Institute. (n.d.). What you're missing if you're only testing for fertility. In Farmers for Soil Health.*	206
Put Your Soil to the (Slake) Test! - *VIDEO*	*Soil Health Series, YouTube*	208

Chapter 23

HOW GOOD ARE YOUR SOILS?
FIELD AND LABORATORY EVALUATION OF SOIL HEALTH

... the Garden of Eden, almost literally, lies under our feet almost anywhere on the earth we care to step. We have not begun to tap the actual potentialities of the soil for producing crops.

—E.H. FAULKNER, 1943

An assessment of the current soil health status on your farm is a good way to begin. By now, you should have some ideas about ways to increase soil health on your farm, but how can you identify the specific problems with your soil, and how can you tell if your soil's health is actually getting better? First ask yourself why you would do a soil health assessment. The most obvious reason is that it allows you to identify specific problems, such as P deficiency or surface compaction, and to target your management practices as part of the effort to increase overall soil health. A second reason might be to monitor the health of your soils over time after you have made some management changes. Is your soil improving after you started planting cover crops, began a new rotation or switched to reduced tillage? While the goal of building soil health is to prevent problems from developing, it also helps to correct previous problems you might have had. A good soil health assessment done over a number of years allows you to see whether you are going in the right direction. Another reason might be to better value your soils. If they are in excellent health due to many years of good management, your land should be worth more when sold or rented than fields that have been worn out. After all, a healthy soil produces more and allows for reduced purchased inputs. Being able to effectively appraise soil health may be an additional incentive for farmers to invest in good management and build equity in their land.

We can approach soil health assessment at three levels of detail: 1) general field observations, 2) field assessments using qualitative indicators and 3) quantitative soil health tests. We'll discuss them each in detail.

GENERAL FIELD OBSERVATIONS

A simple but very good place to start assessing a soil's health is to look at its general performance as you go about your normal practices. It's something like wondering about your own performance during the

Photo courtesy Harold van Es

course of a day: do you have less energy than usual? This might be an indication that something isn't quite right. Likewise, there are signs of poor soil health you might notice as part of the normal process of growing crops:

- Are yields declining?
- Do your crops perform less well than those on neighboring farms with similar soils?
- Does your soil delay water from infiltrating during a downpour?
- When you dig up roots, do they look unhealthy or constrained?
- Does the root system lack mycorrhizal fungi that promote healthy crops?
- Do your crops quickly show signs of stress or stunted growth during wet or dry periods?
- Is the soil obviously compacted? If you use tillage, does it plow up cloddy and take a lot of secondary tillage to prepare a fine seedbed?
- Does the soil crust over easily? Do you observe signs of runoff and erosion?
- Does it take more power to run tillage or planting equipment through the soil?

Figure 23.1. A soil penetrometer is a useful tool to assess soil compaction. Measurements are best made when soils are moist and friable (around field capacity).

- Do you notice increased problems with diseases or nutrient stress?

These questions address problems with soil health, and any affirmative answers should prompt you to consider further action.

FIELD INDICATORS

The next approach involves addressing the same kind of questions listed above, but in a more detailed manner. In several states, farmers and researchers have developed "soil health scorecards" that are based on observations made in the field. The NRCS has developed a somewhat different visual evaluation system, the Cropland In-Field Soil Health Assessment Worksheet (Table 23.1 is based on this worksheet). The goal of this type of assessment is to help you understand your soil's health and improve it over time by identifying key limitations or problems.

Whenever you try to become more quantitative, you should be aware that measurements naturally vary within a field or may change over the course of a year. For example, if you decide to evaluate soil hardness with a penetrometer (Figure 23.1) or metal rod, you should perform at least 10 penetrations in different parts of the field and be aware that your results also depend on the soil moisture conditions at the time of measurement. If you do this after a dry spring, you may find the soil quite hard. If you go back the next year following a wet spring, the soil may be much softer. You shouldn't then conclude that your soil's health has dramatically improved, because what you mostly measured was the effect of variable soil moisture on soil strength. Similarly, earthworms will be abundant in the surface 6–9 inch layer when it's moist but tend to go deeper into the soil during dry periods, although you may still observe the wormholes and casts (Figure 23.2). Make sure you select your locations well. Avoid unusual areas (e.g., where machinery turns) and aim to include areas with higher and lower yields.

Figure 23.2. A soil with many wormholes suggests biological activity and improved potential for aeration and water movement.

This type of variability with time of year or climatic conditions should not discourage you from starting to evaluate your soil's health—just keep in mind the limitations of certain measurements. Generally, soil health is best *measured* in the early spring and late fall under moist (but not too wet) soil condition. But soil health problems are better *observed* during wet or dry periods when you might see runoff or crop drought stress symptoms.

Table 23.1 provides guidance on good soil health indicators, sampling times and how to interpret measurements, and in the following paragraphs we further clarify the practical considerations.

Soil color is the result of a combination of the soil's mineralogy, oxidation status and organic matter content. Some soils are naturally more red (highly oxidized iron), brown (less oxidized iron), grey (poor drainage) or whitish (high lime content), but organic matter makes them more dark (see Chapter 2). We therefore associate black soils with high quality, and within the same soil type and texture class you can reasonably conclude that the darker the soil, the better. However, don't expect a dramatic color change when you add organic matter; it may take years to notice a difference.

Crusting, ponding, runoff and erosion can be observed from the soil surface, as we illustrated in Chapter 15. However, their extent depends on whether an intense rainstorm has occurred, or whether a crop canopy or mulch protected the soil. These symptoms are a sign of poor soil health, but the lack of visible signs doesn't necessarily mean that the soil is in good health: it must rain hard for these signs to occur. Try to get out into the field sometime after a heavy rainstorm, especially in the early growing season. Crusting can be recognized by a dense layer at the surface that becomes hard after it dries (Figure 15.1). Ponding can be recognized either directly when the water is still in a field depression, or afterward in small areas where the soil has slaked (that is, aggregates have disintegrated). Areas that were ponded often show cracks after drying. Slaked areas going down the slope are an indication that runoff and early erosion have occurred. When rills and gullies are present, a severe erosion problem is at hand. Another idea: Put on your rain gear and actually go out during a rainstorm (not during lightning, of course), and you may actually see runoff and erosion in action. You might notice that most of the runoff and erosion that occurs comes from a relatively small portion of the field, and this may help in remedying the problem. Compare fields with different crops, management and soil types. This might give you ideas about changes you can make to reduce runoff and erosion.

You also can easily get an idea about ***the stability of soil aggregates***, especially those near the surface (see Figure 15.1). If the soil seals readily, the aggregates are not very stable and break down completely when wet. If the soil doesn't usually form a crust, you might take a sample of aggregates from the top 3–4 inches of soil from fields that seem to have different soil quality (or from a field and an adjacent fencerow area). Gently drop a number of aggregates from each field into

Table 23.1
Cropland Soil Health Assessment Worksheet

Indicator	Soil Health Concern	Best Time and Use	Observation Benchmarks
Soil cover	Organic matter, organism habitat	Anytime	Greater than 75% surface cover from plants, residue or mulch
Residue breakdown	Organic matter, organism habitat	Anytime; mostly no-till; farmer interview	Natural decomposition of crop residues as expected; previous year residues partially decomposed and disappearing
Surface crusts	Aggregation	Before tillage; before or early in the growing season	Crusting in no more than 5% of field
Ponding	Compaction, aggregation	After rain or irrigation (not when frozen); farmer interview	No ponding within 24 hours after major rainfall or irrigation
Penetration resistance	Compaction	With adequate soil moisture; before tillage; before, early in or after the growing season	Penetrometer rating <150 psi in surface layer and <300 psi in subsoil layer, OR slight or no resistance with wire flag inserted
Water stable aggregates	Aggregation, organism habitat	Anytime	Water-submerged in glass jar: at least 80% remains intact after 5 minutes with little cloudy water
Soil structure	Compaction, soil organic matter, aggregation, organism habitat	Anytime	Granular structure in surface horizon and no platy structure in surface or subsoil horizons
Soil color	Organic matter	With adequate soil moisture	No color difference between field and fence row samples, OR value is in darker range using color chart
Plant roots	Compaction, organic matter, organism habitat	During growing season	Roots covered in a soil film or part of soil aggregates, OR living roots are healthy (no black/dry roots or lesions), fully branched and extended into subsoil
Biological diversity	Organic matter, organism habitat	With adequate moisture; before tillage	More than three different types of organisms observed without magnification
Biopores	Organic matter, compaction, aggregation, organism habitat	Before tillage; mostly no-till	Presence of root or earthworm channels that extend vertically through the soil, with some connecting to the surface

Source: Modified from USDA (2021)

separate glass jars that are half filled with water (the aggregates should be completely submerged in water). See whether they hold up or break apart (slake). You can swirl the water in the jars to see if that breaks up the aggregates. If the broken-up aggregates also disperse and stay in suspension, you may have an additional problem with high sodium content (a problem that usually occurs only in arid and semiarid regions).

Soil tilth and hardness can be assessed with an inexpensive penetrometer (the best tool), a tile finder, a spade or a stiff wire (like those that come with wire flags). Tilth characteristics vary greatly during the growing season due to tillage, packing, settling (dependent on rainfall), crop canopy closure and field traffic. It is therefore best to assess soil hardness several times during the growing season. If you do it only once, the best time is when the soil is moist but not too wet (it should be in the friable state). Make sure the penetrometer is pushed slowly into the soil (Figure 23.1). Also, keep in mind that stony soils may give you inaccurate results: the soil may appear hard, but in fact your tool may be hitting a rock fragment.

Soil is generally considered too tough for root growth if penetrometer resistance is greater than 300 psi, but

fully unrestricted rooting in the surface layer generally requires soil resistance less than 150 psi. The soil is often harder in the deeper soil layers, and it is common to measure a dramatic increase in resistance when the bottom of the plow layer is reached, typically 6–8 inches into the soil. This indicates subsoil compaction, or a plow pan, which may limit deep root growth. It's difficult to be quantitative with tile finders and wire, but the soil is generally too hard when you cannot push them in. If you use a spade when the soil is not too wet, evaluate how hard the soil is and also pay attention to the structure of the soil. Is the plow layer fluffy, and does it mostly consist of granules of about a quarter inch in size? Or does the soil dig up in large clumps? A good way to evaluate that is by lifting a spade full of soil and dropping it from about waist height. Does the soil break apart into granules, or does it fall into large clumps? When you dig below the plow layer, take a spade full of soil and pull the soil clumps apart. They should generally come apart easily in well-defined aggregates of several inches in size. If the soil is compacted, it does not easily come apart in distinct units.

Soil organisms can be divided into six groups: bacteria, fungi, protozoa, nematodes, arthropods and earthworms. Most are too small to see with the naked eye, but some larger ones like ants, termites and earthworms are easily recognized. These larger soil organisms are also important "ecosystem engineers" that assist the initial organic matter breakdown that allows other, smaller species to thrive. Their general abundance is strongly affected by temperature and moisture levels in the soil. They are best assessed in mid-spring, after considerable soil warming, and in mid-fall during moist, but not excessively wet, conditions. Just take a full spade of soil from the surface layer and sift through it looking for bugs and worms. If the soil is teeming with life, this suggests that the soil is healthy. If few invertebrates are observed, the soil may be a poor environment for soil life, and organic matter processing is probably low.

Earthworms are often used as an indicator species of soil biological activity (see Table 23.1). The most common worm types, such as the garden worm and red worm, live in the surface layer when soils are warm and moist, and they feed on organic materials in the soil. The long nightcrawlers dig near-vertical holes that extend well into the subsoil, but they feed on residue at the surface. Look for the worms themselves as well as their casts (on the surface, for nightcrawlers), and holes are evidence of their presence (Figure 23.2), which are typically greatly enhanced in no-till systems. If you dig out a square foot of soil and find 10 worms, the soil has a lot of earthworm activity. After soaking rains, many worms will come to the surface as the channels and burrows become saturated.

With a little more effort, nematodes, arthropods and earthworms can be removed from a soil sample and observed. Since these soil organisms like their environment to be cool, dark and moist, they will crawl away when you add heat and light. With a simple desk lamp shining on soil in an inverted cut-off plastic soda bottle with a small piece of screen at the bottom (what

Figure 23.3. A healthy corn root system with many fine laterals (roots shaken to remove aggregates and make them more visible). Compare with Figure 15.3.

was the lower part of the bottle top) to keep the soil from falling through (called a Berlese funnel), you will see the organisms escape down the funnel, where they can be captured on an alcohol-soaked paper towel (the alcohol keeps them from escaping). Descriptions of how to make and use a Berlese funnel are readily available on the internet.

Root development can be evaluated by digging anytime after the crop has entered its rapid growth phase. Have the roots properly branched, and are they extending in all directions to their fullest potential for the particular crop? Do they show many fine laterals and mycorrhizal fungal filaments (Figure 23.3), and will they hold on to the aggregates when you try to shake them off? Look for obvious signs of problems: short stubby roots, abrupt changes in direction when hitting hard layers, signs of rot or other diseases (dark-colored roots, lesions; fewer fine roots). Make sure to dig deep enough to get a full picture of the rooting environment because many times there is a hardpan present.

General crop performance as affected by soil health is most obvious during extreme conditions. During prolonged wet periods, poor soils remain saturated for an extended time, and lack of aeration stunts crop growth. Leaf yellowing indicates loss of available nitrogen by denitrification. This may even happen with high-quality soils if the rainfall is excessive, but it is certainly aggravated by poor soil conditions. Dense, no-till soil may also show greater effects.

Watch also for the onset of drought stress—leaf curling or sagging (depending on the crop type)—and for stunted crop growth during dry periods. Crops on soils that are in good health generally have delayed signs of drought stress. But with poor soils they may show problems when heavy rainfall, causing soil settling after tillage, is followed by a long drying period. Soils may temporarily hardset and stop crop growth altogether under these circumstances.

Nutrient deficiency symptoms can appear on plant leaves when soils are low in a particular nutrient

Table 23.2
Examples of Nutrient Deficiency Symptoms

Nutrient	Deficiency Symptoms
Calcium (Ca)	New leaves (at top of plant) are distorted or irregularly shaped. Causes blossom-end rot.
Nitrogen (N)	General yellowing of older leaves (at bottom of plant). The rest of the plant is often light green.
Magnesium (Mg)	Older leaves turn yellow at edge, leaving a green arrowhead shape in the center of the leaf.
Phosphorus (P)	Leaf tips look burnt, followed by older leaves turning a dark green or reddish purple.
Potassium (K)	Older leaves may wilt and look scorched. Loss of chlorophyll between veins begins at the base, scorching inward from leaf margins.
Sulfur (S)	Younger leaves turn yellow first, sometimes followed by older leaves.
Boron (B)	Terminal buds die; plant is stunted.
Copper (Cu)	Leaves are dark green; plant is stunted.
Iron (Fe)	Yellowing occurs between the veins of young leaves. Area between veins may also appear white.
Manganese (Mn)	Yellowing occurs between the veins of young leaves. These areas sometimes appear "puffy." Pattern is not as distinct as with iron deficiency. Reduction in size of plant parts (leaves, shoots, fruit) generally. Dead spots or patches.
Molybdenum (Mo)	General yellowing of older leaves (at bottom of plant). The rest of the plant is often light green.
Zinc (Zn)	Terminal leaves may be rosetted, and yellowing occurs between the veins of the new leaves. Area between veins on corn leaves may appear white.

