



## Soil Health Sampling Protocols

### 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](https://bit.ly/CASHforms))
- Permanent marker and/or pen
- Straight shovel (sharpshooter or trenching spade style)
- Penetrometer (optional); [Contact lab](#) to borrow (see back)
- Cooler for in-field sample storage and transfer
- Ice pack(s) (optional); Only needed for hottest days



### Prior to sampling a field

- **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.

### Soil sampling considerations

Soil Health sampling guidelines are similar to those of standard nutrient analysis. Samples should be taken when soils are at field capacity, before field operations, at a minimum 6” depth. Avoid irregular areas.

#### A. Sampling for General Purposes

- Sample 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: Identify 10 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

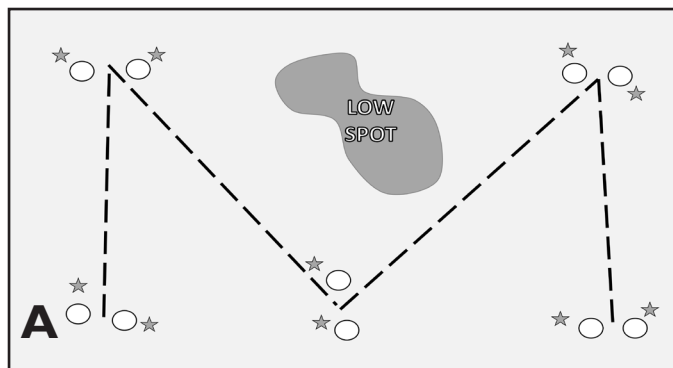
- Ideal for areas with uneven crop performance or for comparing zones, ‘X’ vs. ‘Y’, for example
- Targeted soil sampling from representative areas of each zone

EXAMPLE B: 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?

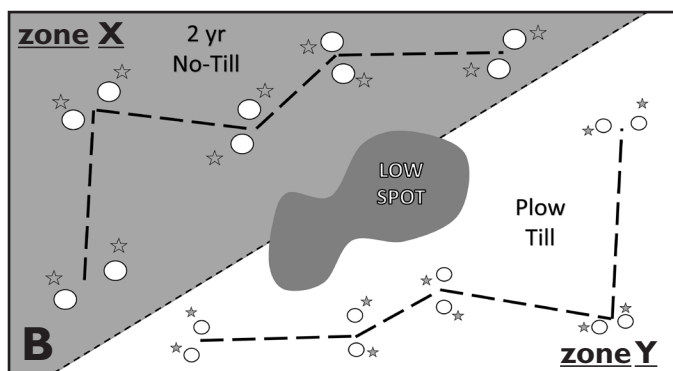
#### Sub-sampling and Penetrometer Locations:



Example A: General field sampling (1 sample)



Example B: Troubleshooting (2 or more separate samples)



For more details please view our eight minute video available at [bit.ly/SoilHealthSampling](https://bit.ly/SoilHealthSampling)

## Steps for soil health sampling

From 10 representative locations in the sampling area:

- A. Remove surface debris.
- 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.
- C1. 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 subsample locations, [collect soil hardness](#) information with a penetrometer. Record maximum hardness (in psi) from the 0-6" and at the 6-18" depth ranges on the [Submission Form](#).
- E. Repeat steps A – D to collect the remainder of the subsamples. Mix thoroughly and transfer 3-6 cups of soil (depending on the [analysis package](#)) into a clearly labeled one-gallon re-closable freezer bag:

- Basic Package - 3 cups
- Standard Package - 4 cups
- Extended Package - 6 cups

[Visit our website](#) for a complete description of each analysis package.

A complete sample will consist of:

- a clearly labeled bag containing 3 to 6 cups of well mixed soil, **double bagged**.
- a completed submission form with **state and county entered** and penetrometer readings clearly recorded.

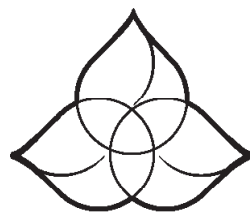
### Soil sample storage requirements

- Always keep samples out of direct sunlight, and if possible, store in a cooler while in the field.
- **IMPORTANT:** When collecting a large number of samples and if you have particular sampling considerations regarding storage or pre-processing, please contact [Soil Health Lab personnel](#) prior to sampling.

### Packaging and shipping requirements

- Visit our website and download the submission form: [bit.ly/CASHforms](http://bit.ly/CASHforms). Save the submission form file for your records. Include your penetrometer readings
- For 1 sample, use a small USPS Flat Rate Box.
- For multiple samples, use a USPS Priority Mail Medium Flat Rate box (up to 6 samples per box).
- **Add packing material** in box to minimize sample movement and use ice packs on hottest summer days.

### Send samples & submission forms to:



**Cornell Soil Health Laboratory**  
G01 Bradfield Hall  
306 Tower Rd.  
Ithaca, NY 14853  
[soilhealth@cornell.edu](mailto:soilhealth@cornell.edu)  
607-227-6055

Further details on packaging and shipping requirements can be found at [bit.ly/SoilHealthShipping](http://bit.ly/SoilHealthShipping).



**ABOVE.** The steps of taking a soil health sample.

NOTE: Keep samples out of the direct sunlight and keep as cool as possible during sampling. Store samples in a cold place after returning from the field and ship to Cornell as soon as possible.





