Part II Soil Health Assessment



In-field soil health assessment

Qualitative, on-farm, in-field assessment of soil health does not need to involve special analyses, only the informed observation and interpretation of soil characteristics. This is usually done by visual assessment, but the smell and feel of soil may also be involved. Field test kits for measuring several indicators are also available (e.g. NRCS soil quality test kit). While this approach is more subjective and therefore can reflect user bias, the results can be very informative in making management decisions when detailed guidelines and training have been provided. Guided, in-field assessment can also be particularly effective to increase awareness and understanding of how important it is to maintain healthy soils, and the importance of key soil processes. Some specific soil indicators, such as compaction measured using a penetrometer in the root zone, are always measured better directly in the field than in a laboratory.

Developing and using in-field assessments:

- Participatory processes in developing qualitative soil health monitoring procedures locally have had significant educational value and opened up communication among farmers and between farmers and other agriculture professionals.
- A number of score cards and kits for measuring soil health in the field have been developed (Figure 2.01, following page). These have used more than 30 physical indicators and more than 10 biological, chemical, and crop observation based indicators of soil health. In this approach, soil physical characteristics might be scored for soil 'feel', crusting, water infiltration, retention or drainage, and compaction. Soil biological properties might include soil smell (low score for sour, putrid or chemical odors vs. high score for 'earthy,' sweet, fresh aroma), soil color and mottling (which reflects balance of aerobic vs. anaerobic bacterial activity, among other things), and earthworm or overall biological activity by in-field respiration measures. Crop indicators of soil functioning such as root proliferation and health, signs of compaction (such as thick angular roots), legume nodulation, and signs of residue decomposition can also provide useful information.
- The rating scales used in soil health score cards vary from just a few categories ("poor, fair, or good") to scales of 1 to 10. The descriptions that define categories or rating scales are best based on local terminology and preferences. High quality photographs are an excellent way to train users and achieve somewhat standardized scoring (Figure 2.02.).

Points to remember:

- Training should include information on sampling, standardized verbal descriptions and, if possible, photos that facilitate uniform scoring and keep users on track. Sufficient information regarding interpretation of results is essential
- To the extent possible, comparisons of measurements should be made between samples taken at a similar time of year in relation to field operations, and at a similar soil moisture content and soil temperature



Crusting at the soil surface.



A subsoil plow pan restricts root growth and decreases resilience during extreme weather.

Soil Health Assessment - Part II

1	Ass	es	sme	ent	Sh	eet			
Date			_ Cr	op					
Farm/Field ID Soil Quality	P	oor		М	edi	um	- (Good	ł
INDICATORS	1	2	3	4	5	6	7	8	9
Earthworms				 			 		
Organic Matter				+			+		
Organic Matter				I I			I I		
Subsurface				 			<u> </u> 		
Compaction Tilth/Friability				1 			1 1 1		
Mellowness									
Erosion									
Water Holding Capacity				 			 		
Drainage infiltration				1 			 		
Crop Condition							 		
рН				 			 		
Nutrient Holding Capacity				 			- 		
Other (write in)				 			 		
				- I			I		

FIGURE 2.01. Example score card from the Maryland Soil Quality Assessment Book (1997) published by the Natural Resource Conservation Service (available online as a pdf file at <u>bit.ly/NRCSSoilHealthCard</u>).



FIGURE 2.02. While the corn root in a compacted soil (left) cannot access water and nutrients from most of the soil volume, dense rooting (right) allows for full access. High quality photographs like these are an excellent way to train users and achieve standardized scoring. *Source: Building Soils for Better Crops*

Development of Cornell 's Comprehensive Assessment of Soil Health

Soil health is a concept that deals with the integration and optimization of the chemical, physical, and biological processes of soil that are important for sustained productivity and environmental quality (Figure 2.03). Over the years the concepts and understanding of the importance of the soils' chemical and even physical properties have been well accepted in the agricultural community as a whole. However, it has not been until more recently that the importance of understanding and managing the soil's biological properties has moved beyond a few leading innovative producers and scientists, to become a focus in broader circles. Scientific research and a larger group of producers are now making significant progress on assessing and managing soil biological functioning in diverse agricultural production systems.





While soil nutrient (chemical) testing has long been available to farmers, physical and especially biological testing had largely remained only in research labs until the first version of the Cornell Assessment of Soil Health was made publicly available in 2006. As the stakeholder community converges on standards for more comprehensive assessment of soil health, and national awareness is bringing about wide adoption, we hope that public and private labs integrate more comprehensive soil health testing, and management suggestions, into their offerings. This can lead to a future where soil testing will involve a more comprehensive testing of soil health for the average land manager.

Our approach...

The Cornell Soil Health Team has been working to address soil degradation issues that have resulted in reduced soil health, lower crop productivity and farm profitability. Among the causes of soil degradation are soil compaction, surface crusting, low organic matter, increased pressure and damage from diseases, weeds, insects and other pests, as well as lower abundance, activity, and diversity of beneficial organisms. To address these issues, a group of interested growers, extension educators, researchers and private consultants and funders established a Program Work Team with support from Cornell Cooperative Extension in the early 2000's. One of the major accomplishments was the development of an initial cost-effective protocol for assessing the health status of soils in New York and the Northeast region.

The protocol has been revised over the years, and is the outcome of a process where many potential indicators were evaluated for their use in standardized, rapid, quantitative assessment of soil health based on relevance to key soil processes, response to management, complexity of measurement, and cost (Table 2.01). An electronic copy of the current Standard Operating Procedures is available at <u>bit.ly/</u> <u>SoilHealthSOPs</u>.

In order to evaluate the many indicators for soil health assessment, soil samples were collected from replicated research trials, grower demonstration trials and from fields of interested growers from across New York State (Figure 2.04, following page) and later Pennsylvania, Vermont, Maryland, New Hampshire, and other parts of the Northeast. The replicated research sites represent different vegetable and field crop production systems being managed using different practices in various combinations.

TABLE 2.01. Potential indicators that were initially evaluated for use in the soil health assessment protocol.

Physical	Biological	Chemical
Texture	Root pathogen pressure assessment	Phosphorus
Bulk density	Beneficial nematode population	Nitrate nitrogen
Macro-porosity	Parasitic nematode population	Potassium
Meso-porosity	Potentially mineralizable nitrogen	рН
Micro-porosity	Cellulose decomposition rate	Magnesium
Available water capacity	Particulate organic matter	Calcium
Residual porosity	Active carbon	Iron
Penetration resistance at 10 kPa	Weed seed bank	Aluminum
Saturated hydraulic conductivity	Microbial respiration rate	Manganese
Dry aggregate size (<0.25 mm)	Soil proteins	Zinc
Dry aggregate size (0.25 - 2 mm)	Organic matter content	Copper
Dry aggregate size (2 - 8 mm)		Exchangeable acidity
Wet aggregate stability (0.25 - 2 mm)		Salinity
Wet aggregate stability (2 - 8 mm)		Sodicity
Surface hardness with penetrometer		Heavy metals
Subsurface hardness with penetrometer		
Field infiltrability		

Part II - Soil Health Assessment

For example, the Gates Farm in Geneva, NY is a 14-acre research site that consists of a total of 72 plots which represent three tillage (no-till/ridge-till, strip-till, and conventional tillage), three cover crops (no cover, rye, and vetch), and two rotation treatments. One rotation emphasizes continuous high-value vegetable production, while the second rotation includes season long soil-building crops. The grower demonstration sites are side-by-side comparisons of different management practices such as the use of a winter rye cover crop versus no cover crop or using strip tillage versus conventional moldboard plowing prior to planting sweet corn (Figure 2.05). Numerous individual fields of interested growers were also initially sampled in cooperation with county educators in order to build a database on the health status of Northeast soils. The selection of the subset of indicators used in the soil assessment protocol is described further on pages 25-26.



Strdp-fill Plow-till No cover Vetch Grain rye

FIGURE 2.05. The 14-acre long-term soil health research site at Gates Farm in Geneva, NY was established in 2003. The 72 plots represent three tillage systems, three cover crops and two rotation treatments replicated four times. One rotation (plots with green vegetation) emphasizes continuous high-value vegetable production and another rotation includes season long soil-building crops (plots with corn residue).

Comprehensive Assessment of Soil Health Overview

The Cornell Comprehensive Assessment of Soil Health (CASH) protocol emphasizes the integration of soil biological, physical, and chemical measurements. These measurements include soil texture (to help interpret other measured indicators), available water capacity, field penetrometer resistance, wet aggregate stability, organic matter content, soil proteins, respiration, active carbon, and macro- and micro-nutrient content assessment. Additional indicators are available as add-ons, including root pathogen pressure, salinity and sodicity, heavy metals, boron and potentially mineralizable nitrogen. These measurements were selected from 42 potential soil health indicators (page 23, Table 2.01) that were evaluated for:

- · sensitivity to changes in soil management practices;
- ability to represent agronomically and environmentally important soil processes;
- consistency and reproducibility;
- ease and cost of sampling;
- cost of analysis;
- ease of interpretation for users.

The results of these measurements have been synthesized into a grower-friendly comprehensive soil health assessment report with indicator scores, constraint identification, and management suggestions. This report can initially be used by agricultural service providers, consultants and growers as a baseline assessment and guide to prioritization of management focus. Subsequent sampling and analysis of the same field can help determine the impact of implemented soil management practices on soil health. The report is explained in further detail on pages 72-76. Table 2.02 on the following page provides a brief description of each indicator. More detailed descriptions, as well as the basic methodology, how each indicator relates to the functioning of the soil, the interpretive scoring function used to assign a rating score, and comments on managing identified constraints can be found on pages 37-71.

This framework facilitates expansion with future indicators, especially biological assessments, as these become more cost effective and interpretable. It also allows for regionspecific or crop-specific indicators or revised scoring approaches for individual indicators, as further implementations of the framework are established.

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Why assess soil health?

- · Increase awareness of soil health
- Understand constraints beyond nutrient deficiencies and excesses
- Target management practices to alleviate soil constraints
- Monitor soil improvement or degradation resulting from management practices
- Facilitate applied research compare management practices to develop recommendations for farm and field specific soil health management planning
- Land valuation facilitate the realization of equity embodied in healthier soils
- Enable assessment of farming system risk



See the Comprehensive Assessment of Soil health website for the most up-to-date package offerings and pricing: soilhealth.cals.cornell.edu.

	<u>Available Water Capacity:</u> reflects the quantity of water that a disturbed sample of soil can store for plant use. It is the difference between water stored at field capacity and at the wilting point, and is measured using pressure chambers.
SICAL	<u>Surface Hardness</u> : is a measure of the maximum soil surface (0 to 6 inch depth) penetration resistance (psi), or compaction, determined using a field penetrometer.
РНҮЗ	Subsurface Hardness: is a measure of the maximum resistance (psi) encountered in the soil between 6 to 18 inch depths using a field penetrometer.
	Aggregate Stability: is a measure of how well soil aggregates resist disintegration when hit by rain drops. It is measured using a standardized simulated rainfall event on a sieve containing soil aggregates between 0.25 and 2.0 mm. The fraction of soil that remains on the sieve determines the percent aggregate stability.
	Organic Matter: is a measure of all carbonaceous material that is derived from living organisms. The percent OM is determined by the mass of oven dried soil lost on combustion in a 500°C furnace.
	Soil Protein: is a measure of the fraction of the soil organic matter which contains much of the organically bound N. Microbial activity can mineralize this N and make it available for plant uptake. This is measured by extraction with a citrate buffer under high temperature and pressure.
AL.	<u>Soil Respiration</u> : is a measure of the metabolic activity of the soil microbial community. It is measured by re-wetting air dried soil, and capturing and quantifying carbon dioxide (CO_2) produced.
IOLOGIC	Active Carbon: is a measure of the small portion of the organic matter that can serve as an easily available food source for soil microbes, thus helping fuel and maintain a healthy soil food web. It is measured by quantifying potassium permanganate oxidation with a spectrophotometer.
B	Add-on Indicators:
	<u>Root Pathogen Pressure Rating</u> : is a measure of the degree to which sensitive test-plant roots show symptoms of disease when grown in standardized conditions in assayed soil. Assessed by rating washed roots through visual inspection for disease symptoms.
	<u>Potentially Mineralizable Nitrogen</u> : is a combined measure of soil biological activity and substrate available to mineralize nitrogen to make it available to the plant. It is measured as the change in mineralized plant-available nitrogen present after a seven day anaerobic incubation.
	Soil Chemical Composition: a standard soil test analysis package measures levels of pH and plant nutrients. Measured levels are interpreted in this assessment's framework of sufficiency and excess but no crop specific recommendations are provided.
AL	Add-on Indicators:
CHEMICA	Salinity and Sodicity: Salinity is a measure of the soluble salt concentration in soil, and is measured via electrical conductivity. Sodicity is a calculation of the sodium absorption ratio (SAR) and is measured using ICP spectrometry to determine Na ⁺ , Ca ²⁺ , Mg ²⁺ concentrations and using an equation to calculate the absorption ratio.
	<u>Heavy Metals</u> : is a measure of levels of metals of possible concern to human or plant health. They are measured by digesting the soil with concentrated acid at high temperature.

TABLE 2.02. Indicators of the Comprehensive Assessment of Soil Health and what they mean.