Source: Modified from Hosier and Bradley (1999)

(Table 23.2). (Note that crop nutrient deficiencies can sometimes result from compaction and poor aeration, even though enough nutrients are present in the soil). Many nutrient deficiency symptoms look similar, and they may also vary from crop to crop. In addition, typical symptoms may not occur if the plant is suffering from other stresses, including more than one nutrient deficiency. However, some symptoms on some crops are easy to pick out. For example, N-deficient plants are frequently a lighter shade of green than plants with sufficient N. Nitrogen deficiency on corn and other grasses appears on the lower leaves first as a yellowing around the central rib of the leaf. Later, the entire leaf yellows, and leaves farther up the stem may become yellow. However, yellowing of the lower leaves near maturity is common with some plants. If the lower leaves of your corn plant are all nice and green at the end of the season, there was more N than the plant needed. Potassium deficiencies on corn also show as yellowing on lower leaves, but in this case around the edges. Phosphorus deficiency is normally noted in young plants as stunted growth and reddish coloration. In corn, this may appear early in the season due to wet and cold weather. When the soil warms up, there may be plenty of phosphorus for the plants. For pictures of nutrient deficiencies on field crops, see Iowa State University's publication *Nutrient Deficiencies and Application Injuries in Field Crops* (IPM 42).

Field images from satellites, aircraft or drones help you see crop performance anomalies and whether certain areas in a field have soil health problems. On a conventional color image, compacted or poorly drained areas show less crop biomass during the early season, i.e., more soil and less crop reflectance in the image. In wet years, areas with poor drainage may exhibit nitrogen deficiencies and appear more yellowish. Vegetation indexes (like NDVI, normalized difference vegetation index) can also help gain insights by showing vegetation density (Figure 23.4). It may not give you a direct cause for the apparent problem, but it will at the least allow you to identify the location and check it out at ground level.

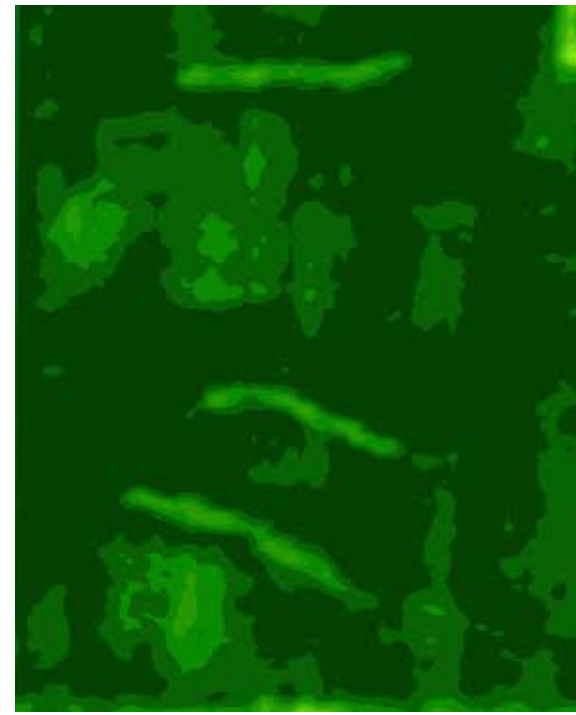


Figure 23.4. A normalized difference vegetation index (NDVI) map of a field shows areas of lower and higher vegetation density (darker areas have more vegetation), and can guide soil health examinations. Source: Yara International.

You can evaluate your soil's health using the simple tools and observations suggested above. Scorecards or assessment worksheets provide a place to record field notes and assessment information to allow you to compare changes over the years.

LABORATORY SOIL HEALTH TESTING

Comprehensive Soil Tests

Growers are used to taking soil samples and having them analyzed for available nutrients, pH and total organic matter by a university, government or commercial lab. In arid regions it is common to also determine whether the soil is saline (too much salt) or sodic (too

Table 23.3
USDA-NRCS-Evaluated Laboratory Soil Health Indicators and Methodologies, and Associated Soil Processes They Measure

Soil Process	Soil Health Indicator	Method[1]
Organic matter cycling and C sequestration	Soil organic matter content	Dry combustion Wet oxidation Loss on ignition
Structural stability	Aggregation	ARS wet aggregate stability NRCS wet aggregation Cornell sprinkle
General microbial activity	Short-term C mineralization	CO_2 respired—4 day CO_2 respired—24 hours
General microbial activity	Enzyme activity	BG NAG Phosphomonoesterases Arylsulfatase
C food source	Readily available pool	POXC POM 28-day mineralization WEOC Soluble carbohydrates Substrate-induced respiration Microbial biomass C
Biological available N	Available organic N pool	ACE protein WEON Correlation with short-term mineralization 7-day anaerobic PMN 28-day PMN Illinois soil N test NAG Protease
Microbial diversity	Community structure	PLFA EL-FAME

[1]Acronyms are: BG = β-Glucosidase; NAG = N-acetyl-β-D-glucosaminidase; POXC = Permanganate oxidizable C; POM = Particulate organic matter; WEOC = Cold/hot water-extractable organic C; ACE = Autoclaved citrate extractable (protein); WEON = Cold water-extractable organic C; PMN = Potentially mineralizable N; PLFA = Phospholipid fatty acid; EL-FAME = Ester-linked fatty acid methyl ester profile.
Source: USDA (2019)

much sodium). This provides information on the soil's chemical health and potential imbalances. As we discussed in Chapter 21, you get the most benefit from soil tests with regularly scheduled analyses (at least every two years) and good records. If your soil test report includes information on cation exchange capacity (CEC), you should expect it to increase with higher organic matter levels, especially in coarse-textured soils. And, as discussed in Chapter 20, soil CEC increases after liming a soil, even if there is no increase in organic matter.

The traditional soil test does not, however, make a comprehensive assessment of soil health, which probably led to the "chemical bias" in soil management. In other words, the widespread availability of good chemical soil tests, although a very useful management tool, may also have encouraged the quick-fix use of chemical fertilizers over the longer-term holistic approach promoted in this book. Several soil health tests have been developed to provide a more comprehensive soil assessment through the inclusion of soil biological

and physical indicators in addition to chemical ones. Indicators were selected based on the soil processes that they represent, and thereby the tests provide insights into a soil's ability to provide ecosystem services (like growing healthy crops). They also consider cost, consistency and reproducibility of the methodologies, as well as relevance to soil management.

In this context, the USDA evaluated a set of indicators and methodologies in an attempt to encourage standardization in soil health testing (Table 23.3). The proposed methods have all proven to provide useful insights into aspects of soil health. Currently (in the year 2020) there is no single standard soil health test, but there is universal agreement that a comprehensive soil health test should include indicators that represent all three types of soil processes: biological, physical and chemical (Figure 23.5). Also, measured values need to be interpreted based on inherent variation in soils as a result of different climates, soil textures, etc.

Some soil health indicators have become more widely adopted. For *physical* indicators, ***aggregate stability*** (Figure 23.6) relates to infiltration, crusting and shallow rooting, and represents the "tilth" of the soil. It generally shows a fast response after the introduction of new management practices like reduced tillage, cover cropping or manure or compost additions. ***Available water capacity*** relates to plant-available water and is relevant to drought resistance. It is more sensitive to inherent soil texture differences than to changes in management.

For *biological* indicators, the most common indicator is total ***soil organic matter*** (SOM) content, which affects almost all important soil processes, including water and nutrient retention, and biological activities. It is often the single most important measurement of soil health, but unfortunately it is not very sensitive to management. It takes many years to measure a real change in SOM, and farmers would generally want to know earlier about the benefits of a management change. ***Active carbon*** is an inexpensive test that relates to a small fraction of the organic material that is more actively engaged with biological functions, and it has shown to be very sensitive to changes in soil management. It is therefore a good early indicator of soil health improvements. Active C is assessed as the portion of soil organic matter that is oxidized by potassium permanganate, and the results can be measured with an inexpensive spectrophotometer (Figure 23.7). Similarly, soil ***protein content*** is an indicator of the soil organic nitrogen potentially available to microorganisms, and it also shows strong response to management changes, especially when more legumes are introduced. ***Respiration*** (CO_2 released by soil organisms) is widely measured as an indicator that integrates both abundance and metabolic activity of soil microbes; it is also correlated with nitrogen mineralization potential. ***Ammonia losses*** from amino sugars in the soil is a related measurement.

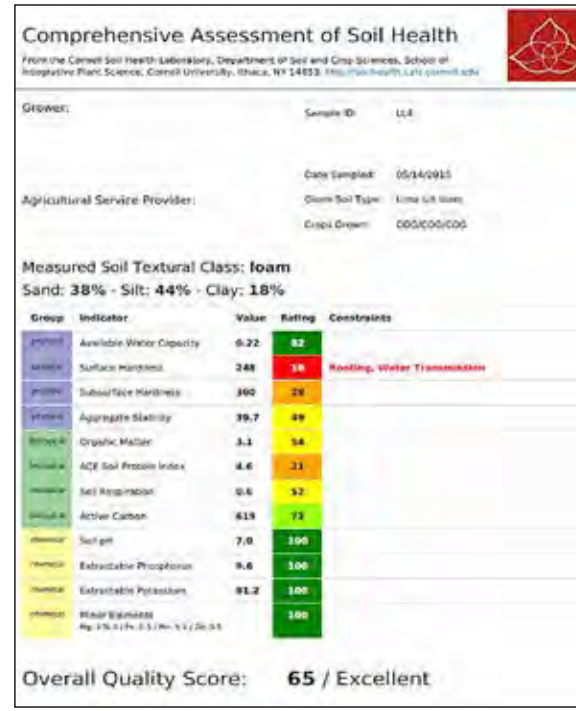


Figure 23.5. Example of a soil health test report.

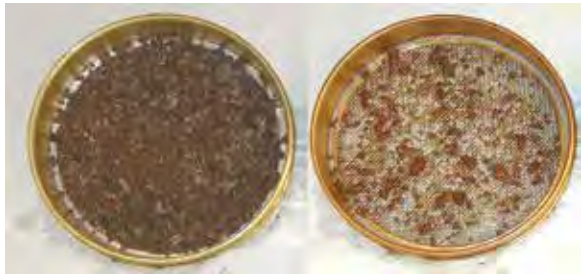


Figure 23.6. Results of an aggregate stability test for silt loam vegetable soils: organic (70% stable, left) and conventional (20% stable, right) management.

There are a number of other biological indicators. The bean root rot bioassay provides an effective and inexpensive assessment of root health and overall disease pressure from various sources (plant-parasitic nematodes; the fungi *Fusarium*, *Pythium*, *Rhizoctonia*; Figure 23.8).

Chemical soil health indicators are discussed in Chapter 21 on conventional soil testing and include macro and micronutrients, and soil reaction (pH). Undesirable elements like salts and sodium should be evaluated in arid regions and covered areas, such as inside greenhouses and high tunnels. In urban or industrial environments, toxic elements like heavy metals, salts, radioactive materials, solvents and petroleum products should be considered when assessing soil health, as discussed in Chapter 22.

Interpreting test results is the next step towards identifying specific soil constraints (see Figure 23.5). This particular report (based on the Cornell CASH test) is for a soil that had been under grain production for many years. For each indicator, the report provides a measured value and the associated score (1–100), which is an interpretation of the measured result. If scores are low (less than 20), specific constraints are listed. An overall soil health score, also standardized to a scale of 1–100, is provided at the bottom of the report, which is especially useful for tracking soil health changes over time. The test report in Figure 23.6 is somewhat typical for grain production fields in the northeastern United States. It shows the soil in good shape regarding the chemical indicators but severely underperforming with respect to the physical and biological indicators. Why is that the case? In this situation, the farmer was diligent about using the conventional soil test and keeping nutrients and pH at optimal levels. But intensive cropping caused an unbalanced soil health profile for this field. The test identified these constraints and allows for more targeted management, which we'll discuss in the next chapter.

You might wonder how measured soil health test values are interpreted through scores. In traditional chemical soil tests, the measured values are related to potential crop response (likely yield increase or decline depending on whether it is a nutrient or a toxic element). For biological and physical indicators, scientists have developed normative scoring functions where test results are compared to a larger population of analyzed soil samples in similar soils and cropping systems (similar to how we interpret cholesterol and potassium levels in human blood samples). This approach allows a sample to be scored and interpreted without knowing the precise impact of high or low values. This normative scoring is typically done by calculating mean and

Figure 23.7. Assessment of active carbon using permanganate oxidation and a portable spectrophotometer. Photo by David Wolfe.

standard deviation values for a population group (say, medium-textured soils in grain crop systems in the mid-western United States) and using the cumulative normal distribution function as a fuzzy scoring curve.

Microbial Soil Tests

Soils can also be tested for specific biological characteristics—for potentially harmful organisms relative to beneficial organisms (for example, nematodes that feed on plants versus those that feed on dead soil organic matter) or, more broadly, for macro- and microbiology. Two common tests—the phospholipid fatty acid (***PLFA***) and fatty acid methyl ester (***EL-FAME***) assays—have shown sensitivity to management changes and are offered by some commercial soil testing labs. They produce an estimate of the soil's living biomass. Also, the biomarkers, or signature fatty acids, identify the presence or absence of various groups of interest such as different bacteria, actinomycetes, arbuscular mycorrhizal fungi, rhizobia and protozoa. The relative amounts or activities of each type of microorganism provide insights into the characteristics of the soil ecosystem. Bacterial-dominated soil microbial communities are generally associated with highly disturbed systems with external nutrient additions (organic or inorganic), fast nutrient cycling and annual plants. Fungal-dominated soils are more common with low amounts of disturbance and are characterized by internal, slower nutrient cycling, and high and stable organic matter levels. Thus, the systems with more weight of bacteria than fungi are associated with intensive agricultural production (especially soils that are frequently plowed), while systems with a greater weight of fungi than bacteria are typical of natural and less disturbed systems. The significance of these differences for the purposes of modifying practices is somewhat unclear, but modifying practices causes biological changes to occur. For example, adding organic matter, reducing tillage and growing perennial crops all lead to a greater ratio of fungi to bacteria. Since networks of mycorrhizal fungal filaments help plants absorb water and nutrients, their presence suggests more efficient nutrient and water use. But we generally want to do these practices for many other reasons—improving soil water infiltration and storage, increasing CEC, using less energy, etc.—that may or may not be related to the ratio of bacteria to fungi.

