Authors
Stacy Zuber and
Eileen Kladivko

How to Understand and Interpret Soil Health Tests

Soil health has received increased attention during the past few years — and for good reason. The USDA-Natural Resources Conservation Service (NRCS) defines soil health as the "capacity of the soil to function as a vital, living ecosystem that sustains plants, animals, and humans."

It is important for us to protect and improve the soil health on our agricultural lands for both short- and long-term productivity. Soil health matters to farmers, consumers, and society as a whole. So clearly, finding ways to improve soil health on our nation's croplands should be a high priority.

But the question of how to adequately measure soil health arises. Soil health intertwines many aspects that function together as a system: soil biology, fertility/chemistry, and physical properties. Ideally, we would have a few simple measurements that indicate a field's current level of soil health. And these measurements would help us identify management practices to increase the soil health.

A soil health test should be much like a "wellness exam" for human health that finds areas that need some attention and provide us with an overall "health rating." In the same way, a soil health test should identify areas

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that need improvement along with an overall score. Soil health tests should provide consistent, reliable results (be reproducible), and they should measure important attributes of soil functions that respond relatively quickly to management. Ideally, these attributes have known values that indicate "good" or "poor" for each function.

Many commercial soil health tests attempt to assess soil health from soil collected from the field. There are also in-field soil assessments that use various soil health test kits, sensory observations, or field soil property measurements.

Soil health tests measure various attributes of soil biology, chemistry/fertility, and physical properties. The various commercially available soil health tests emphasize different aspects of soil health, and there is no one universally accepted way to evaluate soil health. Much of our recent attention focuses on soil biology rather than chemistry or physical properties, because biology has been overlooked or ignored in common soil testing procedures.

Remember that soil fertility testing is a well-established practice — interpretations and recommendations are widely understood and have been accepted and used for many years. Soil physical properties are not routinely tested, but at least they are relatively well understood.

But measuring and interpreting soil biology is very challenging. There are no standard tests or interpretations for soil biology that help field managers know what to do next. There are myriad organisms living in the soil that interact in complex food webs, respond to short-term changes in weather and crops, and respond to longer-term changes in soil management systems. Soil biological tests are newer and their practical implications are not yet clear.

This publication describes four of the more commonly used commercially available laboratory soil health tests that we evaluated on farm sites and at Purdue Agricultural Centers over a four-year period. The tests assess different combinations of biological, chemical, and physical properties. After describing the tests, we will discuss the challenges of using these tests in Indiana croplands.

Organism Groups Important to Soil Biology

There are three main groups of organisms that are important to soil biology:

1. Fungi
2. Protozoa
3. Bacteria

Fungi are one of the most important biological groups in soil. They are decomposers, capable of breaking down complex molecules in crop residues. Fungi also play a vital role in soil aggregation and structure. Increased fungi in the soil can indicate improving soil health.

One specific type of fungi (mycorrhizal fungi) significantly contribute to soil health by forming symbiotic relationships with crop roots (Figure 1). The fungi can help crops reach nutrients (particularly nitrogen and phosphorus) and water that would otherwise be unavailable to the plant.

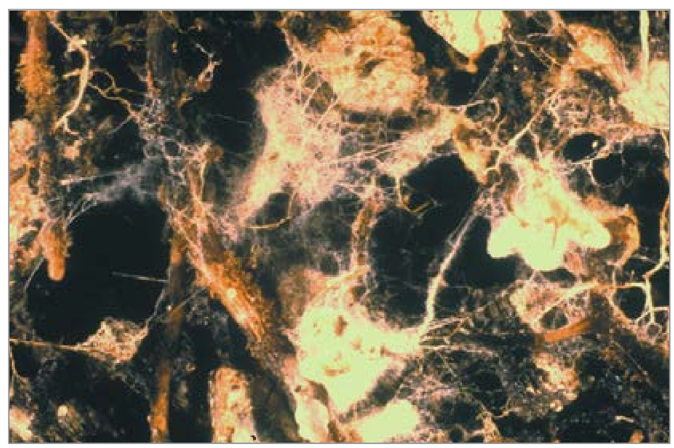

Figure 1. Many plants depend on fungi to help extract nutrients from the soil. These tree roots (brown) are connected to a symbiotic mycorrhizal structure (bright white) and fungal hyphae (thin white strands) that radiate into the soil. Photo provided by Randy Molina, Oregon State University, Corvallis.