Soil Sampling Protocol

Please use our two-page field sheet or view the eight minute video available at <u>bit.ly/SoilHealthSampling</u> Materials list

- Materials list
- 1 large bucket for each sample and one for supplies
- 2 one-gallon freezer storage bag for each sample
- Clipboard and Submission Form (bit.ly/CASHforms)
- Permanent marker and/or pen
- Straight shovel (sharpshooter or drain spade style)
- Penetrometer (optional); <u>Contact lab</u> to borrow
- Cooler for in-field sample storage and transfer
- Ice pack(s) (optional); Only needed for hottest days

Field sampling design

- ASK YOUR BEST QUESTION! Clearly define sampling goals and number of necessary samples.
- **Define sampling goals;** i.e. to assess the current status of a management unit, to identify and troubleshoot constraints in a particular problem area, to compare between different areas on a farm, etc.
- Determine the number of samples to be taken. Decide whether one sample will adequately represent a management unit, or whether an area should be split to compare multiple units. Fields should be divided into sampling units with differences in soil type, management practices, crop growth, yield, etc.
- A. Sampling for General Purposes (1 sample)
- Ideal for sampling uniform fields or areas where you want to assess general needs.
- Baseline assessment before applying treatments.
- Typical in-field soil sub-sample collection strategy. Example A (Figure 2.07 A): In this instance, identify locations within the area you would like to test that are representative of the field or plot. Borders and irregular areas should be avoided, unless a sample is specifically being collected from those areas to identify constraints.
- B. Sampling for Troubleshooting
- (2 or more separate samples)
- Ideal for areas with uneven crop performance or for comparing zones, 'X' vs. 'Y', for example.
- Targeted soil sampling from representative areas of each zone.

Example B: In this instance, identify multiple locations within the two or more areas you would like to test. You don't need to sample the entire field. With targeted sampling, focus on representative areas that will answer a particular question. For example, how is the 2nd year of no-till in zone X affecting the soil health status compared to the long-term plow-till in zone Y?

Sub-sampling and Penetrometer Locations:



Example A: General field sampling (I sample)

one soil health sample.







FIGURE 2.07 A and B. Examples of different sampling goals and how they may affect sampling strategies.



FIGURE 2.06. Materials needed to collect at least

Soil sampling considerations

Soil Health sampling guidelines are similar to those of the <u>standard nutrient analysis</u>. Soil samples can be taken at any time of the year. It is best, however, to establish a regular sampling date, around the same month, to minimize seasonal variation in your results and records. At each of the 5-10 identified sampling stops, collect two soil sub-samples at least 15 feet apart (see field diagrams, previous page). Samples should be taken when soils are at field capacity, before field operations, at a minimum 6" depth. Avoid irregular areas unless a sample is

Steps for taking a soil sample at each location:

- A. Remove surface debris (Figure 2.08 A).
- **B**. Use a drain spade to dig a small hole about 8" deep. From the side of the hole take a vertical, rectangular slice of soil 6" deep and about 2" thick.
- CI.Remove any extra soil to ensure that the sample is the same width at the top and bottom of the slice.
- You want a rectangular, 6" deep x 2" thick slice of soil, the width of the spade. It is important to collect the same amount of soil through the 6" sample profile so that it is not biased with more soil from the surface compared to the subsurface.
- C2.Place into clean pail.
- **D.** Optional At each of the 10 sub-sample locations, <u>collect soil hardness</u> information with a penetrometer. Record maximum hardness (in psi) from the 0-6" and at the 6-18" depth ranges on the <u>Submission Form</u>.
- E. Repeat steps A D to collect the remainder of the sub-samples. Mix thoroughly and transfer 3-6 cups of soil into a clearly labeled one-gallon re-closable freezer bag. The amount of soil required depends on the <u>analysis package</u> selected. See Table 2.03 on the following page for a brief description of each package.



FIGURE 2.08 A - E. The steps of taking a soil health sample. The microorganisms in the soil are sensitive to heat. Keep samples out of direct sunlight and keep as cool as possible during sampling and storage. Store samples in a refrigerator or cold room after returning from the field and ship to Cornell as soon as possible.

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specifically being collected from a problem area to identify constraints.

Following these considerations facilitates proper mixing of sub-samples, prevents soils from smearing during sampling and transport, and ensures appropriate interpretation of field penetration resistance measurements.

NOTE: We do not recommend using a standard soil probe as more cores will need to be collected than a spade to obtain the necessary amount of soil for analysis, and more physical smearing will result, impairing physical indicator measurements.

Pick a package:

TABLE 2.03. Cornell Soil Health Laboratory soil health analysis packages. Select a package depending on your goals.

RECOMMENDED APPLICATIONS	ANALYSIS PACKAGE	NUMBER OF CUPS OF SOIL
Field crops, diary, lawns	Basic	3
Organic production vegetable crops, problem diagnosis, home gardens	Standard	4
Urban/suburban gardens, problem diagnosis, soil health initializing, home gardens, landscaped areas	Extended	6

The Cornell Soil Health Lab offers three types of soil health analysis packages (above). The type of package to select depends on the sampling goals. <u>Visit our</u> <u>website</u> for a complete list of analyses performed for each package. Descriptions of indicators within each package can be found beginning on page 37.

Soil sample storage requirements:

- Always keep samples out of direct sunlight, and if possible, store in a cooler while in the field. High temperatures in a bag of soil will have a detrimental impact on biological indicator measurements.
- Upon returning from the field, store samples in a refrigerator or cold room as soon as possible, cool overnight if necessary, and ship for analysis as soon as possible (see further details below).
- Do not freeze the samples.
- Do not dry the samples.
- **NOTE:** If you are planning on submitting a batch of numerous samples, and have particular sampling considerations to discuss regarding storage or preprocessing, such as for a larger research project, please contact Soil Health Laboratory personnel prior to sampling using the contact information on the <u>soil health laboratory website</u>.

Soil sample shipping to the lab

IMPORTANT: All soil samples shipped to the laboratory need to be **double bagged**. Packing material is required to minimize sample movement during shipping.

For more information on proper packaging and shipping of samples please visit the '<u>Resources</u>' tab on our website (<u>bit.ly/SoilHealthShipping</u>).

A complete sample will consist of:

- One clearly labeled, plastic bag containing 3 to 6 cups of well mixed soil, **double bagged**
- A completed submission form with **state and county entered** and penetrometer readings (optional) clearly recorded
- A shipping box with double-bagged samples, **packing material** and ice packs (on hottest days)

Packaging and shipping requirements:

- Bag each individual sample in a 1-gallon plastic (Ziploc) bag. Freezer bags are preferred. Make sure the bag is properly labeled.
- Double bag your soil sample in a Ziploc bag. You can either place the single sample within another 1-gallon plastic bag or place multiple sample bags in a secondary, larger plastic bag.
- 3. Download and print the <u>Submission Form</u> (<u>bit.ly/CASHforms</u>) (Figure 2.09). Enter the information for each sample. Include your penetrometer readings (optional). Save one copy for your records. **It is important to enter the state and county** from where the soil sample was taken on the form.
- 4. Place the double-bagged sample(s) in a cardboard box. The size of the box depends on the number of samples. In general we recommend a small USPS Flat Rate Box for a single sample or a Priority Mail Medium Flat Rate box for up to 6 samples.
- 5. Place the submission form in the box, on top of the packaging material. Protect the form within its own plastic bag.
- 6.Add packing material (such as crumpled paper or bubble wrap) to minimize sample movement within the box. Add ice packs (also within their own plastic bags) only if shipping during the hottest days of summer. Ice packs and coolers are not returned.

Send samples and submission forms to:

Cornell Nutrient Analysis Lab

c/o Soil Health Lab G01 Bradfield Hall 306 Tower Rd. Ithaca, NY 14853 <u>soilhealth@cornell.edu</u> 607-227-6055

016 Co	brnell As	sessm	ent of	Soil He	Submission Form - PRINTABLE spreadsheet page 1 IMPORTANT INFORMATION RECAPDING chimping SOULS: Fortab Use Only										
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FIGURE 2.09 Sample submission form. Go to <u>bit.ly/CASHforms</u> to download form.

Regulated soils

Soil can contain numerous animal and plant pests, noxious weed seeds, or other materials that have the potential of propagating a harmful organism to the next stage in their life cycle or transmitting diseases. These pests are potentially detrimental to the health and value of agriculture, landscaped areas and natural resources. They include bacteria, plant viruses, fungi, nematodes, and life stages of destructive mollusks, acari, and insects.

Guidance exists from the USDA Animal and Plant Health Inspection Service (APHIS) <u>Plant Protection</u> and <u>Quarantine (PPQ)</u> program, in cooperation with state departments of agriculture and other government agencies, to respond to existing and new plant pests to eradicate, suppress, or contain them. These efforts may be an emergency or longer term domestic programs that target a specific regulated pest. To learn more about current APHIS restricted areas, visit <u>aphis.usda.gov.</u>

In response to the APHIS PPQ program, the Cornell Soil Health Laboratory has categorized three areas of regulated soils - Prohibited, Regulated

and Quarantined – to provide special handling of the samples once they reach the lab. All samples, regardless of the category or whether or not they are regulated, need to be **double bagged** prior to packaging and shipping. Place



Red imported fire ant (Solenopsis invicta). Source: Pest and Diseases Image Library, Bugwood.org

crumpled paper or bubble wrap in the shipping box to minimize sample damage. Figure 2.10 provides general guidance of areas that are likely regulated, prohibited, or may have no restrictions at all.

For more details, including updated regulated areas and downloadable step-by-step instructions on proper packaging and shipping protocols, please visit the '<u>Resources</u>' tab on our website.



FIGURE 2.10. Regulated soils map. *Blue* = no regulated areas; *Purple* = regulated areas in a few counties within the state; *Yellow* = regulated areas in a large portion of counties within a state; *Red* = regulations in areas comprising the entire state. *Source: diymaps.net*

Prohibited Soils: <u>There are certain counties in the</u> <u>United States where soil should neither be packaged</u> <u>nor shipped</u>. Soil received from these counties will be temporarily stored as quarantined samples and destroyed without processing. For a complete list of prohibited counties please visit the '<u>Resources</u>' tab on the soil health website.

Regulated Soils: We can accept soils from most regulated areas throughout the U.S. As with all samples, please be sure to double bag and use packing material to minimize sample damage during shipping. Special lab procedures are required for regulated soils. Please visit the '<u>Resources</u>' tab on our website for more information or visit <u>aphis.usda.gov</u> for a complete, active list of federally regulated soils for the county where your sample is taken.

Quarantined Soils: Quarantined soils are from any area outside the contiguous U.S. Special shipping and lab procedures are required for quarantined soils. You must contact the Cornell Soil Health Lab prior to shipping quarantined soils: <u>rrs3@cornell.edu</u>. Quarantined samples are subject to an additional surcharge.

If you have any question or concerns about packaging and shipping regulated soils, please contact your local lab. The Cornell Soil Health Lab can be reached at <u>soilhealth@cornell.edu</u>.

Scoring Functions

Background

The Cornell Comprehensive Assessment of Soil Health (CASH) scoring functions for each indicator were originally developed to interpret our soil health measurements by adapting work of Andrews et al. (2004)¹. In the context of our soil health assessment, the scoring functions convert a value for a specific indicator to an interpretive rating via a curve that assigns scores between 0 and 100 to the measured values. Most physical and biological indicators are given higher scores for higher measured values, while some are given higher scores for lower measured values (i.e., surface and subsurface hardness, root health rating). Chemical indicators are assigned high scores for measured values that fall within the optimum range for most soils. Outside this range, scores decrease with increasing difference between measured and optimal values.

Since scoring functions for some indicators depend strongly upon soil textural class, several indicators require separate scoring functions for coarse, medium, and fine textured soils. These were developed based on the observed distribution of measured values for the indicators in regional soils of similar texture.

Scoring curves for each indicator have been determined by estimating the cumulative normal distribution function using the mean and standard deviations of samples in the Cornell Soil Health Lab (CSHL) database. Originally, scoring curves were established from data collected across the Northeastern United States. In the years since, the CSHL database has expanded to include a much greater number and spatially diverse set of samples representing over 60% of the U.S. and several countries throughout the world.

During 2014 and 2015 the first round of revisions to the scoring functions occurred using the higher relative sample size. Accompanying these changes was replacing the Potentially Mineralizable Nitrogen (PMN) test with both the Soil Respiration and the Autoclaved Citrate Extractable (ACE) Protein Assay as Biological Indicators.

Regional updates

In 2016, several significant adjustments were made and incorporated into assessment reports. New in 2016 is the preliminary development of regional scoring functions for Physical and Biological Indicators. The CSHL has sufficient sample sizes to investigate NRCS-defined Major Land Resource Areas (MLRA) Regions L, M, N, R and S, which include the Northeast and significant portions of the Midwest and Southeast United States (USDA and NRCS, 2006)² (Figure 2.11).

Our investigation found evidence of significant differences in the mean indicator values between these five regions for all indicators except Surface and Subsurface Hardness and Soil Respiration. In an effort to increase the scope of our database to soils outside the Northeast, the updated scoring functions (all indicators and textural classes) were calculated as the overall mean of the mean and standard deviation of each MLRA Region. This approach accounts for: 1) regional differences in mean indicator values, and 2) unequal sample sizes between regions.



FIGURE 2.11. USDA-NRCS Major Land Resource Area (MLRA) Regions L, M, N, R and S of the Midwest and Eastern United States. *Modified from USDA-NRCS*





For illustration on how scoring curves are developed, the histogram in Figure 2.12 above shows the observed distribution of measured values of active carbon (Active C) for medium textured soils in the CSHL calibration set. The height of the bars depict the frequency of measured values that fall within each range (bin) along the horizontal (X) axis. In this case, all medium texture Active C values were separated into bins in increments of 100 covering the entire range of concentration values (0-100, 100-200, ..., 1200-1300). For instance, approximately 24% of the soil samples in this set had measured Active C concentrations falling between 500 and 600 parts per million (ppm). The normal distribution, or bell curve, superimposed over the bars was calculated using the mean (531 ppm) and standard deviation (182 ppm) of all medium textured soils.

Cumulative Normal Distribution

We used the mean and standard deviation of our data set to calculate the cumulative normal distribution (CND). The CND function is essentially the scoring function, as it provides the score on a scale ranging from 0-100. Figure 2.13 includes the CND function for Active C (ppm) plotted on the horizontal axis and score on the vertical axis. For example, a medium textured soil with measured Active C of 600 ppm would be given a score of 60, as indicated by the red lines drawn on the figure. In practical terms, this means that 60% of medium textured soil samples in the CSHL calibration set had Active C values lower than or equal to that of the sample being scored. NOTE: A score of 50% is associated with an Active C value of 531 ppm, the mean of the normal distribution.