The study of genetic material recovered directly from soil has advanced in recent years. Routinely characterizing the genetic profile of a soil's organic matter to obtain a picture of the organisms present is thus becoming commercially feasible. It is challenging to extract specific genetic material from soils due to the high complexity of soil organic matter, and DNA profiling is mostly used for descriptive purposes (for example, how prevalent different types

Figure 23.8. Examples of root rot bioassays on bean plants: conventional (left) and organic (right) soil management. Photos by George Abawi.

of *pseudomonas* bacteria are). Some tests are showing promise with identifying specific pathogens that may help farmers better manage their fields.

Sensing methods are increasingly considered for soil health assessment. Visible near-infrared and mid-infrared reflectance spectroscopy methods are non-destructive approaches that measure the optical reflectance properties of soil, which is influenced by chemical bonds like O-H (abundant in clay minerals), C-H (abundant in organic matter), etc. They therefore can assess certain soil properties rapidly and at low cost. Such methods appear to be especially efficient when combined with a subset of laboratory-measured properties that can be compared with the spectroscopy results through advanced statistical and machine learning techniques.

SUMMARY

There are many things to be learned by regularly observing soils and plants in your fields. These include being able to evaluate such important aspects as the severity of runoff, erosion and compaction; root development and health; severe nutrient deficiencies; and the presence of earthworms and other easily visible organisms, among other things. Laboratory evaluations of physical and biological indicators as well as comprehensive interpretation frameworks can also be employed. It is, of course, not enough to know whether a particular limitation exists. In the following (and last) chapter we will discuss both how to put together soil and crop management systems for building healthy soils, and how to address particular issues that may arise from field observations or laboratory analyses.

SOURCES

Andrews, S.S., D.L. Karlen and C.A. Cambardella. 2004. The soil management assessment framework: A quantitative soil quality evaluation method. *Soil Science Society of America Journal* 68: 1945–1962.

Fine, A.K., H.M. van Es and R.R. Schindelbeck. 2017. Statistics, Scoring Functions, and Regional Analysis of a Comprehensive Soil Health Database. *Soil Science Society of America Journal* 81: 589–601.

Moebius-Clune, B.N., Moebius-Clune, D.J., Gugino, B.K., Idowu, O.J., Schindelbeck, R.R., Ristow, A.J., van Es, H.M., Thies, J.E., Shayler, H.A., McBride, M.B., Wolfe, D.W., Abawi, G.S., 2016. The Comprehensive Assessment of Soil Health. The Cornell framework. soilhealth.cals.cornell.edu.

Norris, C.E., G.M. Bean, et al. 2020. *Introducing the North American project to evaluate soil health measurements*. Agronomy Journal. doi: 10.1002/agj2.20234.

Sawyer, J., 2010. Nutrient Deficiencies and Application Injuries in Field Crops. Bulletin IPM 42. Iowa State University.

Soil Foodweb, Inc. 2008. www.soilfoodweb.com/.

U.S. Department of Agriculture. 2021. Cropland in-field soil health assessment worksheet. *Technical Note No. 450-06*.

U.S. Department of Agriculture. 2019. Recommended Soil Health Indicators and Associated Laboratory Procedures. *Technical Note No. 450-03*.

van der Heijden, M.G.A., R.D. Bardgett and N.M. van Straalen. 2008. The unseen majority: Soil microbes as drivers of plant diversity and productivity in terrestrial ecosystems. *Ecology Letters* 11: 296–310.

Weil, R.R., K.R. Islam, M.A. Stine, J.B. Gruver and S.E. Samson-Liebig. 2003. Estimating active carbon for soil quality assessment: A simplified method for lab and field use. *American Journal of Alternative Agriculture* 18: 3–17.

IN-FIELD INDICATORS OF HEALTHY SOILS

These soil health assessments can be done in the field using simple tools and your senses.

INDICATOR	CRITERIA

AGGREGATE STABILITY

Promotes water infiltration and storage and creates habitat for soil organisms important in nutrient cycling. Water-stable soil aggregates decrease erosion, surface ponding, and runoff.

Aggregates should:

- Remain intact when submerged in water
- Hold together when wet soils are handled after a rain
- Resist "slaking" or separation of the soil particles

SHI's free smartphone app, Slakes, offers an easy way to measure aggregate stability. Learn more and download Slakes by scanning the QR code with your phone's camera.

RESIDUE BREAKDOWN

Indicates how biologically active soils are.

Residue should:

- Display various stages of decay
- Have minimal residue from older crops
- Cover >70% of the field

Evaluate before full-width tillage. Residue cover can be estimated as shown in this USDA NRCS guide:

WATER INFILTRATION

Ponding indicates poor aggregate stability, surface crusting, degraded soil structure, and/or compaction.

Healthy soils should have:

- No ponding 24 hours after a rain
- No evidence of surface crusting
- No runoff channels
- No soil movement

Comparing your fields to a fence row or other undisturbed areas after rainfall will show how management affects infiltration.

While these indicators can help you assess soil health in the field, the Soil Health Institute has also identified several useful lab measurements. Learn more at **soilhealthinstitute.org/our-work/initiatives/measurements**

SOIL HEALTH INSTITUTE

Enriching Soil, Enhancing Life

INDICATOR	CRITERIA

SURFACE CRUST

Unstable soil aggregates fall apart when bombarded by rain drops, resulting in a surface crust that can inhibit seedling emergence, reduce infiltration, and increase runoff.

Healthy soils have aggregates that:

- Keep the soil surface from drying out
- Provide a mellow seedbed that ensures good seed to soil contact

Crusting generally shows up after intense rainfall or irrigation on tilled fields with no residue cover. Healthy soils have a surface layer that isn't dense or dried out with cracks.

COMPACTION

Caused by tillage, heavy equipment, or hooves, compacted layers decrease rooting depth and plant growth and create an unfavorable environment for soil organisms, contributing to reduced nutrient and water cycling and poor soil structure.

Healthy soil profiles have:

- Granular or aggregated structure
- Roots that grow straight, with no signs of being restricted
- Water that infiltrates quickly after rainfall or irrigation

Compaction can be evaluated nearly any time of the year using a shovel, knife, or metal rod to identify dense layers in the soil profile. Root structure can be used to assess compaction, provided roots have been growing for a sufficient time.

SOIL COLOR

In general, darker soils contain more organic matter, which is important for all soil functions.

Healthy soils:

- Generally are darker on the surface and transition to a lighter color deeper in the soil profile
- Have topsoil that is easy to distinguish from subsoil

Evaluate by comparing samples from the field with undisturbed areas outside the field boundary.

SOIL BIOLOGY

Soil organisms are instrumental in nutrient and water cycling, pest suppression, and building soil aggregates.

Healthy soils will contain:

- Millipedes, centipedes, pill bugs, and springtails
- Earthworms, channels, and huts
- Fungal hyphae (cobwebs) on residue and/or soil aggregates

Evaluate when soil temperatures and moisture are most suitable, generally in the spring or fall. Larger organisms tend to be found in the top 2" to 4" of the soil.

This card was created by referencing the USDA NRCS Soil Health Technical Note No. 450-06 Cropland In-Field Soil Health Assessment Guide.

SOIL HEALTH INSTITUTE
Enriching Soil, Enhancing Life

United States Department of Agriculture

NRCS Natural Resources Conservation Service

MARYLAND SOIL HEALTH CARD

What is Soil Health?

Soil Health is the continued capacity of a soil to function as a vital living ecosystem that sustains plants, animals, and humans. Healthy soils support plants, animals, and humans by:

- Cycling nutrients and increasing their availability
- Increasing water infiltration and availability
- Maintaining a stable porous structure that withstands natural forces (e.g., water, wind)

Healthy, fully functioning soil creates a habitat that sustains diverse soil micro- and macro-organisms.

Why is Soil Health Important?

Soils that lack organic matter, structure, and microorganisms are susceptible to erosion, hold less water, and need more chemical inputs to rebalance their productivity. Improving soil health increases soil aggregates and improves soil structure, resulting in greater water infiltration, decreased erosion, and reduced runoff and sedimentation.

Soil Health Principles to Support High Functioning Soils:

- Minimize soil disturbance
- Maximize soil cover
- Maximize the presence of living roots
- Maximize biodiversity

What is the Soil Health Card?

The Maryland Soil Health Card is a semi-quantitative tool to assist conservation planners and land managers evaluate soil health. Soil Health is evaluated as a function of select physical and biological indicators that can be assessed with minimal equipment and expertise. It can be used to identify soil health resource concerns, make suggestions on how to improve soil health, and monitor the effects of soil management practices.

The Soil Health Card is set up to evaluate a soil's ability to function within its natural capabilities and site limitations. For that reason it should not be used to compare one soil type to another. Instead, it can be used to compare soil management practices or land uses on the same soil type. Before using the Soil Health Card, review the Web Soil Survey to better understand the soils mapped in your area of interest.

Soil chemical properties (e.g., nutrients, pH, EC) can be important indicators of soil health, but are not included in this field assessment. Chemical properties are better assessed through laboratory analysis. There are also additional biological and physical properties that are better measured through laboratory analysis that can be indicative of soil health. Since the Soil Health Card is intended to be entirely field based, those potential indicators are beyond the scope of this assessment.

Using the Soil Health Card

Step 1 Instructions for evaluating each indicator are at the end of this document. Before starting your evaluation, find out the soil series and map unit at the sample location.

Step 2 Use the table on page 3 to identify the best times to assess each soil health indicator

Step 3 Divide the farm and fields into separate sections for evaluation the same way you would divide them for soil fertility sampling: separate by factors such as soil type, topography, and management history (e.g., tillage, crop rotation, irrigation, and manure/fertilizer application).
If soil health is an objective of a conservation plan, an in-field assessment (such as the Maryland Soil Health Card) is recommended in each soil mapping unit that represents at least 20% or 20 acres, of the soils within a conservation management unit (CMU). A CMU is a group of fields of the same land use within an operation that are managed similarly (e.g., same tillage methods, crop rotation, pesticide use).

Step 4 Select a representative spot in your field and evaluate each soil health indicator. Use the Descriptive Ratings and your observations to assign scoring points and a resulting rating (Excellent, Good, Fair, Poor).

Step 5 If you identify soil health indicators that are Fair or Poor, prescribe management strategies and conservation practices (see below) to improve soil health over time.

Step 6 Follow changes in each of the soil health indicators over time, examine current field management practices, and consider ideas for management changes in problem areas.

Using Soil Health Management Strategies and Associated NRCS Conservation Practice Standards to Improve Observed Fair and Poor Soil Health Indicators

Surface Cover, Organic Matter, Earthworm/Macroinvertebrates, and Soil Odor Indicators
Consider management strategies such as:

- Using diverse high-residue crops – see Conservation Crop Rotation (328)
- Using cover crops and cover crop mixes with grasses and legumes – see Cover Crop (340)
- Establishing perennial vegetative cover – see Conservation Cover (327) and Pasture & Hay Planting (512)
- Using no-till or reduced tillage – see Residue and Tillage Management (329 and 345)
- Manage grazing and/or browsing to maintain healthy forage stands – see Prescribed Grazing (528)
- Reducing pesticide risk to beneficial soil organisms – see Pest Management Conservation System (595)
- Applying solid manure or compost at a proper agronomic rate – see Nutrient Management (590)
- Applying plant residues or other suitable materials – see Mulching (484)

These strategies will increase organic matter, soil biological activity, water holding capacity, and nutrient availability.

Infiltration, Compaction, and Soil Structure/Aggregation Indicators
Consider management strategies such as:

- Using diverse high-residue crops – see Conservation Crop Rotation (328)
- Using cover crops, cover crop mixes, and deep-rooted cover crops – see Cover Crop (340)
- Establishing perennial vegetative cover – see Conservation Cover (327) and Pasture & Hay Planting (512)

- Managing grazing and/or browsing to maintain adequate vegetative cover – see Prescribed Grazing (528)
- Managing equipment traffic, especially on wet soils
- Using no-till or reduced tillage – see Residue and Tillage Management (329 and 345)

These strategies will improve soil structure and aggregation by increasing organic matter content and porosity and will improve infiltration while minimizing compaction.

Best Times to Assess Indicators

Some indicators vary seasonally or as a result of the growth stage of the crop (e.g., surface cover). If you are monitoring soil health conditions over time, plan to make repeat measurements at a similar time of year to limit seasonal variability. For example, assessments could be done immediately after harvesting in the fall or prior to planting in the spring.

Indicator	Recommended Timing for Assessment				
	Early Spring, Before Planting	Spring	Summer	Fall	After Rainfall
Surface Cover	X	X	X	X	X
Infiltration	X	X	X	X	
Compaction	X	X		X	
Organic Matter	X	X	X	X	X
Soil Structure	X	X	X	X	X
Earthworms/ Macroinvertebrates	X	X		X	X
Soil Odor	X	X	X	X	X

United States Department of Agriculture

NRCS Natural Resources Conservation Service

Soil Health Card Instructions

Equipment needed: measuring tape, small spray bottle of water, paper towels, 1 quart water, small trowel or soil knife, stopwatch, sharp shooter shovel, wire flag, Munsell Color Chart, Soil Health Card, and Attached References

Soil Texture:

- Take sample from 2-4 inches below the surface.
- Use the Guide for Estimating Soil Texture by Feel to determine the soil texture class (Attachment A).
- Soil texture class is used when evaluating Infiltration.

Surface Cover:

- Estimate the proportion of the soil surface that is covered by living and dead plant material and residue and assign a score and rating.
- Estimates can be made visually using the NRCS surface cover photos (Attachment B) or a measuring tape.

Infiltration:

- Dig a small, 2 inch deep hole with a flat bottom with straight sides. Avoid smearing the sides and bottom of the hole. Lightly scratch the bottom and sides of the hole with the wire flag to break up smearing.
- Pour 1 inch of water into the hole and start the stopwatch. Time how long it takes for the water to completely infiltrate. Water has completely infiltrated when there is no water left in the bottom of the hole and surface is just glistening.
- Repeat two to three times in different locations to get an average time.
- Compare the infiltration time to the rates listed in the Infiltration Chart (Attachment C) using the soil texture determined.
    - The indicator rating is based on how quickly water infiltrates relative to the expected rate for its textural class. Assign a score based on the infiltration time relative to the range (e.g., a faster time within the class range should receive a higher score).

Compaction:

- Hold wire flag about 12-15” from its lower end.
- Push lower end into soil surface, wiggling if needed. The wire shouldn’t bend.
- Observe how deep the wire flag penetrates the soil. Assess in several locations and compare to the narrative descriptions to assign a rating and score.
- Rock fragments can interfere with using the wire flag to test compaction. In these situations, dig a small hole and look at the root growth on the exposed side walls of the hole and in the shovel slice. Note the depth of root growth and directions of root growth. Lateral root growth or preferential root growth in one direction can be indicative of compaction and root restrictions.