Protozoa are another type of biological group that play a key role in nitrogen cycling, because many protozoa prey on bacteria (Figure 2). Protozoa are "messy eaters," which means they release some extra nitrogen into the soil when they feed on bacteria. The nitrogen they release is in a form that is available for crops to take up right away.

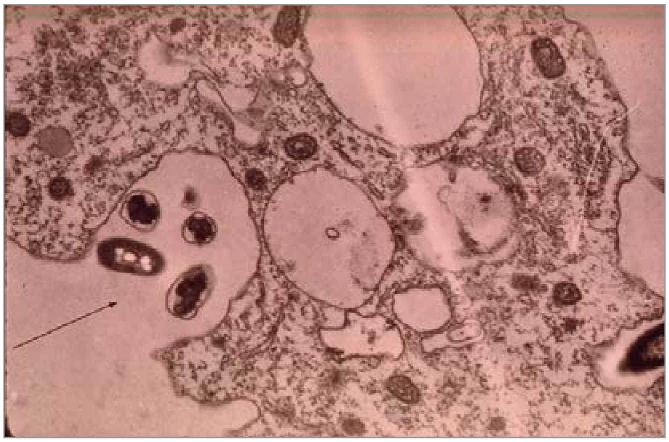

Figure 2. This photo shows an amoeba (a type of protozoa) surrounding and ingesting several bacteria (the dark oval shapes on the left). Photo source: Soil Microbiology and Biochemistry Slide Set. 1976. J.P. Martin, et al., eds. SSSA, Madison, WI.

By numbers, the largest biological group in soil are bacteria (Figure 3). While it is important to have plenty of bacteria to break down residues, a soil microbial community with only bacteria will not be able to function as well as diverse one that contains plenty of fungi and protozoa.

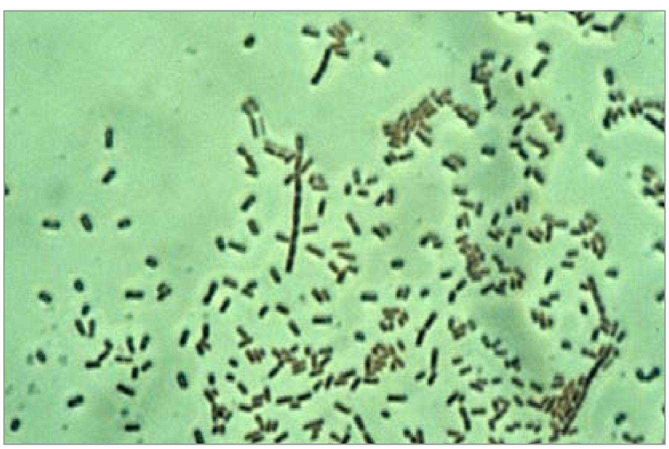

Figure 3. A ton of microscopic bacteria may be active in each acre of soil. Photo provided by Michael T. Holmes, Oregon State University, Corvallis.

While soil biology tests don't directly include an overall soil health score, the results sometimes include ratios of fungi to bacteria or microbe diversity ratings. These measures provide an index to help compare the diversity of the microbial communities in different samples.

Two of the commercial soil health tests we used — phospholipid fatty acid (PLFA) and Earthfort Soil Food Web Biology — focus entirely on soil biological properties. The two tests differ primarily in the methods they use to assess groups of microorganisms.

When you evaluate the results of biological tests, it is important to remember that there is no standard threshold for any microbial group. In general, you want to see higher overall microbial biomass (number), because this indicates a larger microbial community. However, it is also valuable to look at some specific microbial groups to evaluate how well the microbial community may perform its roles in soil functions.

Four Types of Soil Health Tests

1. Phospholipid Fatty Acid (PLFA) Tests

One approach commonly used to describe the soil biology is the phospholipid fatty acid (PLFA) test. PLFA are structural molecules found in the membranes of all active organisms. Certain fatty acids are used to indicate the bacteria, fungi, or other types of microbes, so quantifying the fatty acid content in a soil sample can indicate the size of a specific microbial group as well as the size of the entire microbial biomass.