This approach can be adapted to regions with different soils and climate as scoring functions should be adjusted to fit different conditions for more appropriate interpretation. For example, this framework was applied to a region in Western Kenya (Moebius-Clune et al., 2011)³. In addition, future work to score measured values based on specific land management practices or outcomes such as yield, crop quality, risk, and environmental considerations (as available for standard nutrient testing) is needed.

Cumulative Normal Distribution functions for all indicators along with coarse, medium, and fine textured soils were calculated using the same approach as for active carbon.

As part of the CASH Report Summary (Figure 2.14, page 35), indicator scores are assigned a color rating. The assessment traditionally used a three color system (red, yellow, green for low (0-30), medium (30-70), and high (70-100), respectively).



FIGURE 2.13. Cumulative normal distribution for scoring active carbon in silt soils. In this example, 60% of medium textured soil samples in the calibration set had Active C contents lower than or equal to the sample being scored.

In 2016, the report began using a five-color system - red, orange, yellow, light green, and dark green for very low, low, medium, high, and very high, respectively. See the following page for an example summary report.

We used the following values to set thresholds for rating soil health indicators:

- i. Scores between 0 and 20 are considered very low (red)
- ii. Scores between 20 and 40 are considered low (orange)
- iii. Scores between 40 and 60 are considered medium (yellow)
- iv. Scores between 60 and 80 are considered high (light green)
- v. Scores between 80 and 100 are considered very high (dark green).

The lower the score, the greater the constraint in the proper functioning of processes as represented by the indicator. Land management decisions should therefore place priority on correcting this condition (see Part III of this manual). Low and medium scores do not necessarily represent a major constraint to proper soil functions, but suggest places for improvement in management planning. High or Very High scores suggest that the soil processes represented by these indicators are likely functioning well. As such, management goals should aim to maintain such conditions. A more detailed description of the summary report is provided beginning on page 72.

After all indicators are scored and colored appropriately, a soil health overall quality score is computed as the unweighted average of all individual indicator scores. The overall rating of the soil sample follows the logic of the individual indicator scores (see above). This score may be useful in some cases for making relative comparisons, but it is generally advised that greater attention be paid to the scores of individual indicators and the identification of constraints to proper functioning of important soil processes.



The Cornell Assessment of Soil Health identifies biological and physical soil constraints in addition to conventional soil testing. From left to right: wet aggregate stability, root pathogen pressure and soil protein tests in the lab.

Comprehensive Assessment of Soil Health

From the Cornell Soil Health Laboratory, Department of Soil and Crop Sciences, School of Integrative Plant Science, Cornell University, Ithaca, NY 14853. http://soilhealth.cals.cornell.edu



Grower: Bob Schindelbeck	Sample ID:	LL8
306 Tower Rd. Ithaca, NY 14853	Field ID:	Caldwell Field- intensive management
	Date Sampled:	03/11/2015
Agricultural Service Provider:	Given Soil Type:	Collamer silt loam
Mr. Bob Consulting rrs3@cornell.edu	Crops Grown:	WHT/WHT/WHT
	Tillage:	7-9 inches

Measured Soil Textural Class: silt loam

Sand: 2% - Silt: 83% - Clay: 15%

Group	Indicator	Value	Rating	Constraints
physical	Available Water Capacity	0.14	37	
physical	Surface Hardness	260	12	Rooting, Water Transmission
physical	Subsurface Hardness	340	35	
physical	Aggregate Stability	15.7	19	Aeration, Infiltration, Rooting, Crusting, Sealing, Erosion, Runoff
biological	Organic Matter	2.5	28	
biological	ACE Soil Protein Index	5.1	25	
biological	Soil Respiration	0.5	40	
biological	Active Carbon	288	12	Energy Source for Soil Biota
chemical	Soil pH	6.5	100	
chemical	Extractable Phosphorus	20.0	100	
chemical	Extractable Potassium	150.6	100	
chemical	Minor Elements Mg: 131.0 / Fe: 1.2 / Mn: 12.9 / Zn: 0.3		100	

Overall Quality Score: **51** / Medium

FIGURE 2.14. Example summary report page for a conventional small grain operation. The report is described further on page 72, and a full report including interpretive text is included in Appendix A. Because producers generally manage soil nutrient levels and pH carefully, using standard soil testing, chemical soil health is often found to be in the optimal range (100 rating and dark green in example above). Constraints are more frequently found in physical and biological health, because these aspects of soil health have not previously been tested and explicitly managed (< 20 rating and in red in example above). Orange and yellow-colored ratings should be monitored but are not necessarily a priority for management at this time.



A. More is better graph



B. Less is better graph



C. Optimum graph

FIGURE 2.15 A-C. Three general scoring curve types, depending on the indicator that is evaluated.

Scoring Types

Three general types of scoring are used, whether the curve shape is normal, linear, or otherwise. These are described below:

A. More is Better:

In this situation, the higher the measured value of the indicator, the higher the score until a maximum score of 100 is attained (Figure 2.15 A). Values exceeding this maximum are assigned a score of 100. Indicators falling in this class include Aggregate Stability, Available Water Capacity, Organic Matter Content, ACE Protein, Soil Respiration, Active Carbon, and Potentially Mineralizable Nitrogen. Scoring functions for these indicators are calculated as

Score = 100*CND.

As for Chemical Indicators, potassium content is scored as 'more is better' as well, dependent on established outcome-based thresholds. Micronutrients Magnesium and Zinc are associated with risk of deficiency, so higher values are assigned better scores.

B. Less is Better:

For a few indicators, lower measured values are associated with better soil functioning (Figure 2.15 B). This is the case for Surface and Subsurface Hardness and the Root Health Bioassay Rating. Scoring functions for these indicators are calculated as

Score = 100*(1 - CND).

Manganese and Iron are scored as 'less is better' because these micronutrients are associated with a risk of toxicity from excess levels.

C. Optimum Curve:

Extractable Phosphorous and pH are both scored using an optimum curve (Figure 2.15 C). In this case, the scoring curve rises with increasing measured value until the lower end of the optimum range is reached. Within the optimum range, scores are always 100. Values exceeding the optimum range follow a scoring curve with a negative slope which decreases with further increases in measured value.

Soil Health Indicator Laboratory Protocols and Scoring Functions

Soil Health indicators were selected for the assessment using criteria discussed on page 23, such as their sensitivity to management, changes in measurement consistency and reproducibility, ease and cost of sampling and cost of analysis. The following pages provide a detailed description of each indicator, how it is measured, how it relates to soil functioning and the interpretive scoring function used to assign a rating score.

An electronic copy of the <u>Standard Operating Procedures</u> (2016)⁴ for the suite of physical and biological analyses offered from the Cornell Soil Health Lab (CSHL) is available under the 'Resources' tab <u>on our website</u>.

Soil Texture

Most of a soil's solid material is made up of a mixture of variously sized mineral particles, the relative amounts of which determine a soil's texture. The textural class is defined by the relative amounts of sand (0.05 to 2 mm particle size), silt (0.002 to 0.05 mm), and clay (less than 0.002 mm), as seen in the textural triangle (following page). Particles that are larger than 2 mm are called coarse fragments (pebbles, cobbles, stones, and boulders), and are not considered in the textural class, although they may help define a soil type. Organic matter is also not considered in the determination of soil texture, although it is very important for soil functioning, as we will further discuss (page 47). A soil's textural class—such as a clay, clay loam, loam, sandy loam, or sand—is perhaps its most fundamental inherent characteristic. It affects many of the important physical, biological, and chemical processes in a soil, but is not easily altered by management, and changes little over time. Thus, while texture is not a soil health indicator per se, it informs the interpretation of most soil health indicators.

Basic Protocol (adapted from Kettler et al.)⁵:

- Air dry a portion of the soil sample and sieve past 2mm.
- Approximately 14g (+/- 0.1g) of sieved soil is added to a 50ml centrifuge tube containing 42ml of a dispersant solution (3% sodium hexametaphosphate, a detergent).
- Shake vigorously on reciprocating shaker for 2 hours to fully disperse soil into suspension.
- Wash entire contents of centrifuge tube onto a sieve assembly (Figure 2.16 A). Sieve assembly consists of 0.053mm sieve on top of a plastic funnel above a 1L beaker. Rinse all material through the sieve. Sand captured on top of the sieve is washed into a tared metal can and set aside (B).
- Silt and clay particles collected in the 1L beaker are re-suspended by stirring and allowed to settle for 2 hours (C). The clay in suspension is then carefully decanted. The settled silt is washed into a second tared can. Both tared cans (one containing the sand fraction and the other the silt fraction) are dried at 105° C to constant weight before recording dry weight.

Calculate percent sand, silt clay from: Sand (%) = dry wt sand (g)/dry wt (g) soil added to centrifuge tube.
Silt (%) = dry wt silt (g)/dry wt (g) soil added to centrifuge tube.
Clay (%) = 100% - Sand (%) - Silt (%).







FIGURE 2.16 Steps to determining soil textural class in the lab.

How soil texture relates to soil function:

Texture affects many important soil processes due to the total amount of pore space and how varied pore space is within aggregates. Soils with higher clay contents generally have higher ability to retain nutrients (more cation exchange capacity, or CEC, discussed previously) and can accumulate, or sequester, more organic matter. The size distribution of the particles strongly influences the size of the pore spaces between the particles, the formation and stabilization of soil aggregates, and the spaces between these aggregates. These aggregates and inter- aggregate spaces are as important as the sizes of the particles themselves, because the relative quantities of variously sized poreslarge, medium, small, and very small-govern the important processes of water and air movement. These in turn affect processes like water infiltration, permeability, water storage, aeration, nutrient leaching, and denitrification. In addition, soil organisms and plant roots live and function in the pores. When the soil loses porosity (generally due to management), roots cannot grow as well, and many organisms have more difficulty surviving. Most pores in a clay are small (generally less than 0.002 mm), whereas most pores in a sand are large (but generally still smaller than 2 mm).

On the one extreme of the texture and aggregation spectrum, we see that beach sands have large particles (in relative terms) and very poor aggregation due to a lack of organic matter or clay to help bind the sand grains. A good loam or clay soil, on the other hand, has smaller particles, but they tend to be aggregated into crumbs that have larger pores between them and small pores within. Although soil texture doesn't generally change over time, the total amount of pore space and the relative amount of variously sized pores are strongly affected by management practices.

Using texture in developing scoring functions

Soil texture contributes to inherent soil quality, the characteristics of the soil that result from soil forming processes. It is virtually unchangeable through soil management for a particular soil and is therefore not scored as part of a soil health assessment. Information on soil texture, however, is very valuable by itself for planning management practices. Moreover, soil textural information is used to score most of the other soil health indicators. because interpretations are best made in light of interactions with soil texture. For example, given the same management, coarse textured soils like loamy sands generally have lower organic matter levels than fine-textured clay loams, because they lack the ability to stabilize organic matter through organo-mineral bonds. Measured organic matter contents, along with other indicators, are scored relative to an appropriate distribution for soils of a particular textural grouping, to account for this type of difference. In the soil health assessment scoring process, we distinguish between coarse-textured (sand, loamy sand, sandy loam), medium-textured (loam, silt loam, silt, sandy clay loam) and fine-textured (clay loam, silty clay loam, sandy clay, silty clay, and clay) soils.

CSHL Soil Texture <u>Standard Operating Procedures</u> (CSH 02) can be found under the 'Resources' tab on our <u>website</u>.



Textural triangle used in determining soil texture. Soils with different properties of sand, silt and clay are assigned different classes. Adapted from: USDA-NRCS

Available Water Capacity

Available Water Capacity is an indicator of the range of plant available water the soil can store. In the field, a soil is at the upper end of soil wetness when water that it can't hold against gravity has drained - this is called field capacity. The lower end of the range is called the 'permanent wilting point', when only water unavailable to plants, also called hygroscopic water, is left. The water stored in the soil against gravity is plant available until it decreases to the permanent wilting point. Available Water Capacity is determined from measuring water content at field capacity and permanent wilting point in the lab, and calculating the difference.

Basic Protocol (adapted from Reynolds et al.)6:

- Soil is placed on two ceramic plates with known porosity, and wetted to saturation (Figure 2.17 A).
- The ceramic plates are inserted into two high pressure chambers to extract the water to field capacity (10 kPa), and to the permanent wilting point (1500 kPa) (B).
- After the sample equilibrates at the target pressure, the sample is weighed (C), then oven-dried at 105° C overnight, and then weighed again once dry.
- The soil water content at each pressure is calculated, and the available water capacity can then be calculated as the soil water loss between the 10 and 1500 kPa pressures.



FIGURE 2.17 A-C (A) Ceramic plates with soil are (B) inserted into high pressure chambers. (C) Equilibrated samples at target pressure Samples are weighed and then oven dried overnight.



FIGURE 2.18. Water storage for two soil textural groups. The blue shaded area represents water that is available for plant use.

How AWC relates to soil function

Available Water Capacity is an indicator of how much water per weight of soil can be stored in the field, and therefore how crops will fare in droughty conditions. Soils with lower storage capacity will cause greater risk of drought stress. Water is stored in medium and small sized soil pores and in organic matter. Sandy soils, which tend to store less organic matter and have larger pores, tend to lose more water to gravity than clayey and loamy soils (see Figure 2.18).

A common constraint of sandy (coarse textured) soils is their lower ability to store water for crops between rains, which is especially a concern during droughty periods, and in areas where irrigation is costly or not available. In heavier (fine textured) soils, the available water capacity is generally less constraining, because they naturally have high water retention ability. Instead, they are typically more limited in their ability to supply air to plant roots during wet periods, and to allow for enough infiltration to store water if rains come infrequently in heavy events. Note that total crop water availability is also dependent on rooting depth, which is considered in separate indicators, surface and subsurface hardness.

A guide to demonstrating how soil structure can impact water storage is available under the 'Resources' tab on our <u>website</u>.

