Science Societies

Assessing soil health: Putting it all together

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Turning over a vigorous ryegrass, hairy vetch, oat cover crop blend prior to planting tomatoes in Davis, CA.

> The following article is the last in a six-part series on assessing soil health. It synthesizes measurement information and provides an example of how a minimal set of soil health measurements can reflect multiple aspects of soil functioning. It is part of a larger Soil Science Society of America webinar series produced in partnership with The Soil Health Institute and sponsored by The Walton Family Foundation.

It’s a wrap for the six-part Assessing Soil Health series. In this article, we thought it would be useful to synthesize measurement information and provide an example of how a minimal set of soil health measurements can reflect multiple aspects of soil functioning. But first, it is important remember that there is compelling evidence, through 100 partial-budget interviews of corn and soybean farmers, that soil health management systems can have a positive impact on the pocketbook.

Economic Assessment of Soil Heath

Because economics are generally the gatekeeper for those considering adopting soil health management practices (Bagnall et al., 2020), the Soil Health Institute conducted 100 interviews of corn and soybean farmers who have successfully adopted no-till only, or no-till and cover cropping for at least five years. Partial-budget analyses of these farms show that, on average, adopting no-till only or no-till and cover cropping is more profitable. Specifically, adoption of no-till only or no-till and cover cropping resulted in an 85% ($52/ac) and 88% ($45/ac) increase in net income when growing corn and soybean, respectively. Detailed state-by-state reports on the analyses can be found at **https://soilhealthinstitute.org/economics/**. These reports quantify and identify components of soil health management systems that increase and decrease costs and are presented for each state. Interestingly, 97 of the 100 farmers interviewed reported increased crop resilience to extreme weather, and 67 reported a higher yield compared with their conventional system.

Usefulness of Assessing Soil Health

Where to start? Let's review the principles of soil health management:

1. Armor the soil,
2. Minimize soil disturbance,
3. Increase plant diversity,
4. Keep continual living roots, and
5. Integrate livestock.

These management principles do two things. First, they activate the soil microbiology, which is vital to storing and cycling carbon and nutrients and supporting plant health. Second, they build soil structure, which is important to water cycling, building resilience to extreme weather events, and reducing erosion risk. In soil health, we speak of the microbial community as fundamentally important; the community is the engine that drives soil functioning. Just as important is the physical structure in which the microbial community lives and plant roots grow. Soil structure embodies the physical soil state that ensures resilient soil functioning. Soil samples sent to the laboratory contain soil organic carbon and components, nutrients, and microbial measures. When assessing soil structure, we may measure in the lab or in situ and rely on proxy measures of structure that revolve around specific functioning, such as saturated hydraulic conductivity, plant-available water-holding capacity, and wet aggregate stability, to name a few. The measurements assessed in the North American Project to Evaluate Soil Health (NAPESHM; Norris et al., 2020) are in Table 1.

Table 1. A summary of some measurements assessed in the North American Project to Evaluate Soil Health Measurements

Carbon	Nitrogen	Water/Structure	Community
Soil organic carbon	total nitrogen	water-holding capacity	16S amplicon sequencing
Active carbon (POXc)	autoclaved citrate extractable protein (ACE)	saturated hydraulic conductivity	ITS amplicon sequencing
Potentially mineralizable C (24- and 94-hour CO_2–C)	potentially mineralizable nitrogen—anerobic	porosity/bulk density	shotgun metagenomics
β-glucosidase	N-acetyl β-glucosaminidase	soil stability index	phospholipid fatty acid (PLFA)
Water-extractable carbon	water-extractable nitrogen	aggregate stability	enzymes (C, N, P, S)
Microbial biomass carbon	H3A extractable		

Practically speaking, we want to measure soil heath for two basic reasons. First, we want to track how changes in management practices are improving the soil, answering the question, ***"Is a given management moving toward heathier soil?"*** Secondly, we may be very interested in specific soil functioning to address a management or environmental concern. For example, one may want to manage to maximize payments for an ecosystem service or cope with excessive rainfall or drought. That question might be, "***Is this soil performing a given job to the best of its ability, and by how much?"*** The second question is a measure of a specific performance while the first is more general. To answer the first question, soil health measurements collected over time can be used to track change. Or a soil health measurement could be compared to the full soil health potential. Every soil can be healthy; however, because of inherent soil properties and the climate under which a soil has been formed, measures of healthy soils are not always comparable between soils.