Organic Matter:

- Take soil samples from the indicated depths (0-3" and 3-8").
    - Soil health practices like cover cropping and no-till increase organic matter in the soil. Without regular disturbance from tillage, organic matter may accumulate more quickly in the upper part of the topsoil. Comparing the soil color in the upper and lower part of the topsoil can be a way to demonstrate increased organic matter storage resulting from long-term soil health practices.
- For each sample, break open a soil aggregate to reveal a fresh soil face. Moisten the soil with the spray bottle if it is dry. Do not use a smeared or crushed aggregate for evaluating soil color.
- Use the Munsell Soil Color Book (or the Globe Soil Color Book) to find the closest matching color for each of the samples. Assign the score and rating based on the soil color value and chroma.

Soil Structure/Aggregation (can be done along with the Earthworms/Macroinvertebrates indicator):

- Use the sharp shooter to remove an 8-10 inch slice of soil.
- Use the NRCS structure photos (Attachment D) to describe the soil structure in two zones, 0-3" and 3-8". Compare to the narrative descriptions to assign a score and rating for each depth zone.
    - Fields that have not been tilled for many years may have a different structure in the upper and lower parts of the topsoil. Without regular disturbance from tillage, the soil aggregates can start to form as they would in a natural, undisturbed setting. Comparing the structure in the upper and lower topsoil can be a way to identify or demonstrate this gradual recovery in the soil.

Earthworms and Macroinvertebrates (can be done along with the Soil Structure/Aggregation indicator):

- Use the sharp shooter to remove an 8-10 inch slice of soil.
- Gently separate the soil looking for earthworms and other macroinvertebrates.
- Count the number and general types of macroinvertebrates present. Look for evidence of biological activity (channels, casts, middens, etc). Compare to the narrative descriptions to assign a score and rating.
    - At certain times of year (e.g., winter, periods of drought), earthworms and macroinvertebrates may not be found in the upper part of the soil. Under these conditions it is especially important to look for evidence of earthworm and macroinvertebrate activity when assigning a score and rating.

Soil Odor:

- Take a handful of soil from just below the surface (0-3"), cup it in your hands and smell.
- Compare the smell to the narrative descriptions to assign a score and rating.
    - Healthy soils should have a sweet, earthy aroma. If the soil smells sour, metallic, stagnant, or like kitchen cleanser, this may indicate that the soil is not properly functioning.

Clear Form

MARYLAND SOIL HEALTH CARD

Project Name:	Location:	Assisted By:
Coordinates:		Date:
Crop Rotation and Tillage System:	Current Crop:	Air Temperature/Weather:
Inputs: □ Synthetic Fertilizers □ Manure □ Herbicides □ Pesticides □ Irrigation □ Other:		
Map Unit Symbol:	Soil Series:	Surface Texture:

Indicators		Descriptive Ratings and Potential Scoring Points				Score	Notes
		Excellent 9-11 points	**Good 6-8 points**	**Fair 3-5 points**	**Poor 0-2 points**		
Surface Cover – living and dead matter visible on surface		>80%	60-80%	30-60%	<30%		
Infiltration – Based on surface texture, refer to Infiltration Chart		Soil absorbs water quickly and easily	Soil absorbs water in a timely manner and is not susceptible to runoff or ponding	Infiltration rate is within expected range for textural class. Soil absorbs water, but more slowly and runoff or ponding may occur	Soil absorbs water very slowly and runoff or ponding will occur		
Compaction/Root Growth (Based on moist topsoil conditions)		Wire flag easily penetrates soil to 8" with no resistance. Unrestricted root growth.	Wire flag penetrates soil to 6-8" with a little resistance. Requires a little wiggling of wire flag. Little root growth restriction.	Wire flag penetrates soil to 4-6", requires a lot of wiggling of the wire flag and moderate force. Root growth is restricted.	Wire flag penetrates soil 2-4", requires force. Roots may be growing laterally.		
Organic Matter – Compare to soil color book using hues 7.5YR, 10YR, or 2.5Y	0-3" depth	Soil is black, organic matter is visible. Value ≤2 and Chroma ≤2	Soil is dark brown, organic matter is visible. Value =3 and Chroma =3	Soil is somewhat dark in color, little organic matter is visible. Any value or chroma that doesn't meet good or poor criteria.	Soil is light brown to dull colored, no organic matter visible. Value >4 and Chroma >4		
	3-8" depth	(see criteria above)	(see criteria above)	(see criteria above)	(see criteria above)		

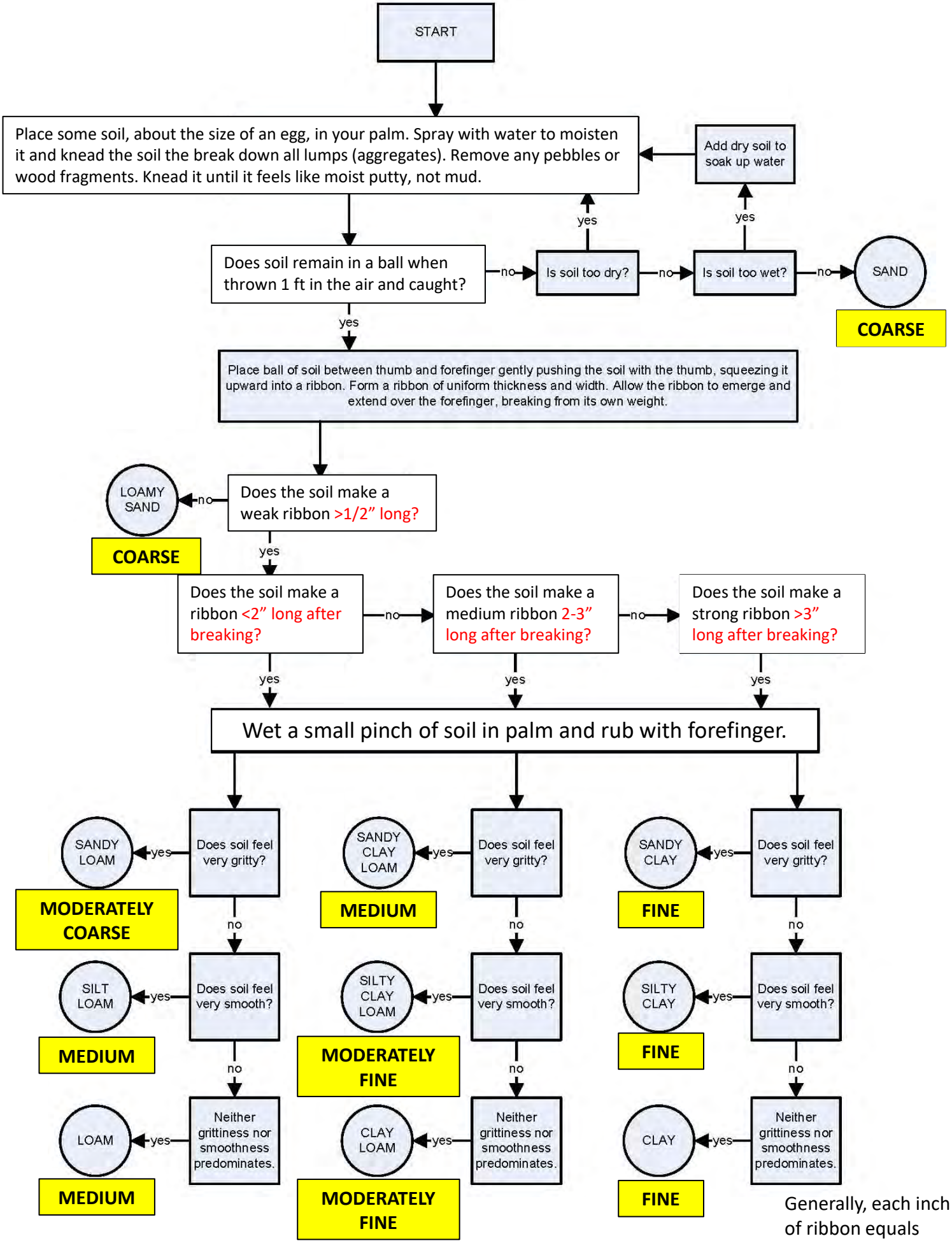
Indicators		Descriptive Ratings and Potential Scoring Points				Score	Notes
		Excellent 9-11 points	**Good 6-8 points**	**Fair 3-5 points**	**Poor 0-2 points**		
Soil Structure/ Aggregation	0-3" depth	Soil is granular, soft, and crumbly, like cottage cheese. Roots are covered in a soil film (rhizosheath) and soil is held together with many fine roots. Living roots are healthy, fully branched, and extend into the subsoil.	Soil is granular, but not soft and crumbly. Soil aggregates are held together with some fine roots.	Soil is blocky and firmer with few fine roots.	Soil is platy, single grain, or massive and hard to break apart. Few or no fine roots.		
	3-8" depth	(see criteria above)	(see criteria above)	(see criteria above)	(see criteria above)		
Earthworms and Macroinvertebrates		≥7 earthworms and macroinvertebrates per shovel slice, more than three different types of organisms observed without magnification, or many obvious middens, casts, and channels.	4-6 earthworms and macroinvertebrates per shovel slice, or obvious middens, casts, and pores. Root and earthworm channels extend vertically through the soil with some connecting to the surface.	1-3 earthworms and macroinvertebrates per shovel slice, or few middens, casts, and channels.	No earthworms or macroinvertebrates present in shovel slice. No middens, casts, or channels.		
Soil Odor		Earthy/sweet odor noticeable > 6 inches from nose.	Earthy/sweet odor noticeable when close to nose.	Little odor at all.	No odor at all, or sour, metallic, kitchen sink, rotten egg or stagnant smell.		
					Total Score =	0	Excellent: 75-99 Good: 50-74 Fair: 25-49 Poor: 0-24

Assessment Indicator	
Surface Cover	0
Infiltration	0
Residue Breakdown	1
Water Stable Aggregates	0
Soil Structure	0
Soil Color	0
Plant Roots	0
Biodiversity	0
Biopores	0
Surface Crusting	1
Earthworm Channels	0

CART ASSESSMENT

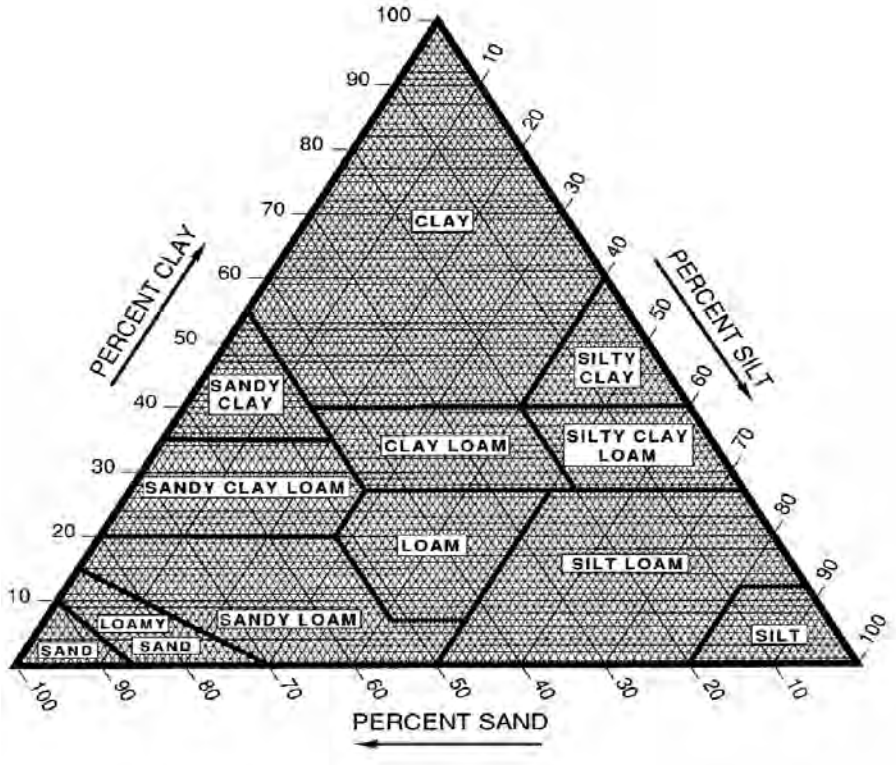
Resource Concern	# Criteria Met	Interpretation
Compaction	0	Compaction is significant
Soil Organic Matter Depletion	1	None - Extensively depleted soil organic matter
Soil Organism Habitat Loss	1	None - Extensively depleted soil organism habitat
Aggregate Instability	1	None - Soil surface aggregation non-existent

GUIDE FOR ESTIMATING SOIL TEXTURE BY FEEL



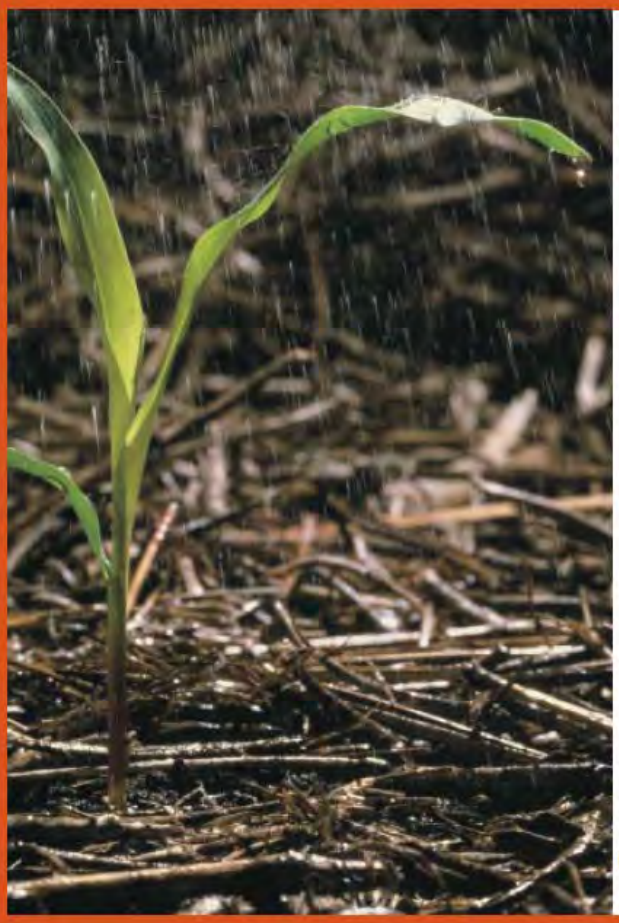
FIELD CRITERIA USED IN DETERMINING MAJOR TEXTURAL CLASSES

TEXTURE CLASS MAJOR (USDA)	FEEL MOIST	ABILITY TO FORM STABLE BALL	ABILITY TO RIBBON OUT	SOIL HANDS	STICKY	CONSISTENCY MOIST	CONSISTENCY DRY
COARSE (sand)	very gritty	no	no	no	no	loose	loose
COARSE (loamy sand)	very gritty	yes	yes, very weak <1/2" long	yes slight	no	loose	loose
MOD. COARSE (sandy loam)	gritty	yes, easily deformed	yes, dull surface poorly formed	yes	no	very friable	soft
MEDIUM (loam)	slightly gritty	yes	yes, dull surface poorly formed	yes	yes, slight to moderate	friable	soft
MEDIUM (silt loam)	velvety	yes	yes, dull surface poor to well formed	yes	yes, slight to moderate	friable	soft
MOD. FINE (silty clay loam)	velvety & sticky	yes very stable	yes, shiny surface well formed	yes	yes	friable to firm	slightly hard
MOD. FINE (clay loam)	slightly gritty & sticky	yes very stable	yes, shiny surface well formed	yes	yes	firm	slightly hard to hard
MEDIUM (sandy clay loam)	very gritty & sticky	yes very stable	yes, shiny surface well formed	yes	yes	friable to firm	slightly hard to hard
FINE (sandy clay)	very gritty ext. sticky	yes very stable	yes, shiny surface well formed	yes	yes very	firm	hard to very hard
FINE (silty clay)	ext. sticky & very smooth	yes, very resistent to molding	yes, shiny surface well formed	yes	yes very	firm to ext. frim	hard to very hard
FINE (clay)	ext. sticky & very smooth	yes, very resistent to molding	yes, shiny surface well formed	yes	yes very	firm to ext. frim	hard to very hard



ESTIMATING SURFACE COVER

(Attachment B)



Farming with Crop Residues

USDA NRCS

United States Department of Agriculture
Natural Resources Conservation Service

February 1992

How to use the photos

Use these photographs of residue amounts to get a good picture in your mind of what the various percentages of ground cover might look like as you look down at evenly distributed residues.