In our studies, we used the PLFA tests offered by Ward Laboratories and Missouri Soil Health Assessment Center, but there are several commercial laboratories that provide PLFA soil analyses. It's important to note that PLFA test results may differ from lab to lab. This is because each lab may use somewhat different fatty acids as key markers, because there are multiple different recommendations in the scientific literature.

The key for farmers and consultants is to be consistent and compare apples to apples by using the same lab and making sure they have not changed their PLFA markers. Some labs may report results for more microbial groups than the ones discussed above — in this publication, we focused on the broad microbial groups that are generally expected to contribute to soil health. Labs may provide other microbial groups (such as actinobacteria, rhizobia, gram-positive and gram-negative bacteria), which may be useful for evaluating very specific interests (such as soil aggregation, the need for soil inoculation, or stress tolerance).

2. Soil Food Web Biology

For the most part, the Earthfort Soil Food Web Biology test focuses on the same groups of microbes as PLFA, but this test uses microscopy to determine the relative abundance of these microbial groups and their activity. It also distinguishes active bacteria and fungi from totals of both groups.

3. Cornell Comprehensive Assessment of Soil Health

The Cornell Comprehensive Assessment of Soil Health is a commercial soil health test that measures and rates 12 different soil attributes, and then combines them to form an overall quality score (out of 100). The 12 measurements include four each of:

- Biological soil properties
- Physical soil properties
- Chemical soil properties

The four measurements in the Cornell assessment that are related to soil biological properties are: soil organic matter, active carbon, protein, and respiration.

Since soil organic matter affects all these properties, it is often used as the most important indicator of overall soil health. But it usually requires several years to document changes. So, we use other measurements that may show more rapid changes but are directly related to the cycling of carbon in organic matter.

Active carbon and soil protein measure the readily available organic matter, which is the fraction of the organic matter that microbes can easily access as food. Soil respiration measures microbial activity in the soil, which the Cornell test measures over a 96-hour period.

The four measurements of physical soil properties in the Cornell assessment are: aggregate stability, available water capacity, surface hardness, and subsurface hardness. Aggregate stability is a good indicator of soil structure (Figure 4). A high aggregate stability can prevent crusting and increase water infiltration. Aggregate stability generally increases as the amount of organic matter increases.

Figure 4. Stable soil aggregates are seen as a sign of good soil health. Photo by Nicole Benally, Purdue University.

Available water capacity measures the amount of water the soil can hold and that plants are able to access. While soil texture (sand, silt, and clay content) primarily determines available water capacity, this measurement also increases as the amount of organic matter increases.

A surface and subsurface hardness test measures the strength of the soil, which can indicate restrictions on root growth or water infiltration.

The four measurements of chemical properties in the Cornell assessment are similar to those found in traditional soil tests: soil pH, phosphorus (P), potassium (K), and micronutrients.

4. Haney Soil Health Nutrient Tool

The Haney Soil Health Nutrient Tool measures biological activity (respiration). The tool also provides several different measures of nitrogen (N), phosphorus (P), and potassium (K), which is an attempt to estimate the availability of these nutrients over the course of the growing season.

The soil health parameter that is unique to the Haney test is water extractable organic carbon and nitrogen, which measures the portion of organic matter that dissolves in water (and therefore is more accessible to soil microbes).

The Haney Soil Health Nutrient Tool also provides a Soil Health Calculation, which combines the water extractable organic carbon and nitrogen result with soil respiration. While there is no threshold that indicates high soil health, an increase in the number over time indicates improving soil health.

INDIANA FIELD TRIALS WITH SOIL HEALTH TESTS

Purdue researchers established field trials across Indiana at 14 farmer sites and three Purdue Agricultural Centers in 2013. Most of the treatments at these sites consisted of cover crops versus no cover crop on fields already in long-term no-till. Researchers also compared some neighboring fields with conventional tillage without cover crops. Researchers collected soil samples each year and sent them to commercial laboratories for the four soil health tests discussed in this publication.

Our analyses showed some differences between soil health test results on no-till plots with and without cover crops, but not as many as we expected to see. There were several more differences between these conservation cropping systems and conventional comparisons, which used tillage but no cover crops.

A key factor may be the short-term (two to three years) addition of cover crops to relatively long-term no-till systems that may already have had fairly good soil health.

Detailed results from all test sites are available on the Conservation Cropping Systems Initiative website, www.ccsin.org.