To understand how healthy a soil is and how healthy a soil can get, a given measurement of soil health needs to be compared to an expected value for that soil in a prime health state, or a reference state. This concept is evolving in soil science research and in the development of soil health concepts. At the Soil Heath Institute, we use a concept called Soil Health Targets while others have written of the Soil Health Gap (Maharjan et al., 2020) and still others have developed probability distribution functions to describe the continuum of soil health expected (Nunes et al., 2021). All of these concepts recognize that we should be evaluating soil health among soils with similar soil health potential and there is a theoretical "reference state" that represents ideal metrics for soil health for each grouping of soils with similar soil health potential. The methods for grouping soils with similar potential and defining and identifying reference states is an active area of research. Soil Health Targets will be a topic for a future article; in the meantime, you may be interested in reading the previously cited papers.

Soil Sampling for Soil Health

Assessing soil health reliably and consistently starts with collecting the soil sample. Annual soil sampling is recommended; changes in soil health will be difficult to detect in more frequent sampling intervals. Consider that timing, with respect to crop rotation and seasonality, will cause variability in soil health measurements. For example, spring sampling, prior to planting and prior to addition of fertilizers, is recommended, but even with consistent timing, measures of soil organic carbon and microbial activity will vary somewhat after a corn versus a soybean crop.

Plant roots grow through soil, and their growth depends upon the soil properties, especially soil structure; conversely, roots improve soil structure by adding organic matter in soil, which further improves the activity of microbes by acting as food source. This symbiotic relationship is important to improve soil health and productivity. Photo by Saroop Sandhu.

Here are our basic sampling tips:

1. Sample annually;
2. Collect a composite (10 to 15) sample from 0- to 15-cm depth;
3. Sample the same location to compare between years; and
4. Sample at the same time every year.

Measurements of Soil Health

The Soil Health Institute has recently evaluated more than 30 soil health measurements using 124 long-term research sites across Canada, the United States, and Mexico (Table 1). This work along with review of copious scientific articles, and interactions with practitioners with needs for assessing soil health at scale, has led to the Institute thinking about ***assessing soil health through evaluating soil functions of water storage and cycling, carbon storage and cycling, nitrogen cycling, and erosion resistance.*** In this assessment, the Institute has a goal of determining what would be the minimum set of soil health measurements. This minimum set of measurements would allow soil health to be measured and assessed at the scale of U.S. agriculture, which is hundreds of millions of row crop acres.

Sampling soils 0 to 15 cm with a knife slice from a soil pit in North Logan, UT.

Evidence from the NAPESHM project suggests that many soil health measures are co-correlated with organic carbon concentration measurements. Hence, if only one measurement could be taken, it would not be difficult to advocate for measuring soil organic carbon concentration. However, just measuring carbon concentration does not explain other soil functioning. Wet aggregate stability is a popular soil health measurement (Stewart et al., 2018) and responds well to changes in soil management practices in the NAPESHM project. It is an excellent proxy for understanding erosion risk and is also a general proxy for soil structure. Wet aggregate stability is very attractive to be included in a minimum measurement set because an individual can use a smartphone application to quantify aggregate stability outside of a laboratory setting (Flynn et al., 2020). It is a physical measurement that is influenced by the soil chemistry and changes due to management because of biological associations with the minerals.

Another measurement that responds well to management is potentially mineralizable carbon, which is a proxy for microbial activity. Mineralizable C is measured by wetting an air-dry soil sample and measuring respiration of CO_2–C over a 24-hour (Haney test) or 96-hour (Cornell CASH test) incubation period. Other measures that correspond to functioning could be modeled with simple linear regressions. For example, plant-available water is modeled by measures of soil carbon, clay, and sand content (r^2 = 0.60; data in peer review). And N mineralization potential is modeled by measures of soil organic carbon, clay, and sand content and mineralizable carbon (24-hour incubation). There is no replacement for measuring soil infiltration or surface saturated hydraulic conductivity. This time-intensive measurement is very telling and useful for hydrology modeling but is not feasible at scale because of time of measurement and the inherent variability of the soil property. Infiltration and surface hydraulic conductivity may be worthwhile if needed to quantify an ecosystem service. Notice this article did not discuss soil fertility. Soil health assessment and measurement is not meant to replace locally relevant nutrient recommendations, nor is a minimum set of soil health indicators meant to replace specific measures to aid discovery of soil processes (e.g., soil science research).

Summary

Measuring and assessing soil health can be overwhelming. Commercial labs offer their suggested suite of measurements, and research soil scientists are still working to provide standard recommendations for assessing how healthy a soil is and how healthy it can be. But there are actionable items that we do know. We know that (1) evidence exists that adopting soil health management systems can improve on-farm profitability; (2) collecting soil samples for laboratory assessment of soil health is important to benchmark impacts of farm management; and (3) a minimum set of measurements can provide quantitative and useful information for assessing soil health. A minimum set of measurements is important for being able to asses and quantify soil health, at scale, over hundreds of millions of acres in agricultural management.

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