30%

60%

How to measure residues

- Use any line that is equally divided into 100 parts. Fifty foot cable transect lines are available for this purpose. Another tool is a 50-foot nylon rope with 100 knots, six inches apart. A 50-foot tape measure using the 6-inch and foot marks also works well.
- Stretch the line diagonally across the rows. Count the number of marks (tabs or knots) that have residue under them when sighting from directly above one end of the mark. It is important to use the same point on each mark for accuracy. Don't count residue smaller than 1/8 inch in diameter.
- Walk the entire length of the rope or wire.

The total number of marks with residue under them is the percent cover under them is the percent cover for the field. If your rope or tape has only 50 marks, multiply by 2; for 25 marks, multiply by 4.

- Repeat the procedure at least 3 times in different areas of the field and average the findings.

Helping People Help the Land.

USDA is an equal opportunity provider and employer.

INFILTRATION RATING BASED ON SOIL TEXTURE CLASS AND INFILTRATION RATE (Attachment C)

USDA Soil Texture Class	Infiltration Rate (Time for 1 in of water to infiltrate)						
	0-1 minutes	1-5 minutes	5-10 minutes	10-30 minutes	30-120 minutes	2-10 hours	over 10 hours
sand or loamy sand	Excellent	Good	Fair	Poor	Poor	Poor	Poor
sandy loam	Excellent	Excellent	Good	Fair	Poor	Poor	Poor
silt loam, loam, or sandy clay loam	Excellent	Excellent	Excellent	Good	Fair	Poor	Poor
silty clay loam or clay loam	Excellent	Excellent	Excellent	Excellent	Good	Fair	Poor
silty clay, clay, or sandy clay	Excellent	Excellent	Excellent	Excellent	Excellent	Good	Fair

SOIL STRUCTURES USED IN SOIL HEALTH

(Attachment D)

Granular

Blocky

Single grain

Massive

Platy

February 2025

Soil Health Division
Technical Note 470-13

Full-Scale Rainfall Simulator Instructor Guide
Version 2

In accordance with Federal civil rights law and U.S. Department of Agriculture (USDA) civil rights regulations and policies, the USDA, its agencies, offices, and employees, and institutions participating in or administering USDA programs are prohibited from discriminating based on race, color, national origin, religion, sex, gender identity (including gender expression), sexual orientation, disability, age, marital status, family/parental status, income derived from a public assistance program, political beliefs, or reprisal or retaliation for prior civil rights activity, in any program or activity conducted or funded by USDA (not all bases apply to all programs). Remedies and complaint filing deadlines vary by program or incident.

Persons with disabilities who require alternative means of communication for program information (e.g., Braille, large print, audiotape, American Sign Language, etc.) should contact the responsible agency or USDA's TARGET Center at (202) 720-2600 (voice and TTY) or contact USDA through the Federal Relay Service at (800) 877-8339. Additionally, program information may be made available in languages other than English.

To file a program discrimination complaint, complete the USDA Program Discrimination Complaint Form, AD-3027, found online at How to File a Program Discrimination Complaint and at any USDA office or write a letter addressed to USDA and provide in the letter all of the information requested in the form. To request a copy of the complaint form, call (866) 632-9992. Submit your completed form or letter to USDA by: (1) mail: U.S. Department of Agriculture, Office of the Assistant Secretary for Civil Rights, 1400 Independence Avenue, SW, Washington, D.C. 20250-9410; (2) fax: (202) 690-7442; or (3) email: program.intake@usda.gov.

USDA is an equal opportunity provider, employer, and lender.

Acknowledgements

Photos
Cover: Doug Peterson, formerly with USDA-NRCS Soil Health Division
Figure 1: Nathan Lowder, USDA-NRCS Soil Health Division
Figure 2: Conservation Demonstrations, Inc.
Figures 3a to 3c and 7a to 7c: Barry Fisher, Fisher Soil Health LLC
Figures 4, 5, 6, and 8: Stanley Boltz, formerly with USDA-NRCS Soil Health Division
Figure 9: Elizabeth Marks, USDA-NRCS Soil Health Division
Figure 10: U.S. Navy courtesy of USDA-NRCS

All photos used with permission.

Author
Version 1: Justin Morris, former Regional Soil Health Specialist, USDA-NRCS Soil Health Division

Contributors
Version 2: Nathan Lowder and Elizabeth Marks, Regional Soil Health Specialists, USDA-NRCS Soil Health Division

Reviewers
Candiss Williams, Loretta Metz, Candy Thomas, Stanley Boltz, Nick Sirovatka, Laura Starr, Doug Peterson, Willie Durham, Barry Fisher, Dennis Chessman, Marlon Winger, Zahangir Kabir, Jeff Duchene, Carissa Spencer, Brian Briski, Jeff Deniger, Patrick Lake, Betsy Dierberger, Steven Alspach, Caleb Stone, Michael Kucera, Keith Scoggins, Brenda Simpson, Johanna Pate, Craig Smith, and Bryon Kirwan

Recommended Citation
U.S. Department of Agriculture, Natural Resources Conservation Service, Soil Health Division. 2025. Full-Scale Rainfall Simulator Instructor Guide, Version 2. Soil Health Division Technical Note 470-13.

Contents

Introduction....5
Getting Prepared....5
Soil Samples and Sampling Trays....7
Rainfall Simulator Setup....7
Soil Slaking Demonstration Guidance....9
Discussion for Slaking Demonstration....10
Rainfall Simulator Demonstration Guidance....11
Rainfall Simulation Talking Points....12
Discussion After Rainfall Simulation....13
Principle 1 - Minimize Soil Disturbance....16
Principle 2 - Maximize Soil Cover....16
Principle 3 – Maximize Biodiversity....17
Principle 4 - Maximize Presence of Living Roots....17
Optional Discussion on Soil Temperature....17
Appendix 1. Quick Instruction Guide for Full-Scale Rainfall Simulator....19
Appendix 2. Links to Helpful Videos....22
Appendix 3. Examples of Frequently Asked Questions and Their Answers....23
References....25

Introduction

The full-scale rainfall simulator demonstration can be one of the most effective tools for introducing people to the principles of soil health and encouraging the adoption of practices which improve soil health. A 2015 survey of individuals who watched a rainfall simulator demonstration found it effective in providing education on the impact of the water cycle, as well as promoting the adoption of conservation practices and monitoring techniques (Smart et al., 2017).

The conversation that accompanies the rainfall simulator demonstration is crucial in helping people understand how management affects soil function. The presenters need to have a solid understanding of the reasons for the observed differences in runoff and infiltration and be able to explain how management contributes to those differences. These two factors are critical for helping land managers make the connection between their management and how well their soils capture and store water.

The Soil Health Division created this instructor guide to: 1) help the presenter prepare for the rainfall simulator demonstration as well as a soil slaking demonstration, 2) detail important talking points for the slaking and rainfall simulator demonstrations, and 3) provide answers to some commonly asked questions. Not every talking point needs to be addressed for an effective demonstration. The presenter should select points that are applicable to their audience and setting.

Appendix 1 provides a quick guide for the main discussion points. This guide can be printed and laminated for easy reference in the field.

Getting Prepared

Soil Samples and Sampling Trays

The foundation for an effective rainfall simulator demonstration begins with properly collecting samples and preparing sampling trays. A metal tray with holes in the bottom, when filled appropriately, will help presenters demonstrate the movement of water vertically (downward) through the soil profile or horizontally and how this relates to overland flow and erosion potentials. See Appendix 2 for links to how-to videos on sampling.

Figure 1. A soil sample tray (left) and a collection template (right).

Collecting a sample is easiest with at least 2 people and can take 20 to 60 minutes per tray. During sample collection, consider the target audience and what you want to demonstrate. Different soil trays may represent the following use and management:

- Cropland under conventional tillage
- No-till or reduced till cropland
- Cropland with cover crops
- Forestland or hedgerow
- Continuous grazed pasture
- Rotational grazed pasture
- Areas with different cover, such as crop residue, mulch, or cover crop
- Areas with a high content of soil organic matter or with soil carbon amendments such as compost or biochar
- Organically managed soils

Collect soil samples for the simulator that have the same surface texture (preferably same soil type). This helps reduce any variability based on soil textural differences. Soil can be collected as: 1) an intact slice or 2) loose soil. An intact slice is recommended if there is living cover in the soil, such as pasture, hayland, or no-till cover crops. Loose soil can be collected when extraction is difficult.

To collect fully intact soil sample cores use a template cutout (fig. 1). Ensure that the sample will be representative of the conditions needed for the demonstration. For example, if one of the trays is from a no-till field with a certain amount of residue, ensure that the sample has the desired quantity of residue already present rather than collecting a sample from a no-till site that has insufficient residue and then adding residue on top. For conventionally tilled and no-till samples, collect soils 1 to 2 weeks before the demonstration so that the soils will be dry. Store them in a dry location as well. If a conventionally tilled soil is cut (intact core) from the field, be careful not to fracture it as this will likely cause preferential flow and lead to confusion in discussions on infiltration.

To collect loose soil, use a shovel and place material into a 5-gallon bucket until the bucket is approximately two-thirds full. Obtain these samples from sites representing each of the management strategies identified in the demonstration. Break up clods with your hands so that the soil resembles conditions in the field at planting time. Spread the broken-up soil on a tarp so it can dry out.

Place the dry soil in the respective trays according to use and management. Place any extra soil in buckets for storage in a dry location. You will need additional soil if you plan to use the samples numerous times due to soil being lost while handling and from sample runoff. Label the buckets for future use.

To show the impact of surface cover on conventionally tilled cropland, fill up a separate tray with soil and cover it with mulch from crop residues while leaving the other tray of conventionally tilled soil without cover.

Invite the landowner or partner to assist with the extraction of each sample. This is a great opportunity for them to learn about the importance of soil structure. They will see evidence of soil life. They can determine, knowing the management history, which areas to avoid, such as compacted or typically wet areas.

When possible, weigh each tray and record the weight immediately after extraction. Be ready to share the respective weights during the demonstration when talking about bulk density, pore space, and water-holding capacity.

Healthy soils of the same volume will weigh less than unhealthy soils because of management effects. For example, a tray containing a sample from a healthy, diverse pasture under proper grazing management can weigh 29 pounds while one from an overgrazed pasture can weigh 37 pounds due to compaction and organic matter content. Samples from areas with no-till, multi-species cover crops commonly are in between these values.

Store sample trays in a protected location for future events. Duration of storage is dependent on care. Watering and sunlight will be needed to maintain current and new vegetation.

Clipping of vegetation on the continuous grazed sample will be necessary. Otherwise, the sample will show improved infiltration since the minimizing disturbance principle was implemented during the storage period.

Depending on your objectives, conventionally tilled samples can be left intact to demonstrate compaction, aggregate instability, crusting, slaking, etc.

Rainfall Simulator Setup

See Appendix 2 for links to videos on setting up and running the rainfall simulator.

When setting up on uneven surfaces, use a hand level and blocks to ensure that the simulator is level side to side and centered over the catch pans. This allows the water that infiltrates to flow into the infiltration jug and prevents spillage.

Set the slope to that of a typical soil in the region by adjusting each metal T bar up or down on the back of the simulator frame (fig. 2). If the audience comes from an area of rolling topography, then focus on erosion. If the audience is from areas with little to no slope, then focus on infiltration and ponding.

Figure 2. Adjusting the metal T bar: set at first mark for 1 percent slope, second for 4 percent, third for 7 percent, fourth for 10 percent, and fifth for 15

Mount the oscillating nozzle so that it is 6 feet above the ground surface. This ensures that the nozzle changes direction beyond the very outer trays on both ends and that the droplet size and speed more closely approximate actual rainfall. If the nozzle changes direction over the outer trays, those trays will get significantly more water than the interior ones. You can check this to make sure that water is hitting the outer trays twice.

Turn on the simulator before the trays are mounted to ensure proper spray pattern and pressure while bleeding out as much air as possible. Pressure needs to be high enough to get full coverage,

but not too high that water is shooting out at high velocity. Generally, a pressure of 7 psi is a good place to start; adjust as necessary to get a realistic water velocity. If pressure is too low from the water source, remove the pressure regulator valve. If trays are already mounted on the simulator before you bleed out the air, hold a bucket underneath the nozzle until only water is coming out.

Ensure that tray edges are well packed so that there is no preferential flow between the sample and the tray it sits in. If the tray is transported to the demonstration site, run your fingers around the pan edge to seal cracks that may have developed during movement of the sample.

Make sure the soil is slightly higher along the edges than in the middle so that water runs through the center and is not directed to the sides.

Trays can be positioned in different orders depending on the samples being demonstrated. It is recommended that trays with samples that have the best soil health be positioned on the outside, so that they do not fill up with soil splattered from trays with poor aggregate stability.

Be conscious of sample trays with tall residues. Place them on outer edges to avoid misdirection of spray pattern.