Challenges and Recommendations

The soil health tests we used in our studies have shown some differences as a result of cover crop and no-till use in annual cropping systems. Although the tests are a promising tool for farmers and advisors to gauge improvements in soil health, some challenges must be addressed before we can recommend their widespread use, especially for soil biology measurements.

These challenges are:

- **These tests are snapshots in time**. As such, they particularly limit our understanding of the soil biology. Organisms cycle rapidly in response to weather, organic additions, plant growth, and other factors, which makes it difficult to know the best time to sample.
- **Soil biology interpretations are in their infancy, and there are no known thresholds for different organisms to know what is good, bad, or neutral.** Thus, we do not yet understand what a target number would be for most of these tests.
- **Soil organisms vary across a field based on known factors (such as topography, texture, and organic matter) and unknown factors.** This variability suggests that farmers should take samples in relatively small, well-characterized areas of a field.

Although we are not confident about recommending the widespread use of soil health tests, we do recommend ways to improve their potential usefulness if you decide you want to try some analyses to gauge progress over time in a field.

If you use a soil health test, we recommend you:

Choose Your Lab and Test(s), Then Stick with It

Different labs use different methods, and you will not be able to gauge progress if you switch to a different lab (Figure 5).

PLFA Measurements	2015 Ward Laboratories (ng/g)	2017 Missouri Soil Health Assessment Center (nmol/g)
Total Microbial Biomass	1,790	103.8
Total Bacteria	1,083	58.7
Total Fungi	101	1.78
Mycorrhizal Fungi	23	4.35
Protozoa	8.4	0.71

Figure 5. It is important to choose a lab and stick with them over multiple years. This table shows PLFA test results from a no-till cover crop treatment at a Purdue Ag Center in two different years. The results were analyzed by two different labs, which used different markers for some of the microbe groups. Note that the results were reported in different units, which made it impossible to directly compare the results (and there is no direct way to convert units).

Pick Your Spot(s)

Choose a few locations in a field, and make sure to mark those points (or use a global positioning satellite (GPS) device) for future sampling. You can pull multiple soil probes within that relatively small area of the field (perhaps 20-30 feet in diameter) and combine them into one sample for the lab, and then return to that same area the next time you sample. If you want to check multiple areas in a field, keep those areas as separate samples.

Be Consistent

Sample at the same time of year, with the same cash crop, the same relative row position, and the same depth each time you sample (Figure 6).

Our preliminary studies suggest that the best time to detect differences due to overwintering cover crops may be about three to five weeks after cover crop termination (or between the V3-V6 stages of corn). The organisms are active and working on decomposing the cover crop residues. If that timing does not work well for your operation, then choose another time, but stick with the time you chose in subsequent years.

The particular cash crop you are growing at the time does affect the analyses, so choose a crop you are likely to keep in the rotation (that is, corn or soybean, even if it is not always a two-year rotation) and then always sample within that crop.

PLFA Measurements	Corn (nmol/g)	Soybean (nmol/g)
Total Microbial Biomass	74.4	78.1
Total Bacteria	41.2	43.1
Total Fungi*	1.06	1.29
Mycorrhizal Fungi	3.62	3.84
Protozoa*	0.18	0.23

Figure 6. A consistent cash crop during sampling is important for comparing soil health test results. This table shows the average PLFA results from corn and soybean plots at a Purdue Ag Center in 2017. While only two of the microbial groups were statistically different between the two cash crops (as indicated by an asterisk), the general trend indicated by these results highlight how the cash crop can affect PLFA and complicate monitoring if you fail to test the same cash crop each time. All results were from the Missouri Soil Health Assessment Center.

We suggest sampling soil to a 4-inch depth rather than 6- or 8-inch depths. We also recommend not sampling near the cash crop row, but nearer the mid-row (but, avoiding banded fertilizer), to more directly measure the effects of the cover crop rather than the cash crop.

If possible, sample when the soil is moist — not saturated and not very dry. Organisms respond rapidly to changes in soil moisture and results from one year when soil was near optimal moisture and another when the soil was bone dry will not provide a true assessment of changes over the years.

Figure 7. Be sure to sample soils consistently about every two years and track trends over four- to six-year periods.