Managing constraints and maintaining optimal available water capacity

Available water capacity can be improved in the short term by large additions of stable organic materials, such as composts, or possibly biochar, that themselves can store larger amounts of water. Mulches may be used to prevent limited water from evaporating. In the long term, building organic matter and aggregation will build porosity for storing water. This can be accomplished by reducing tillage, long-term cover cropping, mulching, rotating annual crops with diverse perennials, and generally keeping actively growing roots in the system to build and maintain soil pores (see Part III). In coarse textured soils, building higher water storage is more challenging than in finer textured soils that inherently store more water. Therefore, managing for relatively high water storage capacity, and also for decreased evaporation through surface cover, is particularly important in coarse textured soils. While the inherent textural effect cannot be influenced by management, choosing management options can be, in part, based on an understanding of inherent soil characteristics.

Scoring function

The graph below depicts Available Water Capacity scoring functions and upper value limits for coarse, medium, and fine textured soils (Figure 2.19). Scoring functions were combined for medium and fine classes because no effects due to texture were observed in the data set.

The red, orange, yellow, light green and dark green shading reflects the color coding used for the ratings on the soil health report summary page (see page 73).



FIGURE 2.19. Available Water Capacity (AWC) scoring functions and upper value limits for Coarse (C), Medium (M) and Fine (F) textural classes. Mean and standard deviation (in parenthesis) for each class are provided. In this case more is better. Higher AWC scores indicate a greater capacity of the soil to store plant available water.

CSHL Available Water Capacity <u>Standard Operating Procedures</u> (CSH 05) can be found under the 'Resources' tab on our <u>website</u>.

Surface and Subsurface Hardness

Surface and subsurface hardness are indicators of the soil compaction status, measured as field penetration resistance in pounds per square inch (psi). It is measured in the field using a penetrometer or soil compaction tester pushed through the soil profile at two depth increments (surface: 0 - 6", and subsurface: 6 - 18"). Measurements should be taken when the soil is near field capacity, since moisture content influences the measurement. The reading in psi can be converted to kilogram-force per square centimeter (kgf/cm²).

Basic Protocol (adapted from Duiker)7:

- Surface and subsurface hardness are measured using a penetrometer, an instrument that measures the soil's resistance to penetration. It consists of a cone-tip, a metal shaft, and a pressure gauge that measures resistance in psi (Figure 2.20 A).
- Most penetrometers come with two different sized tips which correspond to two different gauge scales. The outer and inner scales correspond to the larger ³/₄ inch and the smaller ¹/₂ inch diameter tips, respectively (Figure 2.20 B). For most instances, the ¹/₂" tip should be used. The ³/₄" tip is for very soft soil. Be sure to use the scale appropriate for the tip size.
- The level of soil moisture can greatly affect the ease with which the probe penetrates the soil, and therefore the measured values. It is recommended that penetration readings be taken when the soil is at field capacity (2-3 days after free drainage). If the soil conditions are not ideal, it is important to note conditions at the time so that proper interpretation of the reading can be made.







FIGURE 2.20 A and B. Measuring surface and subsurface hardness with a penetrometer.

- Apply slow even pressure so penetrometer advances into the soil at a rate of 4 seconds per 6 inches or less. Record the highest pressure reading measured for each of the two depths in the sample intake form. If you detect a hard layer, make sure to note its depth – this is important information for management decisions.
- Field profiles of penetration resistance can be created by recording the measured psi every inch through the soil profile and then plotting them on a chart (Figures 2.21 A and B). These charts can be used to identify various layers of compaction, if present. For the soil health test, however, we only target two depths.



FIGURE 2.21 A and B. Soil compaction graphs for (A) a field in intensive vegetable production and (B) a conventionally plow-tilled field and zone-till field with deep ripping on the same farm in the spring of 2005 (Courtesy of C.R. MacNeil).

How soil hardness relates to soil function:

Large pores are necessary for water and air movement and to allow roots and organisms to explore the soil. Field penetration resistance measures whether the soil is compacted. Compaction occurs when large pores are lost as solid soil materials are packed closer together through tillage or traffic with heavy equipment, particularly on wet soils. When surface soils are compacted, runoff, erosion, slow infiltration, and poor water storage result.

Subsurface hardness prevents deep rooting and causes poor drainage and poor deep water storage (Figures 2.22 below and 2.23 on the following page). After heavy rain events, water can build up over a hard pan, causing poor aeration both at depth and at the surface, as well as ponding, poor infiltration, runoff and erosion. Impaired water movement and storage create greater risk during heavy rainfall events, as well as greater risk of drought stress between rainfall events.

Most crop roots cannot easily penetrate soil with penetrometer readings above about 300 psi. Similarly, growth of mycorrhizal fungal hyphae and mobility of other beneficial soil organisms may be severely restricted by excessively hard soil. Since plant roots must be actively growing and exploring the root zone to access water and nutrients, crop quality and yield decline with compaction. Low growth increases weed pressure, and stressful conditions make crops more susceptible to pathogen pressure.

Managing and preventing surface and subsurface hardness constraints

Compaction in surface and subsurface soil occurs very rapidly when the soil is worked or trafficked while it is too wet, and compaction can be transferred deep into the soil even from surface pressure. Thus, compaction can be prevented by avoiding soil disturbance, especially when the soil is wet. Maintaining aggregation is particularly critical for preventing surface compaction (pages 15,46). Compaction can be alleviated by targeted management (Part III). Subsoil compaction can be addressed by deep tillage or by deep rooting crops. Surface compaction can be alleviated by targeted mechanical surface loosening of the soil, followed by fresh organic matter additions and vigorously rooting cover/rotation crops to strengthen and rebuild aggregates (pages 88-97). In the long term, reduced, well-timed tillage and controlled traffic with minimized loads, soil cover, rotations, and active rooting will maintain non-compacted soils.



Wheel traffic compaction from wet soil conditions.



FIGURE 2.22. (Left) Plants growing is soil with good soil structure. (Right) Soil with three types of compaction: surface crusting, plow layer/surface compaction, and subsoil compaction. *Source: Building Soils for Better Crops, 3rd Edition*



FIGURE 2.23. (Left) Dense rooting allows for full soil exploration. (Right) Surface compaction prevents root from accessing water and nutrients. *Source: Building Soils For Better Crops, 3rd Edition*

Scoring function:

The graphs below depict Surface and Subsurface Resistance scoring functions and upper value limits for coarse, medium, and fine textured soils (Figure 2.24). Scoring functions were combined for all classes because no effects due to texture were observed in the data set.

The red, orange, yellow, light green and dark green shading reflects the color coding used for the ratings on the soil health report summary page (see page 73).





FIGURE 2.24 A and B. Surface and subsurface scoring functions and upper value limits for Coarse (C), Medium (M) and Fine (F) textural classes. Mean and standard deviation (in parenthesis) is provided. In this instance less is better. Lower scores indicate a better soil compaction status.

Penn State Extension Soil Penetrometer <u>Standard Operating Procedures</u> and a video demonstrating how to take penetrometer readings in the field can be found on our <u>website</u> and at <u>bit.ly/SoilHealthSampling</u>.

Wet Aggregate Stability

Wet Aggregate Stability is a measure of the extent to which soil aggregates resist falling apart when wetted and hit by rain drops. It is measured using a Cornell Sprinkle Infiltrometer that steadily rains on a sieve containing a known weight of soil aggregates sized between 0.25 mm and 2 mm. The unstable aggregates slake (fall apart) and pass through the sieve. The fraction of soil that remains on the sieve is used to calculate the percent aggregate stability (Figure 2.25 A-C). For details on the Sprinkle Infiltrometer visit soilhealth.cals.cornell.edu.

Basic Protocol (adapted from Moebius et al.)8:

- Soil is air-dried and placed on stacked sieves of 2.0 mm, 0.25 mm and a catch pan. The dried soil is shaken for 15 seconds on a Tyler Coarse Sieve Shaker to separate out aggregates of 0.25 - 2.0 mm size for analysis.
- A single layer of aggregates from 0.25 2.0 mm in size (about 30g) is spread on a 0.25 mm sieve (diameter is 200 mm, or about 8 inches) (A).
- Sieves are placed at a distance of 500 mm (20 inches) below a rainfall simulator, which delivers individual drops of 4.0 mm diameter (B).
- The test is run for 5 minutes and delivers 12.5 mm of water (approximately 0.5 inches) as drops to each sieve. See soils starting to wet in (C). A total of 0.74 J of energy thus impact each sieve over this 5 minute rainfall period. Since 0.164 mJ of energy is delivered for each 4.0 mm diameter drop, it can be calculated that 15 drops per second impact each sieve. This is equivalent to a heavy thunderstorm.
- The slaked soil material that falls through during the simulated rainfall event, and any stones remaining on the sieve are collected, dried and weighed, and the fraction of stable soil aggregates (WSA) is calculated using the following equation:

WSA = Wstable / Wtotal,where

Wstable = Wtotal - (Wslaked +Wstones)

where W = weight (g) of stable soil aggregates (stable), total aggregates tested (total), aggregates slaked out of sieve (slaked), and stones retained in sieve after test (stones). Corrections are made for stones.







FIGURE 2.25 A-C. Aggregate Stability test. A rain simulator is used for 5 minutes on a sieve containing soil aggregates.

How aggregate stability relates to soil function

This method tests the soil's physical ability to hold together and sustain its aggregation, or structure, during conditions with the most impact: a heavy rain storm or other rapid wetting event, such as irrigation, after surface drying weather. This is a good indicator of both physical and biological health (Part I, page 9). Soils with low aggregate stability tend to form surface crusts and compacted surface soils. This can reduce air exchange and seed germination, increase plant stress and susceptibility to pathogen attack, and reduce water infiltration and thus storage of water received as rainfall. This leads to runoff, erosion and flooding risk downstream during heavy rainfall, and higher risk of drought stress later. Poor soil aggregation also makes the soil more difficult to manage, as it reduces its ability to drain excess water, so that it takes longer before field operations are possible after rain events. In heavy (fine textured) soils, enhanced friability and crumbliness from good aggregation makes the soil less dense, so that it is lighter, and is easier to work with less fuel. A well aggregated clay soil allows for excess water to drain through the cracks and fissures between crumbs, while storing water for plant use within the stable aggregates. Good aggregation is critical for resilience to extreme weather (Figure 2.26).



FIGURE 2.26. Pictures of different soil aggregate test results: A Lima silt loam soil from a long-term tillage experiment. (Left) Moldboard plow treatment with 34% water stable aggregates. (Right) Zone-till management with 56% water stable aggregates (0.25 mm sieve).

Managing constraints and maintaining optimal aggregate stability

Stable aggregates are built by biological activity, as aggregates are largely "stuck" together by fungal hyphae, microbial colonies, and plant and microbial exudates. This means plentiful fresh and diverse organic materials (such as green manures, cover crops with vigorous fine roots, animal manures, and mulches) are needed to sustain soil biota, so that they can stabilize soil aggregates. Repeated tillage breaks down stable soil aggregates, especially when organic additions are too low. Such soils can be so degraded that they become addicted to tillage, where crop establishment then requires a soil loosening operation. A successful transition to reduced tillage usually requires focused tillage for crop establishment, and significant organic additions or rotation with a perennial forage or cover crop, to build the soil for minimized disturbance. Reduced tillage, soil cover, and diverse species and rotations with active living roots will maintain stable aggregates in the long term (see Part III).

Scoring function

The graph below depicts Wet Aggregate Stability scoring functions and upper value limits for coarse, medium, and fine textured soils (Figure 2.27).

The red, orange, yellow, light green and dark green shading reflects the color coding used for the ratings on the soil health report summary page (see page 73).



FIGURE 2.27. Wet Aggregate Stability scoring functions and upper value limits for Coarse (C), Medium (M) and Fine (F) textural classes. Mean and standard deviation (in parenthesis) for each class are provided. In this case more is better. Higher scores indicate a greater ability of the soil aggregates to resist falling apart when exposed to rainfall.

CSHL Wet Aggregate Stability <u>Standard Operating Procedures</u> (CSH 03) can be found under the 'Resources' tab on our <u>website</u>.

Organic Matter

The Organic Matter indicator is a measure of carboncontaining material that is, or is derived from, living organisms, including plants and other soil dwelling organisms. Total soil organic matter consists of both living and dead material, including well decomposed, more stabilized materials. Percent organic matter is determined by loss on ignition, based on the change in mass after a soil is exposed to high temperature (500 °C or 932°F) in a furnace. At these temperatures, carbonaceous materials are burned off (oxidized to CO_2), while other materials remain. Organic matter content is often provided by soil analysis laboratories along with major and minor nutrient contents, using a variety of methods.

Basic Protocol (adapted from Broadbent)⁹:

- A sample is dried at 105°C to remove all water.
- The sample is weighed (Figure 2.28).
- The sample is then ashed (for weight loss on ignition) for two hours at 500°C, and the percent of mass lost is calculated after weighing again.
- The % loss on ignition (LOI) is converted to % organic matter (OM) using the following equation:

% OM = (% LOI * 0.7) - 0.23



FIGURE 2.28. Soil mass is determined prior to being exposed to high temperature. Soil is weighed after being ashed to calculate the percentage of mass lost.



FIGURE 2.29. Corn residue on the soil surface is a source of organic matter. *Source: USDA-NRCS*

How organic matter relates to soil function:

Soil organic matter (OM) is where soil carbon is stored, and is directly derived from biomass of microbial communities in the soil (bacterial, fungal, and protozoan), as well as from plant roots and detritus, and biomass-containing amendments like manure, green manures, mulches, composts, and crop residues (Figure 2.29). As discussed earlier, OM in its various forms greatly impacts the physical, biological and chemical properties of the soil. OM acts as a long-term carbon sink, and as a slow-release pool for nutrients. It contributes to ion exchange capacity (nutrient storage), nutrient cycling, soil aggregation, and water holding capacity, and it provides nutrients and energy to the plant and soil microbial communities (Figure 2.30, following page). Soils with high organic matter tend to require lower farm inputs, and be more resilient to drought and extreme rainfall. It has been argued that organic matter management is soil health management.