If one of the trays represents a conventionally tilled field with little to no residue, the tray can be positioned in the center, directly underneath the nozzle. This will prevent soil in the conventionally tilled tray from splashing onto an adjoining tray, causing more soil to end up in an adjoining tray's runoff jug and potentially skewing the results.

To show that all samples are receiving a similar amount of water and that the conventionally tilled tray is not subjected to more water and higher impact forces than the other trays, place rain gauges in the center and outermost samples.

In windy conditions, place same-size heavy-duty washers in the bottom of each jug to keep them from swinging. A little breeze can wreak havoc with empty jugs, preventing water from draining into them.

Place printed signs identifying management in a cover slip or laminate them. If possible, include a picture of the site where the soil sample was taken. Clip the signs to the backsplash using a large binder clip. The sign should describe the current management practice(s) in place for each tray, such as conventional tillage, no-till, cover crops, continuous grazing, rotational grazing, forestland, urban farms, etc. Other information, such as crop rotation or tray weight, also can be added. Alternatively, you can write the management above each tray, using dry erase markers, on the smooth side of the backsplash board.

If the simulator is set up on a tarp, place the lids of the water collection jugs underneath the legs of the simulator to prevent poking holes in the tarp.

Have on hand a 4-by-6-foot piece of filter fabric or plastic tarp. You can turn the tilled soil tray upside down onto the tarp to show the audience the lack of soil moisture penetration in high-disturbance systems.

Print and laminate photos from the area where each soil sample was taken to provide context. You may also want to include the photo of raindrop impact (see Appendix 1, figure 10).

Soil Slaking Demonstration Guidance

In conjunction with the rainfall simulator demonstration, you can also run a soil slaking demonstration to illustrate aggregate stability. This helps the audience understand what aggregate stability is and its importance to soil function. Without this demonstration, one may erroneously conclude that the amount of soil cover is the sole determining factor on whether a soil sample allows water to infiltrate.

Soil slaking is the process by which large soil aggregates break down into smaller pieces when they are suddenly immersed in water (*https://www.nrcs.usda.gov/sites/default/files/2022-10/Slaking.pdf*). Peds and clods are both soil aggregates, but they differ in how they are formed and their permanence. Peds are natural aggregates formed in part by gluey residues secreted by biological organisms. Clods are artificial aggregates that are formed by human activities such as tillage.

Use a completely air-dried soil clod and ped from the same or similar soil type. Comparisons can be made between fields which are: 1) no-tilled versus tilled, 2) planted in cover crops versus fallow, 3) cropland versus fence line, and 4) pastures under rotational grazing versus continuous grazing or dedicated hayland. Obtaining and using a soil clod and ped that matches the soil samples in the rainfall simulator trays will strengthen the demonstration.

Practice with the clod and ped before demonstrating so that you know how they will behave when submerged in water (figs. 3a to 3c).

If the clod from the conventionally tilled soil does not slake significantly after a few minutes, tap on the cylinders for the clod and ped at the same time. Tapping the cylinder commonly creates enough vibration to get the highly disturbed clod to begin slaking.

If the clod from the conventionally tilled soil still does not slake significantly, remove both clod and ped from the water by lifting the wire baskets and dumping them on a table. Cut both clod and ped in half using a knife to show how far water penetrated. The less disturbed ped should be moist all the way through while the highly disturbed clod should have a dry center.

Less disturbed soils have good porosity, allowing water to be rapidly absorbed. Highly disturbed soils have poor porosity, preventing water from rapidly entering the soil. High bulk-density soils, such as those with clay, commonly have less porosity when disturbed.

Clods that should slake are best collected following a crop harvest and rainfall event or in early spring right before planting and after a rainfall event. Collecting clods where there is no growing crop ensures that there is no root activity. Collecting after a rainfall event ensures that any microorganisms remain alive, so the clod does not seal over and prevent water infiltration.

Figure 3a. Two clear cylinders are filled with water to demonstrate how the clod (left) and ped (right) behave when completely submerged in water.

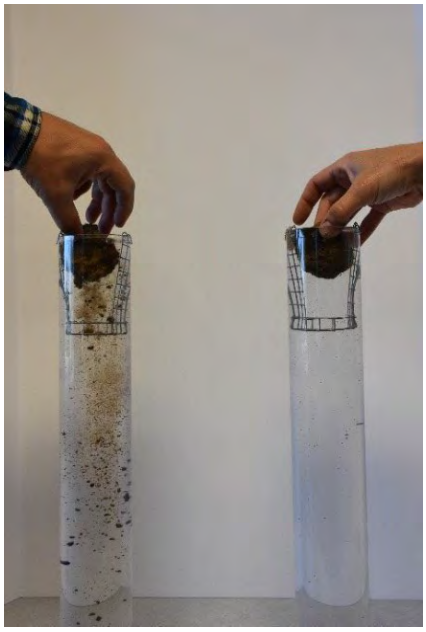


Figure 3b. The clod (left) and ped (right) are gently submerged in water. Initial slaking of the clod can be seen. As the clod and ped pore spaces fill with water, an internal pressure is created.

Figure 3c. Slaking in action. The clod (left) shows poor aggregate stability. Because of the lack of biological residues and exudates ("glue"), the silt and clay particles of the clod disperse easily into the water, making it cloudy. The ped (right) shows good aggregate stability because it has plenty of biological exudates ("glues") that keep the individual soil particles together.

Discussion for Slaking Demonstration

Ask the audience: "Who has heard of or read the term 'soil health' before? What does this term mean?" Soil health is defined as the "continued capacity of a soil to function as a vital, living ecosystem that sustains plants, animals, and humans." This definition teaches us that soil is not just a lifeless substance—it is a living ecosystem comprised of innumerable organisms ranging from earthworms to fungi and bacteria. These organisms directly affect how the soil functions.

Ask: "What are some key soil functions?" Answers can include: 1) grow a crop, feed, or fiber, 2) infiltrate and hold water, 3) maintain physical structure in the presence of water, 4) purify water, 5) provide a home for soil biota, 6) enable good gas exchange (i.e., allow oxygen in and carbon dioxide out), and 7) be a source of minerals and nutrients.

One of the most important soil functions is the soil's ability to take in water (infiltrate) while maintaining its structure, i.e., not dissolve, break apart, or erode. The slaking (aggregate stability)

demonstration can show how two soils of similar texture under different types of management behave when submerged in water. See figures 3a to 3c.

Ask the audience to identify any differences they see between the tilled clod and no-till clod, such as color, texture, or presence or lack of pores and roots. Explain the management of each soil.

Once you have placed the clod and ped in the baskets and completely submerged them in water (fig. 3b), note that water is rushing into the pores and pushing out air (as seen from the bubbling).

The ped and clod behave quite differently. The ped is holding together (maybe a few large chunks come off), whereas the clod is coming apart to the point that the water is becoming cloudy (fig. 3b).

Ask: "What do you think is suspended in the cloudy water?" Answer: The smallest soil particles—clays and silts (and possibly organic matter, if present).

When soil is held together with roots and biological exudates ("glues") from plant roots, bacteria, and fungi, the internal pressure from the water does not cause the smallest soil particles (clays and silts) to slake.

A healthy soil may slake a small amount, but the water remains clear. In addition, the aggregates that do slake still maintain their integrity. These aggregates are described as being stable.

Soil not held together by roots and biological glues begins to slake at the smallest soil particle level. Individual clays and silts become suspended, making the water cloudy. The aggregates that make up this soil are unstable in the presence of water.

Consider: What would the water look like if the clod or ped was from a field where the aggregates are unstable? How would that field behave in a rainfall event?

Rainfall Simulator Demonstration Guidance

Begin the rainfall simulator demonstration after the slaking demonstration, if used. See figure 4. Briefly explain the simulator and how it functions, including how the sample tray and catch pan work to allow water to go into either an infiltration or runoff jug.

Explain the type of management that is represented by each sample tray.

Turn on the simulator's oscillating nozzle before turning on the water. This prevents water overapplying into only one tray and leading to skewed results.

Rainfall Simulation Talking Points

The rainfall simulator mimics an extreme rainfall event by applying about 1 inch of water (as measured through the rain gauges).

Raindrop velocity during an intense thunderstorm is around 14 to 20 mph ("The Weather Guys," 2013). Low-functioning soils cannot absorb the stresses of extreme weather events that high-functioning soils can.

Figure 4. Rainfall simulator being operated on plastic in an enclosed setting. To prevent holes being poked in the plastic, the white plastic jug lids that came with the simulator are flipped upside down and placed in under the legs of the simulator frame. The plastic is elevated around the perimeter to contain any water and soil that may splash off the simulator.

With changing weather patterns, dry areas are getting drier and wet areas are getting wetter. For example, in Vermont, from 1950 to 2021, average rainfall increased 27 percent and the number of 2-inch extreme precipitation events in a 24-hour period increased 302 percent. In Nevada, during the same period, average rainfall stayed the same but the number of 2-inch extreme precipitation events in a 24-hour period increased 142 percent. These changes indicate that rainfall is more concentrated than before, a condition that can lead to more drought. If the soil cannot capture and store this precipitation, drought conditions can worsen. Climate data, trends, predictions, and interpretations are available at the NRCS National Water and Climate Center (*https://www.nrcs.usda.gov/programs-initiatives/sswsf-snow-survey-and-water-supply-forecasting-program/national-water-and*). For detailed information on how the climate is changing in your State, please see NRCS Climate Quick Reference Guides (*https://webapps.jornada.nmsu.edu/climate-quick-guides/*).

The three processes of soil erosion are: 1) detachment (from the ground), 2) transportation (via water or wind), and 3) deposition (where the soil particles end up). How far do you think soil particles can move as a result of raindrop impact? Two feet vertically and 5 feet horizontally (refer to figure 10, the raindrop splash).

In the simulation, the first raindrops detach silt- and clay-sized soil particles from surface aggregates. Where do these particles go? They land back on the tray, filling up surface pores and creating a surface crust.

It is important to note that surface aggregates can dissolve (disaggregate) into smaller particles in the presence of water. The smaller particles can move straight down into the pore space from ¼ to ¾ inch in depth, creating a surface crust within just a few minutes.

A surface crust reduces air exchange by preventing oxygen from entering the soil and preventing carbon dioxide from leaving the soil. As a result, infiltration is reduced, and runoff and erosion are increased. A crust negatively impacts the water and nutrient cycles.

The crust causes the soil to become anaerobic, leading to denitrification. Many disease-causing organisms thrive in anaerobic conditions.

Consider: Can you see any differences between how water is interacting with these samples? What is happening?

Look at the backsplash behind the highly disturbed tray. What is on the backsplash? Since many plant diseases come from pathogenic organisms on the soil surface (Soil Health Institute, 2021), disease can be transported to the plant when soil is splashed onto leaf surfaces.

Draw the audience's attention to the runoff jugs of the highly disturbed trays. Point out not only the volume, but also the cloudiness of the water. Does this remind you of the slaking demonstration performed earlier?

After applying about 1 inch of water, turn off the water, then turn off the oscillating nozzle.

Discussion After Rainfall Simulation

Allow the simulator to finish dripping for 1 or 2 minutes (fig. 5). Pull the infiltration jugs out one at a time and discuss what happened with each jug. Place them in front of the respective runoff jugs so that the audience can more easily compare what ran off versus what infiltrated for each tray (fig. 6).

How much soil was lost relative to the thickness of the dime that was placed on the soil surface before the rainfall began? Once the audience sees how much soil eroded, remove the dime and flip the tray onto a tarp to reveal the dry soil in the lower portions of the tray (figs. 7a to 7c).

Dig into the dry soil and pick it up so that it falls through your fingers to emphasize how little the water infiltrated (fig. 7c). Next, flip one of the trays exhibiting high infiltration. Show that aggregates are still visible and that the entire sample is wet.

Refer to the slaking demonstration and the aggregate that is still stable. That aggregate is stable because of the microbial glues that hold the soil particles together even though water is

Figure 5. Discussion of key points during a rainfall simulator demonstration. The brown tarp directly in front of the audience will be used later to show how far water infiltrated into two of the trays.

Figure 6. Two trays are flipped upside down to show how deeply water infiltrated. On the left, the soil material is from a field under conventional tillage. On the right, the soil material is from a field under no-till only. The runoff jugs are placed closest to the audience, and the infiltration jugs are placed closest to the presenter. Notice the light brown color on the top of the material from the conventionally tilled field.

Figure 7a. The conventionally tilled tray is removed from the rainfall simulator just after the water is turned off. It is placed on a tarp and the contents dumped to demonstrate how far water infiltrated into the sample.

Figure 7b. As the tray falls on the tarp with great force and is lifted quickly, a lot of dust is created.

Figure 7c. The sample is dug into with bare hands and filtered through the fingers to emphasize the soil's dryness.

rushing into the pore spaces and pushing out air. The same principles are at work in the clod and the pan.

For the conventionally tilled sample, the main reason soil went into the runoff jug is because the aggregates on the surface were unstable. The unstable aggregates lacked the microbial glues needed to maintain structural integrity in the presence of water, just like the highly disturbed aggregate in the slaking demonstration.

You can also use nitrate (NO^{-3}) and phosphate (PO_4^{-3}) strips to check the runoff water from the erosion samples. Depending on the sample, the runoff water may contain NO^{-3} or PO_4^{-3}. Dipping the test strips into the collected runoff water to indicate this can provide a valuable lesson. If nitrate or phosphate are present, discuss nutrient dollars lost and environmental impact on surface waters and greenhouse gases. Make sure there will be desirable results before the audience demo. Soils that are not well aggregated will generally have more soluble nitrate and phosphorus.

Which sample(s) are holding the most water? Generally, the sample from rotated and well-recovered pasture holds the most water as it is the lightest sample with the most pore space.

Share the weights of each tray. Relate weight to pore space, which can store water and allow the soil to breathe (inhale oxygen and exhale carbon dioxide).

Figure 8. Full-scale rainfall simulator with two grassland and three cropland samples. The cover crop tray in the middle also contains a sample from a no-till field.

What are some things that influence how water is interacting with each sample (fig. 8)?

- Amount of past soil disturbance
- Amount and type of surface cover

- Amount of plant and animal diversity
- Amount of roots and root channels

What influences all four of these characteristics? Management.