Track Changes Over Time

Perhaps repeat the chosen test(s) every two years so that you can detect trends over a four- to six-year period (Figures 7 and 8). Since there are currently no established values for healthy soils, the approach is to look for changes over time that arise from improved management. Multiple samples over time are needed to detect changes.

	Soil Health Measurements	2013	2015
Cornell Comprehensive Assessment of Soil Health	Quality Score	44.4	57.1
	Aggregate Stability (%)	29.7	19.1
	Organic Matter (%)	2.57	2.83
	Active Carbon (ppm)	377	444
Haney Soil Health Tool	Water Extractable Organic Carbon (ppm)	132	140
	Water Extractable Organic Nitrogen (ppm)	11.3	10.2
	Soil Respiration (ppm)	28	78
	Soil Health Calculation	4.8	10.2

Figure 8. It is important to track soil health test changes over time. This table shows Cornell Comprehensive Assessment of Soil Health and Haney Soil Health Tool results for 2013 and 2015 of a no-till cover crop treatment at a Purdue Ag Center. Most of the soil health measurements increased in the two years between tests, but some (aggregate stability and water extractable organic nitrogen) did not. These results indicate a general improvement in soil health at this site, but we need to take a closer look at the measurements that decreased during that same time period.

Interpret with Caution

Many of the soil health tests, particularly those focused on soil biology, are highly variable (Figure 9). Even if you see large differences over time, don't jump to conclusions about whether your soil's health is increasing or decreasing. Because of the highly variable nature of these tests, it will be difficult to determine if those differences are real or just due to random error. You will need tests over multiple years to determine if a trend is consistent or not.

	Corn	Soybean
Strip 1	84.3	85.7
Strip 2	71.2	74.6
Strip 3	67.8	73.9
Average	**74.4**	**78.1**

Figure 9. Remember that soil health test results can vary greatly. This table shows individual PLFA values for Total Microbial Biomass that comprise the average values shown in Figure 6. While the difference between the corn and soybean averages seems fairly large (74.4 vs. 78.1 nmol/g), there is a large variation among the three strips and a large overlap in values between the corn and soybeans. Thus, we cannot be confident that differences in the averages are significant.

Focus on Large Management Changes

You are more likely to be able to see differences if you make larger management changes rather than smaller changes (Figure 10). For example, if you have a field that has been conventionally tilled or even had problems with erosion and now is transitioning to no-till and cover crops, it would be a good choice for monitoring with time (Figure 11). These tests are less likely to detect relatively small changes (like adding a cover crop to an already long-term no-till system).

Soil Health Measurements	No-till + Cover Crop	No-Till, No Cover Crop	Tilled, No Cover Crop
Quality Score	71.4	65.8	47.1*
Aggregate Stability (%)	30.3	29.6	29.3
Organic Matter (%)	3.73	3.59	3.10*
Active Carbon (ppm)	718	662	450*
Soil Respiration (ppm)	781	562	452*

Figure 10. Remember to focus on large changes. This table shows results for Cornell Comprehensive Assessment of Soil Health measurements from three treatments on a farm site in 2017. Both the no-till without cover crops and tilled without cover crops treatments were compared to the no-till with cover crops (shaded blue). Statistically significant differences are indicated by an asterisk (*). We saw several differences between the tilled treatment without cover crops compared to the no-till plus cover crops, but no statistical differences when the only difference in treatments was adding cover crops to a long-term no-till system.

Figure 11. Focus on evaluating larger management changes to your system, such as when converting from a tilled system without cover crops to a no-till system with cover crops (as shown in the alternating field strips).

Conclusion

These tests show promise as important tools for gauging the improvements in soil health as you integrate conservation cropping practices into your system. However, these tests are expensive and there are many challenges to using and interpreting them. Keep our recommendations in mind to help optimize the usefulness and value of these tests.

Acknowledgement

The photos for Figures 1-3 come from Soil and Water Conservation Society (SWCS). 2000. *Soil Biology Primer*. Rev. ed. Ankeny, IA: Soil and Water Conservation Society.

Find Out More

If you want to know more about specific results from our Indiana studies on farmer fields and Purdue Agricultural Centers, we have a summary report of the farmer sites, a report on the Purdue Agricultural Centers, and 14 individual farmer site reports on the Conservation Cropping Systems Initiative (CCSI) website,
www.ccsin.org. Go to the "Soil Health Hubs" tab and select "CCSI Interim Reports."

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