Part II - Soil Health Assessment

Managing constraints and maintaining optimal organic matter content

Intensive tillage and lack of carbon inputs decrease organic matter content and overall soil health with time. Increasing organic matter in the soil takes time and patience. It is unlikely that a single incorporation of a green manure will noticeably increase the percent organic matter. Adding more stable organic matter such as compost, or possibly biochar, can



FIGURE 2.30. Adding organic matter results in a cascade of changes within the soil. *Source: Building Soils for Better Crops, 2nd Edition*

improve water infiltration and retention in the short term. Retention and accumulation of OM in the long term is improved by reducing tillage intensity and frequency (as much as is feasible within the constraints of the production system), and repeated use of diverse organic matter additions from various sources (amendments, residues, and the active growth of crops, forages, or cover crops, particularly their roots) which all stimulate both microbial community growth and the stabilization (sequestration) of carbon in aggregates. The appropriate selection of organic matter input will depend on the management goal(s) and other microbial activity and food source related constraints identified. Additional information on organic matter amendments and other resources can be found in Part III, page 96.

Scoring function:

The graph below depicts Organic Matter scoring functions and upper value limits for coarse, medium, and fine textured soils (Figure 2.31).

The red, orange, yellow, light green and dark green shading reflects the color coding used for the ratings on the soil health report summary page (see page 73).



FIGURE 2.31. Soil Organic Matter (OM) scoring functions and upper value limits for Coarse (C), Medium (M) and Fine (F) textural classes. Mean and standard deviation (in parenthesis) for each class are provided. In this case more is better. Soils with higher OM scores generally require lower inputs of nutrients and are more resilient to drought and extreme rainfall.

CSHL Organic Matter Standard Operating Procedures can be found under the 'Resources' tab on our website.

Soil Protein Index

The Autoclaved Citrate Extractable (ACE) Protein Index is an indicator of the fraction of the soil organic matter that is present as proteins or proteinlike substances. This represents the large pool of organically bound nitrogen (N) in the soil organic matter, which microbial activity can mineralize, and make available for plant uptake. Protein content is an indicator of the biological and chemical health of the soil, and is very well associated with overall soil health status.

Basic Protocol (adapted from Wright et al.)¹⁰:

- Proteins are extracted from sieved, well-mixed, air-dried soil, using a protocol modified from Wright and Upadhyaya (1996) and Clune (2008).
- 3.00 g of soil are weighed into a pressure- and heat- stable glass screw-top tube, with 24.00 ml of sodium citrate buffer (20 mM, pH 7.0), and the mixture is shaken to disperse aggregates and mix well (5 min at 180 rpm) (Figure 2.32 A).
- The tubes are autoclaved for 30 min (121° C, 15 psi) and then cooled (B).
- 2 ml of the slurry is withdrawn to a smaller microcentrifuge tube (top of C), and centrifuged at 10,000 x gravity to remove soil particles.
- A small subsample of this clarified extract is used in a standard colorimetric protein quantification assay (BCA; demonstrated in tubes at bottom of C), to determine total protein content of the extract.
- The Cornell Soil Health Lab uses the Thermo Pierce BCA protein assay, miniaturized for use in 96-well microplates, incubated at 60° C for uniform response to different protein types (D), and read color development in a BioTek spectrophotometric plate reader (E).
- Extractable protein content of the soil is calculated by multiplying the protein concentration of the extract by the volume of extractant used, and dividing by number of grams of soil used.

How soil protein relates to soil function

Plant residues are ultimately the source of much of the soil organic matter. These are made up of several types of compounds, and of these, protein contains the largest fraction of N (Figure 2.33, following page). Microbial biomass secondarily builds up as these residues and other organic matter amendments decompose, and this biomass is largely similar in composition, although it contains a few additional compound types. Some of these contain N, but not in as great a proportion as in protein.









FIGURE 2.32 A-E. Lab procedure for the Autoclaved Citrate Extractable (ACE) Protein Index.

Part II - Soil Health Assessment

Protein content, as organically bound N, influences the ability of the soil to store N, and make it available by mineralization during the growing season. Soil protein content has also been associated with soil aggregation and thus water storage and movement.

Managing constraints and maintaining optimal soil protein content

To store and maintain N in the soil organic matter, we need to accumulate compounds that are relatively stable, rich in N (low C:N ratio), microbially degradable, and potentially abundant in amendments, crops, cover crops, or residues (Part III). Protein content can be increased by adding biomass such as manure, fresh green biomass, and high-N well





finished compost, and by growing biomass in place by maintaining the presence of living, actively growing roots – particularly legumes that are well nodulated – and soil microbes. Protein content tends to decrease with increasing soil disturbance such as tillage.

Scoring Function

The graph below depicts ACE Soil Protein Index scoring functions and upper value limits for coarse, medium, and fine textured soils (Figure 2.34). It is important to note that extremely high N mineralization could increase losses of N to the environment and thus harm air and water quality.

The red, orange, yellow, light green and dark green shading reflects the color coding used for the ratings on the soil health report summary page (see page 73).



FIGURE 2.34. ACE Soil Protein Index scoring functions and upper value limits for Coarse (C), Medium (M) and Fine (F) textural classes. Mean and standard deviation (in parenthesis) for each class are provided. In this case more is better. Higher protein index scores indicate a larger pool of organically-bound N in the soil.

CSHL ACE Soil Protein Index <u>Standard Operating Procedures</u> (CSH 07) can be found under the 'Resources' tab on our <u>website</u>.

Soil Respiration

Respiration is a measure of the metabolic activity of the soil microbial community. It is measured by capturing and quantifying carbon dioxide (CO_2) released from a re-wetted sample of air dried soil held in an airtight jar for 4 days. Greater CO_2 release is indicative of a larger, more active soil microbial community.

Basic Protocol (adapted from Zibilske)

- 20.00 g of air-dried, sieved soil are weighed into an aluminum weighing boat, which is pre-perforated with 9 pin-holes through the bottom.
- The weighing boat with soil is placed on top of two staggered filter papers in the bottom of a standard 1 pint wide-mouth mason jar (Figure 2.35 A).
- A trap assembly (a 10 ml glass beaker secured to a plastic tripod 'pizza stool') is placed in the jar, and the beaker filled with an alkaline CO₂ - trapping solution (9 ml of 0.5 M KOH) (B).
- 7 ml of distilled, deionized water is pipetted into the jar onto the side, so that the water runs down and is wicked up into the soil through the filter paper.
- The jar is sealed tightly and incubated undisturbed for 4 days.
- Trap electrical conductivity declines linearly with increasing CO₂ absorption, as OH⁻ concentration in the trap declines and CO₃²⁻ concentration in the trap increases.
- After incubation, the jar is opened and the conductivity of the trap solution is measured (C).
- CO_2 respired is calculated by comparison with the conductivities of the original trap solution, and a solution representing the trap if saturated with CO_2 (0.25 M K₂CO₃).







FIGURE 2.35 A-C. Soil Respiration is measured by capturing and quantifying CO₂ released from samples.

How soil respiration relates to soil function

Respiration is a direct biological activity measurement, integrating abundance and activity of microbial life. It thus is an indicator of the biological status of the soil community, which can give insight into the ability of the soil's microbial community to accept and use residues or amendments, to mineralize and make nutrients available from them to plants and other organisms, to store nutrients and thus buffer their availability over time, and to develop good soil structure, among other important functions (Part I, page 5). Soil biological activity thus influences key physical, biological, and chemical soil processes, and is also influenced by constraints in physical and chemical soil functioning. Several individual enzyme and process activity assays are possible, as is quantification of microbial biomass size. However, measuring respiration by trapping evolved CO₂ gives a rapid, low cost, integrative measure of general microbial activity level.

Managing constraints and maintaining optimal soil biological activity

The soil's biological activity is improved by keeping the soil covered with plants or residues throughout the season, adding fresh, microbially degradable amendments, growing biomass in place by maintaining living roots for as much of the year as possible, increasing diversity of species in the system through rotations, interseeding, or intercropping, and by reducing the use of biocides such as pesticides, fungicides, and herbicides (see Part III). Beneficial soil biological activity tends to decrease with increasing soil disturbance such as tillage, heavy traffic, and compaction, as well as with extremes in low or high pH, or contamination by heavy metals or salts.

Scoring function

The graph below depicts Soil Respiration scoring functions and upper value limits for coarse, medium, and fine textured soils (Figure 2.36). Scoring functions were combined for all classes because no effects due to texture were observed in the data set.

The red, orange, yellow, light green and dark green shading reflects the color coding used for the ratings on the soil health report summary page (see page 73).



FIGURE 2.36. Soil Respiration scoring functions and upper value limits for Coarse (C), Medium (M) and Fine (F) textural classes. Mean and standard deviation (in parenthesis) is provided. In this case more is better. Higher respiration scores indicate the presence of a larger, more active soil community.

CSHL Soil Respiration <u>Standard Operating Procedures</u> (CSH 06) can be found under the 'Resources' tab on our <u>website</u>.

Active Carbon

Active carbon is an indicator of the small portion of soil organic matter that can serve as a readily available food and energy source for the soil microbial community, thus helping to maintain a healthy soil food web. To begin the process of measuring active carbon, soil is mixed with a potassium permanganate solution, which starts off deep purple in color. The permanganate oxidizes the active carbon and loses some of its color. The more active carbon found in the soil, the more the purple color declines. This color change is measured with a spectrophotometer or colorimeter.

Basic Protocol (adapted from Weil et al)¹²:

- Soil is air dried and sieved to 2 mm.
- A 2.5 g sample of air-dried soil is placed in a 50 ml centrifuge tube filled with 20 ml of a 0.02 M potassium permanganate (KMnO₄) solution, which is deep purple in color (Figure 2.37 A).
- The soil and KMnO₄ are shaken for exactly 2 minutes to oxidize the active carbon in the sample. The purple color becomes lighter as a result of this oxidation reaction.
- The sample tube is then allowed to settle for 8 minutes, pipetted into another tube, and diluted with distilled water.
- Absorbance is measured at 550 nm (B).
- The absorbance of a standard dilution series of the KMnO₄ is also measured to create a calibration curve for interpreting the sample absorbance data.
- A simple formula is used to convert sample absorbance value to active C in units of mg carbon per kg of soil.



soil function: Research has shown that active carbon is highly correlated with and similar to particulate

How active carbon relates to

organic matter (POM), which is determined with a more complex and labor-intensive wet-sieving and/or chemical extraction procedure. Due to its role in providing available food and energy sources for the soil microbial community, active carbon is positively correlated with percent organic matter, aggregate stability, and with measures of biological activity (such as respiration) and microbial biomass. Research has shown that active carbon is a good "leading indicator" of soil health response to changes in crop and soil management, usually responding to management much sooner (often years sooner) than total organic matter percent. This is likely because when a large population of soil microbes is fed plentifully over an extended period of time, well decomposed organic matter builds up. Thus, monitoring the changes in active carbon can be particularly useful to farmers who are changing practices with the goal of building up soil organic matter.



FIGURE 2.37 A and B. (A) Extracts before and after dilution. The samples on the left are after they have been weighed, shaken, and settled. The samples on the right show the dilution as they are prepared for (B) samples are measured for absorbance at 550 nm.

Managing constraints and maintaining optimal soil biological activity

Reducing tillage and increasing organic matter additions from various sources will increase active carbon, and will feed, expand, and balance the microbial community, thus increasing total organic matter over the long term. Various sources include amendments, residues, and active and diverse forage, crop, or cover crop growth, with living roots providing labile carbon to soil microbes for as much of the year as possible (see Part III).

Scoring function:

The graph below depicts active carbon scoring functions and upper value limits for coarse, medium, and fine textured soils (Figure 2.38).

The red, orange, yellow, light green and dark green shading reflects the color coding used for the ratings on the soil health report summary page (see page 73).



FIGURE 2.38. Active carbon scoring functions and upper value limits for Coarse (C), Medium (M) and Fine (F) textural classes. Mean and standard deviation (in parenthesis) for each class are provided. In this case more is better. Higher active carbon scores indicate a trend toward more organic matter building up in the soil through biological activity.

CSHL Active Carbon <u>Standard Operating Procedures</u> (CSH 04) can be found under the 'Resources' tab on our <u>website</u>.

Standard Nutrient Analysis

As part of the Cornell Assessment of Soil Health, a traditional soil fertility test analysis package for the Northeastern United States is used, that measures pH and extracts plant macro- and micronutrients to estimate plant nutrient availability. Measured levels are interpreted in the framework for sufficiency and excess but are not crop specific. The analysis results for pH, extractable phosphorus and potassium are scored and integrated into the Cornell Assessment of Soil Health Report (see page 73). Selected secondary nutrients and micronutrient analyses are combined into one rating for the report.

Basic Protocols

Extractable Phosphorus Extractable Potassium Magnesium Iron Manganese Zinc

Analysis Method:

Nutrients are extracted from soil by shaking with Modified Morgan's solution, which is an ammonium acetate plus acetic acid solution buffered at pH 4.8. After shaking, the extraction slurry is filtered through a paper filter, and the filtrate is analyzed on an inductively coupled plasma emission spectrometer (ICP, Spectro Arcos) for the elements Al, As, B, Ba, Be, Ca, Cd, Co, Cu, Fe, Li, Mg, Na, P, Pb, S, Se, Sr, Ti, V, Zn and Cl. As part of the soil health assessment, P, K, Mg, Fe, Mn, and Zn are scored and included in the report.

pH: The pH of a suspension of two parts water to one part soil is determined by pH electrode probe, using a Lignin pH robot.

How nutrient analysis results relate to soil function

Adequate nutrient availability is of course critical to crop production. Chemical analysis – standard soil nutrient and pH testing – has been foundational for maintaining agricultural productivity. By identifying which nutrients need to be added through amendments, or whether pH needs to be adjusted for improved nutrient availability from the soil, these tests have guided farmers since the 1900's in alleviating constraints in the availability of specific nutrients to their crops, and thus increasing yields. This critical component of soil health assessment is the one that is the most accepted and adopted by land managers to date.