To improve soil function, including the water cycle, we need to know and implement the four key principles of soil health:

- Minimize Soil Disturbance
- Maximize Soil Cover
- Maximize Biodiversity (both plants and livestock where possible)
- Maximize Presence of Living Roots

Discuss how the soil samples relate to these principles:

Principle 1 - Minimize Soil Disturbance

Soil disturbance can result from physical, chemical, or biological activities. Physical soil disturbance, such as tillage, results in bare and/or compacted soil that provides a poor environment for soil microbes. Misapplication of farm inputs can disrupt the symbiotic relationships between fungi, other microorganisms, and plant roots. Overgrazing, a type of biological disturbance, can lead to reduced root mass, increased runoff, and increased soil temperatures. Note that all forms of soil disturbance diminish habitat for soil microbes and result in a diminished soil food web. Discussion points could include:

- *Continuous Grazing*. Disturbance is high because plants do not have time to recover from grazing and root depth is restricted. "If you overgraze the shoot, you overgraze the root."
- *Rotational Grazing*. Disturbance is managed or low because livestock are in the pasture for a few days then relocated to other pastures. This allows plants to become more abundant and have deeper roots.
- *No-Till*. Soil aggregates form and preferential pathways from roots and soil biology are maintained.
- *Conventional Tillage*. Disturbance is high from several tillage passes per year.

Principle 2 - Maximize Soil Cover

Soil cover conserves soil moisture, reduces soil temperature, intercepts raindrops (thus reducing their destructive impact), suppresses weed growth, and provides habitat for organisms of the soil food web that live above ground at least some of the time. This is true regardless of land use (cropland, hayland, pasture, or range). Keeping the soil covered while allowing crop residues to decompose (so that their nutrients can be cycled back into the soil) requires careful planning. Producers must give careful consideration to their crop rotation (including any cover crops) and residue management if they are to keep the soil covered and fed at the same time. Discussion points could include:

- *Continuous Grazing*. Cover is minimal because of continuous livestock grazing. This results in shorter vegetation and little plant residue on soil surface. Dedicated hayland can have large amounts of bare soil as sward thins due to shading and residue is removed.
- *Rotational Grazing*. Cover is maximum because plants are allowed to recover before being re-grazed. Forage canopy can thicken because more sunlight reaches the ground as plants are grazed throughout the season. Residue is often retained.

- *Cover Crop.* Cover is maximum because a canopy (living vegetation) or residue (dead vegetation) is left in field after harvest and not incorporated.
- *No-Till.* Cover is maximum as residues or mulch are left on the soil.
- *Conventional Tillage*. There is little to no cover (less than 15 percent) from crop residue or living plants.

Principle 3 – Maximize Biodiversity

Plants use sunlight to convert carbon dioxide and water into carbohydrates, which are the building blocks for roots, stems, leaves, and seeds. They also interact with specific soil microbes, releasing carbohydrates (sugars) through their roots and into the soil to feed the microbes in exchange for nutrients and water. A diversity of plants is required to support a diversity of soil microorganisms. The key to improving soil health is ensuring that food and energy chains and webs consist of several types of plants and animals.

Biodiversity is ultimately the key to the success of any agricultural system. Lack of biodiversity severely limits the potential of any cropping system and increases the potential for disease and pest problems. A diverse and fully functioning soil food web provides for nutrient, energy, and water cycling, allowing a soil to function optimally. Increasing the diversity of a crop rotation and cover crops increases soil health and soil function, reduces input costs, and increases profitability. Discussion points could include:

- Typically, perennial pastures and hayfields have the greatest biodiversity.
- Adding diversity to a crop field could include growing cover crops, adding manure, and/or rotating crops.

Principle 4 - Maximize Presence of Living Roots

Living plants maintain a rhizosphere, an area of concentrated microbial activity close to the root. The rhizosphere is the most active part of the soil ecosystem because it is where the most readily available microbial food is and where peak nutrient and water cycling occurs. Microbes provide nutrients (and other compounds) to the plant at the root-soil interface. Growing long-season crops or a cover crop following a short-season crop supports the foundation species of the soil food web as much as possible during the growing season.

Healthy soil is dependent upon how well the soil food web functions. Providing plenty of easily accessible food to soil microbes helps them cycle the nutrients that plants need to grow. Sugars from living plant roots, recently dead plant roots, crop residues, and soil organic matter all feed the many and varied organisms of the soil food web. Discussion points could include:

- Managing pastures and hayfields so that vegetation is allowed to grow tall promotes the size and abundance of living roots.
- Using cover crops can extend the season during which the soil has roots growing in it.

Optional Discussion on Soil Temperature

If the rainfall simulator is outside in direct sunlight, use soil thermometers to show the difference in soil temperature based on cover and management. While the rainfall simulator shows how

different types of management affect the water cycle, management can also greatly impact soil temperature (fig. 9).

Where there is little to no soil cover, soil temperatures can often be higher than the air temperature during the day and lower at night.

Compacted soils are colder in springtime and often wetter, limiting air exchange.

As soil temperatures become too cold or too hot, plants and soils are negatively affected.

- Potential plant effects from either cold or heat stress:
  - Plants stop respiring (taking in CO_2)
  - Reduction in photosynthesis
  - Reduction in plant growth and crop yields
  - Reduction in root expansion or growth
- Potential plant effects from cold stress:
  - Longer maturity times for crops
  - Accumulation of nitrates, which can cause nitrate toxicity if plants are used as a feed source for livestock
- Potential soil effects from either cold or heat stress:
  - Increased loss of moisture from soil surface (evaporation)
  - Reduced soil biological activity
  - Reduced mineralization and nutrient cycling
  - Fewer plant-available nutrients

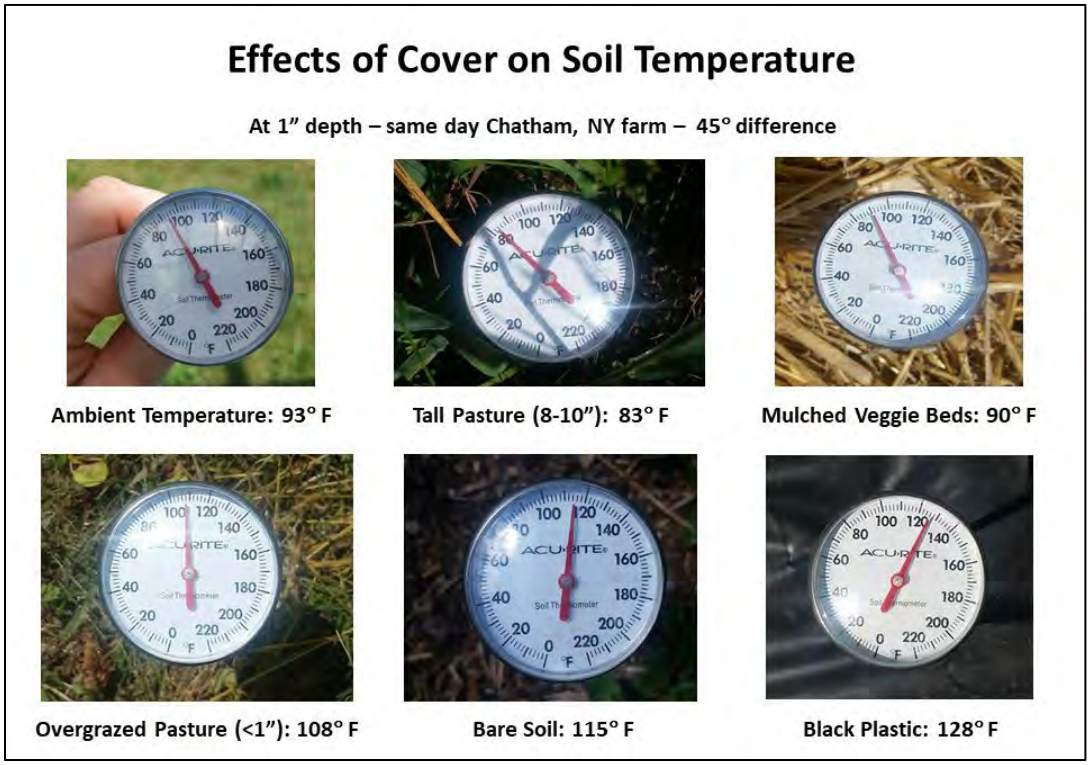


Figure 9. Examples of the effects of surface cover on soil temperature.

Appendix 1. Quick Instruction Guide for Full-Scale Rainfall Simulator

Discussion Before Rainfall Simulation

- Soil health is the continued capacity of a soil to function as a vital, living ecosystem that sustains plants, animals, and humans.

- Soil is a living ecosystem comprised of innumerable organisms, ranging from earthworms to fungi and bacteria, that directly affect how the soil functions.

- One of the most important soil functions is the ability to take in water (infiltrate).

- To see infiltration in action, the demonstration on slaking (aggregate stability) shows how soils under different forms of management behave when completely submerged in water.

[Briefly explain the rainfall simulator and how it functions. Include an explanation on how the sample tray and catch pan allow water to go into either an infiltration or runoff jug. Each tray will receive about 1 inch of water as measured through the rain gauges.

Explain the management for each sample tray.

Turn on oscillating nozzle first, then the water.]

Discussion During Rainfall Simulation

- Raindrop velocity during a rainstorm is around 14 to 20 mph.

- The steps of erosion are detachment, transport, then deposition. How far do you think soil particles can splash when a drop of water hits bare soil? Two feet vertically and 5 feet horizontally (fig. 10).

- Surface aggregates can dissolve into smaller soil particles that can move straight down in the pore space from ¼ to ¾ inch. Tillage destroys these pore spaces.

- Soil particles that detach and land back on the tray or dissolve and move down fill up the remaining surface pores, preventing additional water from infiltrating.

- A crust forms within just a few minutes. It prevents water and air from entering the soil *and* carbon dioxide from leaving the soil. The soil becomes anaerobic, and denitrification follows.

- Are there any differences between how water is interacting with these samples? If so, why?

- Look at the backsplash behind the highly disturbed tray. What is on the backsplash?

[As the runoff jugs begin to receive water from the highly disturbed trays, draw attention to not only the volume of water but also to its cloudiness.]

Discussion After Rainfall Simulation

[Pull the infiltration jugs out one at a time and discuss what happened with each jug. Place them in front of the respective runoff jugs so that the audience can more easily compare results.]

- How much soil loss occurred around the dime of the most highly disturbed sample?

[Point out how the whole surface has eroded and the lack of well-formed aggregates. Once people see how much eroded, remove the dime and flip the tray onto a tarp to reveal the dry soil in the lower portions of the pan.

Dig into the dry soil and pick it up so that it falls through your fingers to emphasize how little the water infiltrated.]

- One of the most important natural cycles on our planet is the water cycle. A resilient cropping system depends on soil with good infiltration and the ability to supply water throughout the growing season.

- Globally, the single most limiting factor for crop yields is lack of water. Photosynthesis and nutrient transport in plants require water.

- One of the most important soil functions is the capacity of a soil to take in water (infiltrate) while keeping sand, silt, and clay particles tied together or aggregated.

[Point to and discuss differences in runoff and infiltration between the various samples while relating the differences to the functionality of the water cycle.]

- Which sample(s) holds the most water? Generally, soil from the rotated and well recovered pasture holds the most water as it is the lightest sample with the most pore space. What are some things that influence how water is interacting with each sample? Amount and type of surface cover, amount of past soil disturbance, stability of surface aggregates, and number of roots and root channels. What affects all of these? Management.

- With changing weather patterns, dry areas are becoming drier and wet areas are becoming wetter. If soil is not able to capture and store water, drought conditions can worsen. For detailed information on how the climate is changing in your State, please see the NRCS Climate Quick Reference Guides.

- To improve soil function, including the water cycle, we need to know and implement all four principles of soil health:
    - Minimize Soil Disturbance
    - Maximize Soil Cover
    - Maximize Biodiversity
    - Maximize Presence of Living Roots

[Explain each principle and whether that principle was adhered to or not in sampled areas.]

- What else was lost with the eroded soil? Valuable nutrients, including soil organic matter, nitrogen, phosphorus, potassium, and sulfur.

- Is anything else attached to soil particles? This could include soil carbon, fertilizer, nutrients, pesticides or herbicides, and manure.

- While the message of soil erosion and degradation of the water and nutrient cycles is not positive, we know how to reverse these processes by following the principles of soil health. These principles work anywhere on the planet.

[Reemphasize the four soil health principles.]

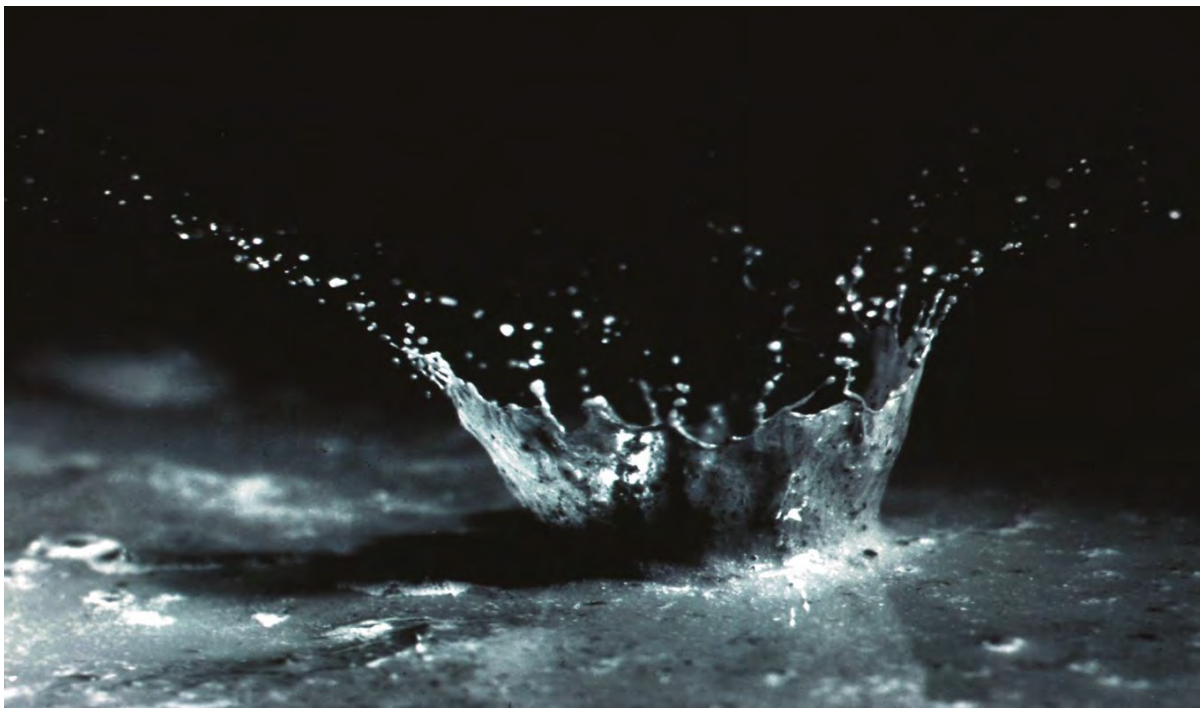


Figure 10. Raindrop splash.