Standard Nutrient Analysis (continued)

Soil pH is a measure of how acidic the soil is, which controls how available nutrients are to crops. Optimum pH is around 6.2-6.8 for most crops (exceptions include potatoes and blueberries, which grow best in more acidic soil). If pH is too high, nutrients such as phosphorus, iron, manganese, copper and boron become unavailable to the crop. If pH is too low, calcium, magnesium, phosphorus, potassium and molybdenum become unavailable (Figure 2.39). Lack of nutrient availability will limit crop yields and quality. Aluminum toxicity can also be a concern in low pH soils, which can severely decrease root growth and yield, and in some cases lead to accumulation of aluminum and other metals in crop tissue. In general, as soil organic matter (SOM) increases, crops can tolerate lower soil pH. Soil pH also influences the ability of certain pathogens to thrive, and of beneficial organisms to effectively colonize roots.

Extractable Phosphorus is a measure of phosphorus (P) availability to a crop. P is an essential plant macronutrient, as it plays a role in photosynthesis, respiration, energy storage and transfer, cell division, cell enlargement, and several other process in plants. Its availability varies with soil pH and mineral composition. Low P





values indicate poor P availability to plants. Excessively high P values indicate a risk of adverse environmental impact. P can be considered a contaminant and runoff of P into fresh surface water will cause damage through eutrophication, so over-application is strongly discouraged, especially close to surface water, on slopes, and on large scales.

Extractable Potassium is a measure of potassium (K) availability to the crop. K is an essential plant macronutrient as it plays a role in photosynthesis, respiration, energy storage and transfer, regulation of water uptake and loss, protein synthesis, activation of growth related enzymes, and other processes. Plants with higher potassium tend to be more tolerant of frost and cold. Thus, good potassium levels may help with season extension. While soil pH only marginally affects K availability, K is easily leached from sandy soils and is only weakly held by increased OM, so that applications of the amount removed by the specific crop being grown are generally necessary in such soils.

Minor Elements, also called secondary nutrients (calcium, magnesium and sulfur) and micronutrients (iron, manganese, zinc, copper, boron, molybdenum, etc.) are essential plant nutrients taken up by plants in smaller quantities than the macronutrients N, P, and K. If any minor elements are deficient, decreased yield and crop quality may result. Toxicities can also occur when concentrations are too high. The CSHL's minor elements rating indicates whether four measured nutrients (magnesium, iron, manganese, and zinc) are deficient or excessive (Table 2.03, page 58). Micronutrient availability is strongly influenced by pH and OM. Low pH increases the availability of most micronutrients, whereas high pH increases the availability of others (see Figure 2.39 above). High OM and microbial activity tend to increase micronutrient availability. Note that this test does not measure all important micronutrients. Consider submitting a sample for a complete micronutrient analysis to find out the levels of the other micronutrients.

Managing constraints and maintaining optimal nutrient availability

Management of fertilizers and liming amendments has been well researched and communicated by numerous authors worldwide. Much has been written about this topic elsewhere, so that we will only briefly summarize some important concepts.

Nutrient balances:

Once adequate nutrient levels are present in the soil, nutrients still have to continue to be imported to a farm and added to the soil. The amounts added must be adequate to replace nutrients that leave the farm in products that are harvested and sold, or that leave through environmental losses, or else these nutrients are essentially mined by plant uptake until they become deficient. Maintaining optimal pH through lime or wood ash applications, and adding organic matter, will help immobilize aluminum and

heavy metals, and contribute to maintaining proper nutrient availability.

Soil Health: biological and physical influences on nutrient availability:

Nitrogen is the only nutrient that can be biologically "produced" on farm. Legumes and their symbiotically associated rhizobia can fix unavailable, but plentiful N₂ from the air, transforming it to plant available forms. Nitrogen is also the most dynamic of the nutrients – which is to say its availability in soil changes rapidly as influenced by weather, physical soil condition, microbial activity, and the availability of organic materials. This is why it is not extracted in this analysis– its availability can differ by the time test results are returned. While in season N tests are in use, using models along with soil tests (e.g. Adapt-N, <u>adapt-n.cals.cornell.edu</u>) to estimate the impact of weather on fertilizer needs is likely the future of nitrogen management.

Other nutrients can only come from soil minerals, organic matter, and external sources of fertility, although biota can

Cover crops planted between rows of corn.

help in making these more available to plants. Availability of nutrients present in the root zone is very much influenced by soil microbes and plant roots. For example, some cover crops, such as buckwheat, are good at mining otherwise unavailable P so that it becomes more available to the following crop. When plants associate with mycorrhizal fungi, these can also help make P (and other nutrients and water) more available to the crop. The influence of such biological and physical processes is generally not taken into account by standard extractants such as the one used here. There is active research ongoing to adjust fertility recommendations by using additional physical and biological information, such as indicators of microbial species presence and activity.

Part II - Soil Health Assessment

Scoring functions

Scoring function graphs are shown below for pH, extractable phosphorus (P) and potassium (K) on coarse, medium, and fine textured soils (Figure 2.40 A-C). Scoring functions were combined for all classes because no effects due to texture were observed. For pH, a score of 100 is assigned for values between 6.3-7.2 and 5.3-6.2 for normal and acid-loving plants, respectively. Concentration values for P between 3.5-21.5 ppm and \geq 74.5 ppm for K are given a maximum score of 100. Scoring functions were combined for all textural classes because no effects due to texture were observed in the data set.

The red, orange, yellow, light green and dark green shading reflects the color coding used for the CASH summary report.



The Micronutrient score reported in the CASH Summary Report is determined as the mean of sub-scores for Magnesium (Mg), Iron (Fe), Manganese (Mn) and Zinc (Zn) (Table 2.03 A). The sub-scores can either be 0 (sub-optimal) or 100 (optimal), independent of texture (Table 2.03 B).

TABLE 2.03 A and B. The optimal ranges for micronutrients for all soil textural classes. Individual micronutrient sub-scores can be either 0 (sub-optimal) or 100 (optimal). The overall micronutrient score is determined using the mean of the sub-scores.

А		
	OVERALL	MEAN OF
	MICRO-	MICRO-
	NUTRIENT	NUTRIENT
	SCORE	SUB-SCORES
	100	100
	56	75
	11	50
	4	25
	0	0

В

	SUB-SCORE (ppm)			
NUTRIENT	0	100		
Magnesium	< 33	≥ 33		
Iron	> 25	≤ 25		
Manganese	> 50	≤ 50		
Zinc	< 0.25	≥ 0.25		

FIGURE 2.40 A-C. Scoring function graphs for pH (A), extractable phosphorus (B) and extractable potassium (C) for Coarse (C), Medium (M) and Fine (F) textural classes. If all four micronutrients are optimal, the Micronutrient Score is 100 (very high). If all four are sub-optimal, the score is 0.

150

200

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100

Extractable Potassium (ppm)

50

С

Add-on Test: Potentially Mineralizable Nitrogen

Potentially Mineralizable Nitrogen (PMN) is an indicator of the capacity of the soil microbial community to convert (mineralize) nitrogen tied up in complex organic residues into the plant available form of ammonium. Soil samples are anaerobically incubated for 7 days, and the amount of ammonium produced in that period is measured as an indicator of nitrogen mineralization. This indicator has been replaced with the soil protein and respiration measurements in the CASH package, as those two separately indicate the activity of the microbial community in aerobic conditions, and the availability of N containing organic residues. PMN is available as an add-on test.

Basic Protocol (adapted from Drinkwater et al.)¹³

- As soon as possible after sampling, the fresh soil sample (stored at 40°F) is sieved.
- Two 8g soil samples are placed into 50 ml centrifuge tubes.
- 40 ml of 2.0 M potassium chloride (KCl) solution is added to one of the tubes, which is shaken on a mechanical shaker for 1 hour, and filtered
- 20 ml of the filtrate is collected from this tube and analyzed for ammonium concentration, as a measure of pre-incubation ammonium.
- 10 ml of distilled water is added to the second tube, which is hand shaken, capped with a nitrogen gas (N₂) atmosphere, and incubated for 7 days at 30°C (86°F).
- After the 7 day anaerobic incubation, 30 ml of 2.67 M KCl is added to the second tube (creating a 2.0 M solution). The tube is shaken, filtered, and the filtrate is collected and analyzed for ammonium concentration (Figure 2.41).
- The difference between the pre-incubation and post-incubation measurements is used as an indicator of N mineralization.

How PMN relates to soil function

Nitrogen is the most limiting nutrient for plant growth and yield in most agricultural situations (Figure 2.42, following page). Almost all of the nitrogen stored in crop residues, soil organic matter, manures and composts, is in the form of complex organic molecules (e.g., proteins) that are not available to plants (i.e., cannot be taken up by plant roots). We rely on several microbial species to convert this organic nitrogen into the ammonium and nitrate forms that plant roots can utilize (Part I, Figure 1.10). The PMN test provides us with one indication of the capacity of the soil biota to recycle organic nitrogen that is present into plant available forms.



FIGURE 2.41. Potentially Mineralizable Nitrogen (PMN) processed in the lab. The difference between pre-incubation and post-incubation measurements is used as an indicator of N mineralization.

Managing constraints and maintaining optimal nitrogen mineralization

Soils with high levels of nitrogen-rich organic matter (e.g., soils where legumes are in rotation or that frequently receive animal manure) tend to have the highest populations of microbes involved in nitrogen mineralization and the highest PMN rates. Follow management suggestions provided for improving soil protein and respiration constraints to manage for optimal nitrogen mineralization (see Part III).



FIGURE 2.42. Nitrogen is the most limiting nutrient in crop production. The center two rows of sweet corn are severely nitrogen deficient.

Scoring function

The graph below depicts the Potentially Mineralizable Nitrogen (PMN) scoring function and upper value limits for coarse, medium, and fine textured soils (Figure 2.43). Scoring functions were combined for all textural classes because no effects due to texture were observed in the data set.

The red, orange, yellow, light green and dark green shading reflects the color coding used for the ratings on the soil health report summary page (see page 73). It should be noted that while none of the scoring functions currently are calibrated to decline with very high nitrogen mineralization potential, extremely high N mineralization could increase losses of N to the environment, and thus impact air and water quality.



FIGURE 2.43. Potentially Mineralizable Nitrogen (PMN) scoring functions and upper limits for Coarse (C), Medium (M) and Fine (F) textural classes. Mean and standard deviation (in parenthesis) is provided. In this case higher scores indicate potentially higher levels of N rich organic matter, indicating higher levels of microbial population involved in N mineralization.

CSHL Potentially Mineralizable Nitrogen <u>Standard Operating Procedures</u> (CSH 08) can be found under the 'Resources' tab on our <u>website</u>.

Add-on Test: Root Pathogen Pressure

Root pathogen pressure is a measure of the degree to which sensitive test-plant roots show symptoms of disease when grown for a set time in controlled conditions in assayed soil. It is assessed qualitatively, after roots are washed, by visual inspection for root size, color, texture and the absence or presence of symptoms of damage by root pathogens. These include the fungi *Fusarium*, *Rhizoctonia*, and *Thielaviopsis*, the oomycete *Pythium*. The apparent pathogen pressure is given a rating from 2 to 9, with higher numbers indicating greater pathogen-induced damage.

Basic Protocol (adapted from Abawi et al.)¹⁴:

- Approximately 200 ml of fresh soil is placed in each of 4 cone-tubes which have cotton balls placed in the bottom to prevent soil loss through the drainage holes (Figure 2.44 A).
- Each tube is planted with one green bean seed. Commercially available, treated seeds are used to more closely represent on-farm conditions (B).
- The hilum (curved) side of the seed is placed flat, horizontally, to encourage successful seed germination and emergence (straight vertical shoots).
- The plants are maintained in a greenhouse under supplemental light and watered regularly for 4 weeks (C).
- The plants are removed from their containers and the roots washed and rated as described in the examples shown to the right:



FIGURE 2.44 A-C. Root Pathogen Pressure test in the greenhouse using green bean seed.



FIGURE 2.45 A-D. Root Pathogen Pressure Rating System.

Rating System:

- 2 = White and coarse textured hypocotyl and roots; healthy (Figure 2.45 A);
- 4 = Light discoloration, with lesions covering up to a maximum of 10% of hypocotyl and root tissues (B);
- 6 = Moderate damage, with lesions covering approximately 25% of hypocotyl and root tissue, with tissues remaining firm (C);
- 7 to 9 = Advanced damage and decay, with 50 to 75% (or more for higher ratings) of hypocotyl and roots showing lesions and severe symptoms of pathogen damage (D).

How root pathogen pressure relates to soil function:

Pathogen pressure refers to the degree to which plants encounter potentially growth-limiting attack by disease causing organisms. This is a function of:

- the presence of pathogens
- the compatibility between pathogens and the plants that are growing
- environmental conditions including which other microbial communities are present at the time, weather, and soil physical and chemical characteristics, particularly those that can stress plants or make them more susceptible to pathogen attack, such as poor drainage, high compaction, or nutrient deficiencies (Figure 2.46).

Healthy roots are essential for vigorous plant growth and high yield as they can efficiently obtain nutrients and water from soil. Root pathogenesis negatively impacts plant growth and root effectiveness, as well as more beneficial root associated microbiota in their contribution toward proper functioning of other important soil processes (Part I, page 16).

While one-size-fits-all pathogen pressure assays for lab testing of soils are difficult to devise, several relevant options for certain crops and pathogens are available. For vegetable production systems, a soil bioassay with beans was shown to be highly effective in assessing root pathogen pressure as a component of overall soil health. Beans are susceptible to the major pathogens that impact vegetable, legume, and forage crops grown in the Northeast region, which makes them suitable as an indicator plant. The selection of other indicator plants might be needed for the proper assessment of root pathogen pressure of soils in different production systems.

High pathogen pressure identified by the assay indicates that disease-causing organisms are present, and that the other members of the microbial community are not suppressive of them. Lower pressure indicates either that few pathogens are present, or that the rest of the microbial community is able to prevent them from successfully colonizing the roots.



FIGURE 2.46. Disease Triangle, illustrating the interaction between susceptible host, compatible pathogen, and conducive environmental conditions necessary for the development of plant disease. For example: strawberry plants in the presence of the strawberry pathogen *Botrytis cineria*, in wet environmental conditions, will likely become infected with Botrytis grey mold.

Managing constraints and maintaining low pathogen pressure

To manage root pathogen pressure constraints in the field, make sure to evaluate rotations and cover crops for their ability to suppress pathogens, and especially avoid consecutively planting hosts of the same pathogen. Some cover crops (e.g. sorghum-sudangrass, mustards) can be used to effectively biofumigate against certain pests and pathogens. Plants differ in their efficacy as hosts for various pests. Some produce compounds that inhibit or suppress pathogens, or may stimulate microbial communities that are antagonistic or parasitic to crop pathogens.

Organic matter inputs from rotational and cover crops, green manures, and composts have a major impact (both positive, and negative if poorly chosen) on populations of soilborne microbial pathogens, plant parasitic nematodes, and other pests. Plant residues remaining from previous crops that have been diseased can harbor pathogens and serve as a source of inoculum in following seasons, allowing disease to spread. This makes rotation all the more important. It is also important to alleviate physical and chemical plant stressors that make crops more susceptible to pathogen attack, such as poor drainage, high compaction, poor irrigation practices, or nutrient deficiencies (see Part III).

Soil health management keys to preventing pathogen pressure:

- keep note of seed, seedling, and mature plant health and disease throughout growing season
- improve sanitation of tools and equipment
- carefully manage diseased plant residues
- rotate with non-compatible or resistant crops and cover crops
- limit environmental conditions that are conducive to disease spread
- foster beneficial and disease suppressive microbial communities

Scoring function:

The graph below depicts the Root Health Bioassay rating scoring function and upper value limits for coarse, medium, and fine textured soils (Figure 2.47). Scoring functions were combined for all textural classes because no effects due to texture were observed in the data set.

The red, orange, yellow, light green and dark green shading reflects the color coding used for the ratings on the soil health report summary page (see page 73).



FIGURE 2.47. The Root Health Bioassay Rating scoring function and upper limits for Coarse (C), Medium (M) and Fine (F) textural classes. Mean and standard deviation (in parenthesis) is provided. In this case, a lower score is better and indicates there is little pathogen pressure in the field.

CSHL Root Health Bioassay Rating <u>Standard Operating Procedures</u> (CSH 09) can be found under the 'Resources' tab on our <u>website</u>.

Add-on Test: Heavy Metal Contamination¹⁵

Heavy metal testing (also sometimes called total elemental analysis) is available for situations where contamination is suspected, or as a precaution. Heavy metal content to measure levels of metals of possible concern to human or plant health (e.g. arsenic, barium, cadmium, chromium, copper, lead, nickel, zinc) as well as other elements are measured. Testing soils for heavy metals can help identify whether contamination from past human activities (such as high traffic, industrial or commercial activity, spills, or pesticide application) is affecting the site.

It is important to understand that levels of metals can vary greatly across a site, and sometimes at a very small scale, so additional samples may be needed. More information is available from the Cornell Waste Management Institute's "Guide to Soil Testing and Interpreting Results" (available at <u>cwmi.css. cornell.</u> <u>edu/guidetosoil.pdf</u>).

Basic Protocol (Total Soil Digestion)

- A dried soil sample is digested in concentrated acid at high temperature.
- After cooling, samples are generally diluted with deionized water.
- Particulates in the digestate are removed by filtration, centrifugation, or by allowing the sample to settle.
- The sample is analyzed by inductively coupled plasma (ICP) or flame atomic absorption (AA) instruments.

Method details differ among different labs: Different acids, temperatures, and heating mechanisms are used, and improvements to methods are still being made. Nitric acid, perchloric acid, or a combination of the two are common. Heating methods include microwave digestion, hot plate digestion, and automated instruments. Depending on the method, additional acid or other reagents may be added. The Cornell Nutrient Analysis Laboratory generally follows thier own proceedures. In some cases they follow EPA protocols. This information is available at cnal.cals.cornell.edu. In some situations less expensive screening tests (e.g., for lead) may be appropriate. Some laboratories (including the Cornell Nutrient Analysis Laboratory) offer total elemental analysis with lead screening. Screening procedures may involve methods similar to the protocol described above, or may use technology such as x-ray fluorescence instruments. For current and complete Standard Operating Procedures, please contact the Cornell Nutrient Analysis Lab (<u>cnal.cals.</u> <u>cornell.edu</u>). The information below about interpreting results generally applies to both screening tests and total elemental analysis.

How Heavy Metals Relate to Soil Function

Soil characteristics can affect the transport and fate of heavy metals, and whether they can be readily taken up by plants or animals. Most heavy metals (e.g., barium, chromium[+3], copper, lead) are adsorbed strongly to clays and organic matter, which limits the potential for plants to take these up when soil pH is not in the acid range. A few - notably cadmium, nickel and zinc - may remain soluble enough at near-neutral pH to be excessively taken up by plants from contaminated soils. For most heavy metals, uptake (via plant roots) into food crops may be higher if soil is acidic (pH < 5-6), high in salts, or low in organic matter (Figure 2.48, following page). Arsenic adsorbs poorly on organic matter, but well on clays and iron oxides, and is more available to plants in non-acid (pH > 6) than acid soils.

Additionally, heavy metals (e.g., copper, nickel, zinc) at elevated concentrations in soil may suppress natural microbial processes. For example, soil copper at high levels inhibits organic matter decomposition (Figure 2.49, following page).

Interpreting Heavy Metals Results¹⁶

Laboratories report the concentrations of individual heavy metals or other elements measured in a soil sample (usually in mg/kg or ppm, which are equivalent). Test results can inform decisions about how to manage a site, farm, or garden, and other activities, to promote healthy soils, high quality crops, and efforts to protect human health by reducing exposure to contaminants for healthier communities.

Yet, understanding heavy metals results is not always an easy task. There is no single standard for acceptable concentrations in the soils of farms, gardens, or residential yards. Some guidance can be found by comparing soil test results to soil background levels or state guidance values, where these are available.



FIGURE 2.48. Lead uptake by vegetables is greater in low pH soil, and differs by crop type. *Source: Healthy Soils, Healthy Communities Project*



FIGURE 2.49. Simple colorimetric test for microbial inhibition in copper (Cu)-contaminated soils. Indigo carmine was used as redox indicator to measure O₂ consumption (indicating healthy microbial activity) in Arkport soils spiked with CuSO₄ 10 years earlier. *Source: M. McBride*

For example, in New York State (NYS), soil test results can be compared to the Department of Environmental Conservation (DEC) Soil Cleanup Objectives (NYSDEC SCOs, 2006, Table 2.04). These values are developed by the NYSDEC and the NYS Department of Health for the NYS environmental remediation programs, but can be used outside of these programs as guidance levels to help interpret levels of chemicals in soil when considering human health and the environment. The guidance values for residential scenarios are typically the most appropriate reference point for farmers, gardeners, homeowners, and other citizens.

Interpreting Heavy Metals (continued)

It is not uncommon to find heavy metals in soil at levels near or above guidance values. Health risks associated with metals in soils at levels slightly or moderately above guidance values cannot be ruled out, but are likely to be low. High levels of exposure can be associated with health effects, and the higher the levels are, the greater the concern.

Some heavy metals can be toxic to plants (phytotoxic) at levels below human health-based guidance values (Harrison et al. 1999)¹⁷. For example, copper can cause toxicity and stunted growth in some crops at concentrations above 75-100 ppm in soil. This is more likely to be a concern if pH is low. Nickel can cause toxicity and stunted growth in some crops at concentrations above 40-60 ppm (Figure 2.50). Zinc levels above 150 ppm may cause toxicity and stunted growth in some crops. However, at near-neutral pH (6.5 - 7.5), zinc is insoluble enough that toxicity to plants would require zinc levels above 200 ppm.



FIGURE 2.50. Increasing levels of nickel (Ni) contamination impede plant growth. *Source: M. McBride*

Other heavy metals may be taken up by plants and not harm the health or growth of the plant, even though they may be a concern for human health.

,	,						
	Level in soil (parts per million [ppm])						
Metal	Guidance Value Protective of Public Health	NYS Rural Background Level	NYC Urban Background Level				
Arsenic	16	< 0.2 - 12	4.1 - 26				
Barium	350	4 - 170	46 - 200				
Cadmium	2.5	< 0.05 - 2.4	0.27 - 1.0				
Chromium	36	I - 20	15 - 53				
Copper**	270	2 - 32	23 - 110				
Lead	400	3 - 72	48 - 690				
Mercury	0.81	0.01 - 0.20	0.14 – 1.9				
Nickel**	140	0 - 25	10 - 43				
Zinc**	2200	10 - 140	64 - 380				
* See NYSDEC	2006, NYSDEC and NYSI	DOH 2005, Retec Group,	Inc. 2007				
** Can be toxic	to plants below health-ba	sed guidance values					

TABLE 2.04. Guidance values and background levels of metals commonly found in garden soils*. See Healthy Soils, Healthy Communities resource *Metals in Urban Garden Soils* for more information.

Managing Heavy Metals in Soil¹⁸

When developing a site management plan for a contaminated site, it is important to balance the many known benefits of farming, gardening, outdoor recreation, and consuming fresh fruits and vegetables with possible risks from exposure to soil contaminants.

The type of crops being consumed also have varying levels of contaminants, depending on what part of the plant is being consumed (Table 2.05).

Soil amendments are an important technique for mitigating heavy metals in soils. For example, organic matter (composts, peat) forms strong complexes with heavy metals such as lead and cadmium, and limits availability to plant roots. Lime additions raise soil pH, reducing solubility and plant availability of most metals. Phosphate has been shown to reduce lead solubility under some circumstances, though it is generally not effective or practical for non-acid soils where lead solubility is already low.

Additional risk-minimizing strategies:

- If needed, add clean soil or organic matter; adjust soil pH; promote good drainage (Figure 2.51 A, following page).
- Wash hands / wear gloves when working with soil.
- Keep soil from coming indoors on shoes, pets, or clothing.
- Keep an eye on children.
- Avoid or contain contaminated areas: use raised beds where appropriate for growing edible crops (B); mulch, plant ground cover, or otherwise cover areas of bare soil to reduce dust.
- Wash produce well to remove soil particles from plant surfaces, and peel root crops (C).
- If contamination is a concern, consider planting food crops that are least likely to have contaminants on or in them (like fruits) or grow ornamental plants.
- Avoid or limit activities that can increase soil contamination, such as the use of certain fertilizers and treated wood.

TABLE 2.05. Crop type and contaminant considerations for managing heavy metals in sc	oils.
---	-------

Сгор Тур	e	Considerations
Root		More likely to have higher levels of contaminants because edible portion grows directly in soil
Leafy Greens and Herbs		More likely to have higher levels of contaminants because of dust/soil splash
Fruit	-	Plant barriers help prevent contamination; surface contamination can be washed off of most fruits more easily

Using plants to remove heavy metals from soil (a type of phytoremediation) is generally not effective for reducing metals levels in farm or garden soils. Many metals are not readily taken up into plant tissue when soil pH is near neutral (6.5 - 7.5). For those metals that are more easily taken up by plants (such as cadmium, copper, nickel, and zinc), the plants that take them up most readily are also relatively small in stature and slow growing, and they will take many years to "clean up" soils with metal levels even moderately above guidance values. Also, unlike some other contaminants, metals are chemical elements and therefore are not broken down into less toxic compounds by phytoremediation. Metals that are removed from the soil are relocated into the roots or other parts of the plants, which means the plants must be disposed of properly, and not eaten or composted.



Amending soil with compost.



Gardening in a raised bed with clean soil and landscape fabric barrier.



Washing garden-grown vegetables.

FIGURE 2.5 I A-C. Strategies to help reduce risk of heavy metal contamination in urban soils.

Add-on Test: Salinity and Sodicity

Soils become saline when the concentration of soluble salts (mostly made up of compounds of Mg^{+2} , Ca^{+2} , Na^+ , K^+ , Cl^- , SO_4^{-2} , HCO_3^- and CO_3^{-2}) in the soil profile becomes excessive. **Salinity** can be measured by electrical conductivity, and this is offered as the 'soluble salts add-on' with a Cornell Soil Health Assessment. **Sodic** soils are those with excessive sodium ion concentrations, relative to magnesium and calcium, measured by the sodium adsorption ratio. Salinity and sodicity are quite different from each other. These conditions may occur together or separately.

Basic Protocol (adapted from Rhoades)¹⁹ Electrical Conductivity (EC) - to measure salinity

Soluble salts are extracted from the soil with water, in a 1:1 soil:water suspension by volume, and the electrical conductivity of the supernatant is determined as follows:

- 20ml of distilled deionized water are added to 20 ml of dried ground soil and stirred;
- Suspension is settled for one hour;
- Electrical conductivity of the supernatant is measured with a calibrated conductivity meter (Figure 2.52).



FIGURE 2.52. Electrical conductivity (EC) meter used to measure salinity.

Sodium Adsorption Ratio (SAR) - to measure sodicity

- Sodium, calcium, and magnesium concentrations of the supernatant above can additionally be determined using inductively coupled plasma (ICP) spectrometry
- Sodium Adsorption Ratio (SAR) is calculated using the equation where concentrations of sodium (Na⁺), calcium (Ca²⁺) and magnesium (Mg²⁺) are in meq/L:

S.A.R. =
$$\frac{Na^{+}}{\sqrt{\frac{1}{2}(Ca^{2+} + Mg^{2+})}}$$

Saline soil effects on plants:

- Drought stress symptoms
- Wilting
- Stunted growth
- Necrosis (death of cells or tissues) of leaf tips
- Toxicities from build-up of certain elements
- Certain plants are more tolerant to salt

Sodic soil effects:

- Sodium disperses soil particles
- Soil particles do not aggregate
- Clay particles fill in soil pore spaces
- Limited or no water and air movement
- Difficult to impossible for plant growth in sodic soils

How salinity and sodicity relates to soil function

Problems with salts (salinity) and sodium (sodicity) may occur naturally, but are especially prevalent under irrigated agriculture in semi-arid and arid areas, where water from rainfall would not otherwise be adequate for crop production. This situation is prevalent in western regions of the United States. It is also prevalent in high tunnels and greenhouses used for season extension in the Northeast – these are effectively irrigated deserts when they are covered year-round. Localized saline-sodic soils may also occur in coastal regions when soils are affected by sea water, or in urban areas in cold climates where salt de-icing materials are used. Salinity and Sodicity have severe impact on growing crops through very different mechanisms.