Appendix 2. Links to Helpful Videos

Taking soil samples for the rainfall simulator:

- Filling soil pans (general): Click here (Kansas Association of Conservation Districts KACD, 2023) *(https://youtu.be/SkyCg6n3Drw?si=N0BNLdNT2p-kay2o)*
- Conventional tillage (1:57): Click here (USDA-NRCS, 2020) *(https://www.youtube.com/watch?v=1SInShHGIBQ&list=PL4J8PxoprpGbMQXtmEITklPyRAuDTd4Wj&index=1)*
- No-till with cereal rye residue (4:47): Click here (USDA-NRCS, 2020) *(https://www.youtube.com/watch?v=-3ZNk0nQjJw&list=PL4J8PxoprpGbMQXtmEITklPyRAuDTd4Wj&index=4)*
- Living cereal rye cover crop (4:56): Click here (USDA-NRCS, 2020) *(https://www.youtube.com/watch?v=AcxupYaO15I&list=PL4J8PxoprpGbMQXtmEITklPyRAuDTd4Wj&index=3)*
- Hayland (5:36): Click here (USDA-NRCS, 2020) *(https://www.youtube.com/watch?v=EzSw6tdbpdU&list=PL4J8PxoprpGbMQXtmEITklPyRAuDTd4Wj&index=2)*

Setting up and running the rainfall simulator:

- From the manufacturer: a detailed guide (Rainfall Simulator.com) *(https://rainfallsimulator.com/guides-and-videos/)* and video (Minnesota NRCS, 2019) *(https://youtu.be/yE5xRaFZyps?si=vCHcXYm1RsDBZ0ym)*
- From the Kansas Association of Conservation Districts: a series of helpful videos on using the rainfall simulator trailer; access playlist here *(https://youtube.com/playlist?list=PLNG9C-x7xM37qmXLABmqSwTspg4uk8Oc9&si=cve0mcgCgi4UV9OS)*.

Appendix 3. Examples of Frequently Asked Questions and Their Answers

Q.1. I farm where fractured bedrock is very close to the soil surface. Underneath the fractured bedrock is an aquifer that is contaminated by nutrients. If water infiltration is increased by using soil health improvement practices like no-till and cover crops, nutrients applied to the field will also infiltrate easier, passing through the fractured bedrock and causing greater contamination of the aquifer. Won't the improved infiltration be a detriment in this case?

A.1 There are four important things to keep in mind in answering this question: a) soil structure, b) surface cover and roots, c) soil organisms, and d) possible misconceptions based on demonstration. Let's first discuss the difference between infiltration in a healthy soil and preferential flow in an unhealthy soil. Unhealthy soils have poor soil aggregation, meaning that they don't have the crumbly structure characteristic of healthy soils. Rather, unhealthy soils typically are more cloddy (the soil comes out in large chunks), have less pore space (for air and water), and are subject to crusting, erosion, and runoff. When these soils dry out, they shrink somewhat and crack. The cracks are channels where any liquid, whether water or slurry, can easily bypass the soil and reach the fractured bedrock. As a result, the unhealthy soil does not absorb any of the liquid but instead becomes a solid mass (liquid may only enter where the cracks are caused by shrinking). This is preferential flow.

a) Soil structure improves with the formation of more water-stable aggregates. Under non-saturated conditions, when there is plenty of pore space, any liquid applied to the surface doesn't just flow straight down. The liquid also moves horizontally through interconnected soil pores, where it can be metabolized by more soil life. Healthy soils have a higher content of organic matter. Organic matter has a negative chemical charge and can act as a sponge, absorbing water and holding onto nutrients.

b) Different cover crop species have different root types. Tap roots are larger in diameter than other roots. They grow vertically and are effective at penetrating certain restrictive layers, such as plow pans. Fibrous roots are smaller in diameter. They grow both laterally and vertically and are effective at improving soil structure. Integrating cover crop species with more fibrous rooting architectures, such as grasses, can greatly reduce off-season nutrient losses.

c) The concentration of soil life around a root hair is thousands of times greater than it is anywhere else in the soil. Thus, the more living roots there are in the soil, and growing in different directions, not just straight down, the more soil life can potentially metabolize (digest) the nutrients applied to the field. (The nutrients must not be applied in excess of what the current population of soil organisms can metabolize.) As the soil biota digest the nutrients being applied, they immobilize (tie up) those nutrients in their bodies so that they are not readily leachable.

d) Since the trays of the rainfall simulator are only 2 ½ inches deep, there is a limited amount of pore space to absorb water and liquid nutrients. This means that some of the infiltration jugs may be quite full after running the simulation, which gives the perception that those soils will not absorb a significant amount of dissolved nutrients. In a field setting, however, healthier soils that are deeper than the simulator trays will have additional pore space to absorb and prevent nutrients from leaching through the profile.

_____

Q.2. If water infiltration is increased after the implementation of soil health improvement practices like no-till and cover crops, nutrients applied to the field will also infiltrate easier, passing through the soil and ending up in the tile line. Won't the improved infiltration be a detriment in this case?

A.2. Refer to answer for question 1.

_____

Q.3. I've heard that cover crop roots will plug up tile lines. Why would I want to plant them if that's true?

A.3. Cover crop roots may plug up tile lines when weather conditions are favorable for their growth, such as a rainy period followed by a prolonged dry period and a mild winter. So, it is advisable to have an early termination strategy. Additionally, corrective measures can be used if it seems that the roots are from a cover crop and not from the cash crop, trees, or weeds. Early termination strategies include:

- Alternating shallow-rooting covers with deep-rooting covers
- Terminating a cover crop earlier in spring
- Alternating winterkill covers with those that overwinter
- Where new drainage system are installed, avoiding seeding the cover crop immediately over the new tile trench for the first year while the soil is quite loose.

For more information, see the Purdue University Extension publication "Agricultural Tile Drains Clogged with Cover Crop Roots?" (Kladivko et al., 2016).

_____

Q.4. I've heard that cover crops make the soil cooler in spring because they shade the soil surface, and that bare soil warms up quicker because it is darker. Is this true?

A.4. No, actually the opposite is true. While bare soil can be warmed by the sun during the day, it will become colder at night or during sudden temperature drops. Also, compacted soils are often colder and wetter in the spring as there are fewer air spaces in the soil. Air spaces allow water to drain and ambient air to enter the soil. Producers find that in wet years they can access their cover-cropped fields a lot sooner than their fields that do not have cover crops.

_____

Q.5. How fast is the simulator's "rainfall"? It looks a lot more intense than rainfall on my land.

A.5. The simulator's rainfall intensity mimics a 10-year storm and is what NRCS uses as a guideline for designing terraces. The intensity is simulated with a low-pressure (6 to 10 psi) nozzle placed 7 to 8 feet above the soil surface.

References

Cooperative Institute for Meteorological Satellite Studies, “The Weather Guys” (Steve Ackerman and Jonathan Martin). 2013. How Fast Do Raindrops Fall? University of Wisconsin-Madison. Online: https://wxguys.ssec.wisc.edu/2013/09/10/how-fast-do-raindrops-fall/ (accessed November 8, 2024).

Kladivko, E., B. Fisher, and L. Brown. 2016. Agricultural Tile Drains Clogged with Cover Crop Roots? Purdue University. Online: https://ag.purdue.edu/department/agry/agry-extension/_docs/cover-crops/tilesandcovercroproots.pdf (accessed November 8, 2024).

Smart, A.J., P.J. Bauman, S. Boltz, and J. Hemenway. 2017. Demonstration-based education generates behavior change related to conservation practices. Journal of Extension 55(3), Article 3IAW8. Online: https://www.researchgate.net/publication/317816113_Demonstration-Based_Education_Generates_Behavior_Change_Related_to_Conservation_Practices (accessed November 8, 2024).

Soil Health Institute. 2021. Soilborne Plant Pathogen Fact Sheet. Blog post on 02/19/2021. Online: https://soilhealthinstitute.org/news-events/soilborne-plant-pathogen-fact-sheet/ (accessed November 8, 2024).

U.S. Department of Agriculture, Natural Resources Conservation Service. NRCS National Water and Climate Center. Online: https://www.nrcs.usda.gov/programs-initiatives/sswsf-snow-survey-and-water-supply-forecasting-program/national-water-and (accessed November 8, 2024).

U.S. Department of Agriculture, Natural Resources Conservation Service, Southwest Climate Hub and New Mexico State University. NRCS Climate Quick Reference Guides. Online: https://webapps.jornada.nmsu.edu/climate-quick-guides/ (accessed November 8, 2024).

VIDEO - Soil Health Minute: Rainfall Simulator

https://youtu.be/Y4pwNIPX4AA?si=NV-w17VLXA9AmmEx

Soil Health Minute: Rainfall Simulator

Soil Health Monitoring: Like Maintaining Your Equipment

Soil Health Institute

Why monitor soil health?

Just like you perform regular maintenance on your tractor to keep it running well and catch problems early, your soil needs regular testing to assess its condition and maintain productivity and profitability. The table below compares common steps you take to maintain your equipment with the parallel steps needed to maintain your soil's health. Notice how the same principles apply to both!

	EQUIPMENT HEALTH	YOUR SOIL'S HEALTH
Conduct routine inspection	• Check oil, filters, fluid levels, wear indicators. • Multiple checks give complete picture of equipment status.	• Test nutrient levels, pH, organic matter, and microbial activity. • Practical and affordable indicators offer a comprehensive view of soil health status.
Track key indicators	• Monitor engine hours, temperature, pressure gauges. • Regular monitoring catches problems early.	• Track soil structure, water infiltration, nutrient cycling, and compaction. • The Soil Health Institute recommends measuring Organic Carbon, Carbon Mineralization, and Aggregate Stability.
Preventative practices	• Regular oil changes, greasing, and cleaning prevent breakdowns and extend equipment life.	• Cover cropping, crop rotation, and reduced tillage prevents erosion, nutrient depletion and compaction.
Comprehensive management	• Consider operating conditions, load, usage patterns. • Proper operation and maintenance reduce repair needs.	• Consider physical, chemical, biological soil properties, practices like cover crops and rotation, plus targeted chemicals to reduce fertilizer and pesticide needs.
Consult experts	• Call dealer mechanic for complex issues.	• Work with NRCS, Extension, Certified Crop Advisors.
Implement corrective actions	• Replace parts, adjust settings, upgrade components to address mechanical issues.	• Apply amendments and adjust practices to fix nutrient deficiencies and soil imbalances.
Long-term management	• Follow service schedule and adjust based on use. • Continuous monitoring and preventive maintenance extend equipment life, reducing breakdowns and costs.	• Follow testing schedule and adjust practices based on results and changing conditions. • Continuous monitoring and proactive management maintain soil productivity, increasing yields and lowering costs.

Key Takeaways

Just like your equipment, your soil's health benefits from:

Early detection: prevents bigger problems

Regular monitoring: catches changes before they become costly

Prevention: more effective than expensive repairs

Holistic approach: works better than quick fixes

Long-term care: pays off with sustained performance

The Bottom Line:

Soil health monitoring helps you make better management decisions, leading to higher yields, reduced input costs, and improved long-term profitability.

Thank you to our partner, the Soil Health Institute, for producing this educational resource.

SOIL HEALTH INSTITUTE
Enriching Soil, Enhancing Life

FarmersforSoilHealth.com

Farmers for Soil Health is a collaborative initiative led by the Soy Checkoff, Pork Checkoff, and National Corn Growers Association in partnership with state commodity groups and conservation organizations.

SOY CHECKOFF™ pork checkoff NATIONAL CORN GROWERS ASSOCIATION

What You're Missing if You're Only Testing for Fertility

Soil Health Institute

Understanding your soil is the foundation of good farm management. Soil testing gives farmers, agronomists and landowners the data needed to assess and improve their soil's physical, chemical and biological properties, supporting better decisions that enhance productivity and long-term sustainability. But not all soil tests tell the same story. There are two different approaches – soil fertility testing and soil health testing – and understanding the difference between them is key to getting the most out of your farming operation. Here's what each test measures and why using both gives you the fullest picture of your soil.

Soil Fertility is the measure of a soil's capacity to supply essential nutrients for crop growth. It's assessed through routine soil tests that quantify nutrient levels (like phosphorus and potassium), which have been researched and calibrated over decades to optimize crop yield responses and guide fertilizer and lime application rates.

Soil Health is really about how alive and well your soil is. It's not just about nutrients. It reflects the physical, chemical and biological characteristics of soil working together to hold water, support the tiny organisms that cycle nutrients and bounce back from stress. Because these properties can shift over time in response to management, soil health is both a snapshot of how well your soil functions today and a long-term measure of whether your practices are sustaining the land for the future.

Why You Need Both

While soil fertility testing tells you what nutrients your soil has and what to add, soil health testing tells you how well your soil is functioning as a living system. Used together, fertility testing optimizes what you apply today, while soil health testing helps you understand whether your broader management practices (tillage, cover crops and rotations) are moving the soil in the right direction over time. The bottom line: Soil health testing is not a replacement for regular soil fertility testing and vice versa; they are complementary and each is needed to get a full picture of your soil's condition.

The table below summarizes the key differences between the two approaches.

	Soil Fertility Testing	Soil Health Testing
Focus	Chemical properties needed for plant growth	Physical, chemical and biological soil conditions
Primary Goal	Provide actionable data for fertilizer and lime application rates to manage crop nutrient availability and optimize yield	Evaluate soil as a functioning, living ecosystem that sustains plants, animals and humans
Properties Measured	• Essential nutrient levels (nitrogen, phosphorus, potassium, calcium, magnesium) • Some micronutrients • pH and organic matter	• Organic carbon concentration • Carbon mineralization potential • Aggregate stability
When and How Much Soil to Sample?	• Every 2-3 years (or based on crop rotation) • Gathering 1 sample per 2.5-5 acres	• Every 3-5 years • Gathering 1 sample per 20 acres (based on management zones)
	If you are unsure of what sample intensity or frequency is needed for a specific soil test, we suggest you contact a local certified crop advisor or technical service provider for specific recommendations	
Best Used For	Shorter-term fertilizer and amendment decisions	Long-term soil management and conservation planning

Takeaway	Both tests serve different but complementary purposes. Soil health testing gives producers a fuller picture of soil function beyond nutrient availability alone.

Learn how to collect accurate samples for soil health testing by searching "How to sample" on *soilhealthinstitute.org*.

Thank you to our partner, the Soil Health Institute, for producing this educational resource.

SOIL HEALTH INSTITUTE
Enriching Soil, Enhancing Life

FarmersforSoilHealth.com

Farmers for Soil Health is a collaborative initiative led by the Soy Checkoff, Pork Checkoff and National Corn Growers Association in partnership with state commodity groups and conservation organizations.

SOY CHECKOFF™ pork checkoff® NATIONAL CORN GROWERS ASSOCIATION

VIDEO - Put Your Soil to the (Slake) Test!

https://youtu.be/BPHme3WFGJM?si=njIS6qkriLWd-Y53

Put Your Soil to the (Slake) Test!