High salinity decreases the osmotic potential of the soil water relative to plant water. This means that the crops must exert more energy to get water from a saline soil, which holds the water more tightly. Therefore soils with high salinity could have sufficient water but growing crops will lack access to it and may wilt and die (Figure 2.53 A and B). In addition, high concentrations of some elements that make up the salts in the soil such as sodium and chloride can become toxic for some plants, affecting their metabolism and consequently reducing their growth.

High sodium concentrations break down soil structure, as sodium replaces calcium and magnesium on mineral surfaces. This prevents fine particles from sticking to each other, so that aggregates are dispersed into single grains. A sodium-affected soil becomes crusted and severely compacted, so that water cannot properly infiltrate or drain, and water storage is diminished as well (C) (page 45). This has a major impact on soil physical functioning, so that crops will not be able to grow properly. Sodic soils also have high pH, negatively affecting the availability of certain nutrients like phosphorus.



Salt affected corn. Photo credit: University of Delaware



Cotton grown in saline-sodic soil (Turkey).



Crusting in a saline-sodic urban soil.

FIGURE 2.53 A-C. Management challenges in saline and sodic soils.

Scoring functions:

Tables 2.06 A and B below shows threshold criteria for interpreting salinity measured by the 1:1 volumetric extraction of soluble salts (A). These thresholds are general interpretations that are not crop specific (B). The effect of soil salinity is often judged by the extent to which crops respond to different levels of salinity. Some crops are very sensitive while some others are more tolerant. Vegetables sensitive to salinity include radish, celery, and green beans, while those with high salt tolerance include kale, asparagus and spinach. Crop response is also influenced by texture.

	-	EC (mm	nhos cm ⁻¹) B`	y soil tex	TURE
		COARSE	LOAMY	SILT	SILTY
		SAND TO	FINE	LOAM TO	CLAY
DEGREE OF	CROP	LOAMY	SAND TO	CLAY	LOAM
SALINITY	RESIDUE	SAND	LOAM	LOAM	TO CLAY
Non-saline	Almost negligible effects	0 - 1.1	0 - 1.2	0 – 1.3	0 – 1.4
Slightly-saline	Yield of the most sensitive crops reduced	1.2 – 2.4	1.3 – 2.4	l.4 – 2.5	1.5 – 2.8
Moderately saline	Yield of most crops reduced	2.5 - 4.4	2.5 - 4.7	2.6 - 5.0	2.9 – 5.7
Strongly saline	Only tolerant crops yield well	4.5 - 8.9	4.8 - 9.4	5.1 - 10.1	5.8 - 11.4
Very strongly saline	Only very tolerant crops yield well	> 9.0	> 9.5	> 10.1	> 11.5

TABLE 2.06A. Interpretation of 1:1 soluble salts test (Dahnke and Whitney, 1988).

TABLE 2.06B. General threshold criteria defined to classify a soil as saline, sodic, or saline-sodic. It is important to note that the pH of the soil is also important in defining these conditions.

ECe = Electrical Conductivity of a saturated soil extract

pH = Acidity or alkalinity of the solution

SAR = Sodium Adsorption Ratio

	ECe	ρН	SAR
SALINE	> 4 mmho cm ⁻¹	< 8.5	< 13
SODIC	< 4 mmho cm ⁻¹	> 8.5	> 13
SALINE - SODIC	> 4 mmho cm ⁻¹	> 8.5	> 3

Managing salinity and sodicity concerns

Salinity and sodicity problems have multiple causes and may be difficult to address. In general, salts can be leached out of the soil with the application of excess water through natural rainfall or irrigation. But this is often problematic in regions where shallow groundwater is a primary source of the salts, which in turn is often the results of excessive irrigation. Such areas may therefore require installation of subsurface drainage to remove the excess groundwater before salts can be leached.

Sodicity is often addressed through the application of gypsum, where calcium substitutes for the sodium on the soil exchange complex, thereby improving soil aggregation and reducing pH. It is then important to leach the sodium out of the surface soil to prevent the reoccurrence of sodicity.

Soil Health Assessment Report

The raw data from the individual indicators and background information about sample location and management history from the <u>sample submission</u> form (page 30) are synthesized in an auto-generated and grower-friendly report (Appendix A). The soil health assessment report presents measured values, interpretive ratings, and constraints identified by soil health indicators in a summary page, followed by a short narrative description of each indicator's importance and status, and selection tables with suggestions for targeted management.

The soil health assessment report summary is laid out in a visually enhanced format to present information to growers and agricultural service providers (Figure 2.54, following page). The sections of the summary page include:

- 1) **Background information:** includes the farm and agricultural service provider's name and contact information, provided sample name or field identification, sample lab ID, date of sampling, current and prior crop and tillage, provided soil type and both provided and measured soil texture information.
- 2) **Measured indicators:** provides a list of physical, biological, and chemical indicators that were measured for soil health assessment. Note that values measured for add-on indicators are provided separately.
- 3) **Indicator values:** presents the values of the indicators that were measured in the laboratory or field, in the units of measure as provided in the indicator descriptions that follow the report's cover page (see Appendix A for a complete sample report).
- 4) Ratings: interprets that measured value using the provided texture-adjusted scoring functions (pages 32-35) on a scale of 0 to 100, where higher scores are better. Ratings are color coded. Those in red (20 or less) are particularly important to take note of as they may indicate a constraint to proper soil functioning. Any in orange and yellow (between 20)

and 60), particularly those that are close to a rating of 20, are also important in addressing current or potentially developing soil health problems. Green and dark-green (60 or higher) indicates high scores, which suggest optimal or near optimal functioning.

- 5) **Constraints:** If the rating of a particular indicator is poor (red color code), associated soil health constraints will be highlighted in this section. This is useful for identifying priorities for targeting management efforts. Suggested management practices to address the identified constraints can be found in Part III of this manual, and are briefly summarized in tabular form at the end of the assessment report.
- 6) **Overall quality score:** computed by averaging the individual indicator ratings to provide an indication of the soil's overall health status. However, it is of greater importance to identify which particular soil processes are constrained in functioning or suboptimal, so that these issues can be addressed through appropriate management. Therefore the ratings for each indicator are more important information. The overall quality score is further rated as follows: less than 40 is regarded as very low to low, 40-60 is medium, 60-80 is high and 80 to 100 is regarded as very high. The highest possible quality score is 100 and the lowest possible is 0, thus it is a relative overall soil health status indicator.



Poor aggregation can result in poor water infiltration and storage.

Comprehensive Assessment of Soil Health

From the Cornell Soil Health Laboratory, Department of Soil and Crop Sciences, School of Integrative Plant Science, Cornell University, Ithaca, NY 14853. http://soilhealth.cals.cornell.edu



Grower:	Sample ID:	LL8
306 Tower Rd. Ithaca, NY 14853	Field ID:	Caldwell Field- intensive management
	Date Sampled:	03/11/2015
Agricultural Service Provider:	Given Soil Type:	Collamer silt loam
Mr. Bob Consulting rrs3@cornell.edu	Crops Grown:	WHT/WHT/WHT
	Tillage:	7-9 inches

Measured Soil Textural Class: silt loam

qı	Indicator	Value	Rating	Constraints
sical	Available Water Capacity	0.14	37	
sical	Surface Hardness	260	12	Rooting, Water Transmission
sical	Subsurface Hardness	340	35	
sical	Aggregate Stability	15.7	19	Aeration, Infiltration, Rooting, Crusting, Sealing, Erosion, Runoff
gical	Organic Matter	2.5	28	
gical	ACE Soil Protein Index	5.1	25	
gical	Soil Respiration	0.5	40	
gical	Active Carbon	288	12	Energy Source for Soil Biota
nical	Soil pH	6.5	100	
nical	Extractable Phosphorus	20.0	100	
mical	Extractable Potassium	150.6	100	
mical	Minor Elements Mg: 131.0 / Fe: 1.2 / Mn: 12.9 / Zn: 0.3		100	

FIGURE 2.54. Sample Soil Health Assessment Report with (1) Background info, (2) Measured indicator, (3) Indicator value, (4) Rating, (5) Constraints, and (6) Overall quality score.

Using the Assessment of Soil Health Information

The Cornell Assessment of Soil Health focuses on identifying priorities and opportunities for improved soil management. The color coded results and constraints listed on the summary page (page 73) help the user get an overview of the field's soil health status.

Identified constraints in soil process functioning are highlighted in red, and the associated soil processes represented by these constrained indicators are listed. While the overall soil quality score is provided at the bottom of the report summary page to integrate the suite of indicators, it is important to note that the most important information is which indicators are suboptimal, because it is this information that informs management decisions. As an entry point in our understanding of soil health, any measured soil constraint can be taken as a management target.



Spade and buckets used to collect soil health samples.

Soil Health Assessment Information:

- Part of an overall planning process
- Contains grower-friendly report
- Presents measured values, interpretive ratings
- Identifies priorities and opportunities
- Suggests management options
- Monitors change
- Measures progress

The soil health report is part of an overall Soil Health Management Planning Process and can be used to:

- Understand soil processes and past management impacts
- · Identify constraints, assess soil health status
- Select and implement management strategies that address needs and are feasible for the operation
- Monitor change
- Measure progress and adjust management

It is important to recognize that the information presented in the report is not intended as a measure of a grower's management skills, but as a tool to understand soil processes and past management impacts to inform management decisions towards addressing specific soil constraints that have not been previously measured as part of standard soil testing.

When multiple constraints are considered together, management strategies can be developed that select particular practices to address needs that are feasible for the operation and can restore functionality to the soil. These strategies become part of the Soil Health Management Plan discussed in Part III.

Using Soil Health Assessments in Soil Health Management Planning

Considerations in interpreting soil health assessments

First some general guidance to consider when embarking on evaluating the information gained from soil health assessments, and using it to decide on management solutions:

The report is a management guide, not a prescription: Nutrient management has largely been prescription-based (for example, a soil test report is returned with a recommendations to 'add 80 pounds of potassium per acre to increase plant available potassium'). The soil health report shows the aspects of the soil needing attention in order to alleviate constraints and thus enhance productivity, resilience, and sustainability. However, there is not a single and specific prescribed treatment for a given identified constraint, because options for addressing soil health constraints are more complex and varied (and also still less well understood) than options for alleviating nutrient deficiencies. Rather multiple diverse management options are provided for any given constraint, to guide the producer in understanding the types of practices that would alleviate the constraint identified. The choice and details of management efforts to be used in overcoming identified soil health constraints are dependent on various factors related to the operation, as will be discussed in the Soil Health Management Planning Process section in Part III.

Different management approaches can be used to mitigate the same problem: A number of different management practices that achieve similar outcomes can be used to address a constraint, as shown in the management suggestions tables provided as part of the soil health assessment report (see Part III). For example, growers seeking to increase aggregate stability in their fields need to find ways to protect and build soil aggregates through improving biological activity that accomplishes this, as discussed previously (page 46). They might approach this by using manure, growing shallow, dense-rooted cover crops, mulching, reducing tillage, or a combination of these methods, depending on their operational opportunities and challenges.

Management practices can affect multiple

indicators: A single management practice can affect multiple indicators and the functioning of soil processes associated with them. For example, adding manure to the soil will improve soil aggregation, increase organic matter, increase active carbon and soil protein contents, increase microbial activity, and improve soil nutrient status. The magnitude of such synergistic effects are dependent on the specific management practices, soil types, and management history.

Certain indicators are related, but over-interpretation of these relationships may be misleading: While several soil health indicators used in this assessment provide information about interrelated processes, the degree of interrelationship varies with soil type and previous management history. For example, a general relationship exists between total soil organic matter and active carbon contents. However, active carbon is an indicator of actively decomposing organic fractions that are readily available to the soil microbial community. A soil may be high in stabilized soil organic matter from past high carbon inputs and microbial activity, but it may be lacking the fresh decomposable component currently, and thus may show relatively low active carbon content. An example of such a situation is provided in the case study titled "Implementation of a Soil Health Management Plan Resolves Pond Eutrophication at Tuckaway Farm, NH" available online at <u>blogs.cornell.edu/whatscroppingup</u>

Direct comparison of two fields that have been managed differently may lead to confounded interpretations: Comparing two soil health assessment reports of fields with different management practices, histories, and soil types should be done with care. The absence of baseline data and similar inherent soil types for such comparisons makes it difficult to conclude on beneficial effects of a management practice. However, if a field was managed the same way and then divided up into comparable sections with different management practices (preferably replicated), a soil health assessment can be used to compare management alternatives.

Soil health changes slowly over time:

Soil health problems have generally developed as a result of long-term management choices, so it can be expected that a "heavy footprint" on soil health parameters cannot be instantaneously alleviated as is the case for most nutrient deficiency problems. Generally, management practices to address soil health constraints take variable amounts of time for desired effects to be observed and measured. Some changes in the indicators can be seen in the short term, while others may take a much longer period to be realized. For example, fertilizer application for nutrient deficiencies, and even targeted deep sub-soiling to alleviate a subsoil plow pan, or surface disturbance to alleviate compacted surface soils, may produce immediate effects within a season. But with conversion to no-tillage it may take 3-5 years before beneficial changes in soil health and productivity become noticeable. The speed of change also depends on climate and soil type. For example in very cold or very warm climates, measurable changes may take longer. Some producers are experiencing more rapid changes when they strategically combine multiple locally-adapted practices into soil health management systems, such as combining reduced tillage with cover cropping, grazing of those covers, and improved rotations.

The Comprehensive Assessment of Soil Health Report fits into the Soil Health Management and Planning Framework to be discussed in further detail in Part III.

REMEMBER - SOIL HEALTH MANAGEMENT PLANNING AND IMPLEMENTATION IS A LONG-TERM INVESTMENT!



Growing Aroostook cereal rye cover crop. Photo credit: Troy Bishopp

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