## What is Soil Health?

The terms ‘soil health’ and ‘soil quality’ are becoming increasingly familiar worldwide. A modern consensus definition of soil health is “the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals and humans” (USDA-NRCS, 2012).

In general, soil health and soil quality are considered synonymous and can be used interchangeably, with one key distinction conceptualized by scientists and practitioners over the last decades: soil quality includes both *inherent* and *dynamic* quality.

*Inherent* soil quality relates to a soil’s natural composition and properties influenced by geologically long-term factors and processes including the type of parent material, topography, organisms, climate, and time. Changing just one of the factors will produce a different soil. Inherent soil quality cannot generally be influenced by human activity.

In contrast, *dynamic* soil quality, which is equivalent to soil health, refers to soil properties that transform as a result of soil use and management over the human time scale. (Fig. 1).

Soil health invokes the idea that soil is an ecosystem full of life that needs to be carefully managed to regain and maintain the ability to function optimally.

### Important soil functions related to crop production and environmental quality

- Retaining and cycling nutrients
- Supporting plant growth
- Sequestering carbon
- Allowing infiltration, and facilitating storage and filtration of water
- Suppressing pests, diseases, and weeds
- Detoxifying harmful chemicals
- Supporting the production of food, feed, fiber, and fuel



**FIGURE 1.** Dynamic soil quality - beneficial vs. unfavorable management. Both photos are inherently the same Buxton silt loam.

Left - Management for improved soil health: tillage radish growing in long-term pasture/hay with occasional annual crops.

Right - Intensive management leading to soil degradation: long-term annual tillage and vegetable production without cover crops or other organic inputs.

Due to management differences, soil health has diverged significantly.

When the soil is not functioning to its full capacity, sustainable productivity, environmental quality, and net farmer profits are jeopardized over the long term. Impaired function may result from constraints to specific and interacting soil processes. Below are some examples of the economic benefits of maintaining and improving soil health:

- Better plant growth, quality, and yield
- Reduced risk of yield loss during periods of environmental stress (e.g., heavy rain, drought, pest or disease outbreak)
- Better field access during wet periods
- Reduced fuel costs by requiring less tillage
- Reduced input costs by decreasing losses, and improving use efficiency of fertilizer, pesticide, herbicide, and irrigation applications.

# Characteristics of a Healthy Soil

## Good soil tilth

Soil tilth refers to the overall physical character of the soil in the context of its suitability for crop production. Soil with good tilth is crumbly, well structured, dark with organic matter, and has no large and hard clods (Fig 2).

## Sufficient depth

Sufficient depth refers to the extent of the soil profile through which roots are able to grow to find water and nutrients. A soil with a shallow depth as a result of a compaction layer or past erosion is more susceptible to damage in extreme weather, thus predisposing the crop to flooding, pathogen attack, or drought stress.

## Good water storage and good drainage

During a heavy rain, a healthy soil will take in and store more water in medium and small pores, but will also drain water more rapidly from large pores. Thus, a healthy soil will retain more water for plant uptake during dry times, but will also allow air to rapidly move back in after rainfall, so that organisms can continue to thrive.

## Sufficient supply, but not excess of nutrients

An adequate and accessible supply of nutrients is necessary for optimal plant growth and for maintaining balanced cycling of nutrients within the system. An excess of nutrients can lead to leaching and potential ground water pollution, high nutrient runoff and greenhouse gas losses, as well as toxicity to plants and microbial communities.

## Small population of pathogens and pests

Plant pathogens and pests can cause diseases and damage to the crop. In a healthy soil, the population of these organisms is low or is less active. This could result from direct competition from other soil organisms for nutrients or habitat, etc. In addition, healthy plants are better able to defend against a variety of pests.



**FIGURE 2.**

Good soil tilth: Zone tillage for 10 years increased organic matter compared to conventional tillage.

## Large population of beneficial organisms

Soil organisms help with cycling nutrients, decomposing organic matter, maintaining soil structure, biologically suppressing plant pests, etc. A healthy soil will have a large and diverse population of beneficial organisms to carry out these functions and thus help maintain a healthy soil status.

## Low weed pressure

Weeds compete with crops for water and nutrients that are essential for plant growth. Weeds can block sunlight, interfere with stand establishment and harvest and cultivation operations, and harbor disease causing pathogens and pests.

## Free of potentially harmful chemicals and toxins

Healthy soils are either devoid of excess amounts of harmful chemicals and toxins, or can detoxify or bind such chemicals. These processes make these harmful compounds unavailable for plant uptake, due to the soil's richness in stable organic matter and diverse microbial communities.

## Resistance and resilience to degradation

A healthy, well aggregated soil, is resilient, full of diverse organisms and is more resistant to degradation from wind and rain erosion, excess rainfall, extreme drought, vehicle compaction, disease outbreak, and other potentially damaging influences.

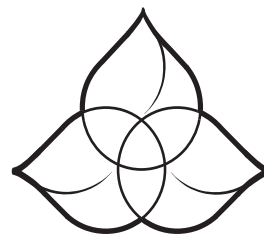
For a more comprehensive overview of soil health concepts including a guide on conducting in-field qualitative and quantitative soil health assessments, please download the Cornell Soil Health Manual at [bit.ly/SoilHealthTrainingManual](http://bit.ly/SoilHealthTrainingManual).

## Acknowledgement

Thanks to the NE Sustainable Agriculture Research & Education Program, New York Farm Viability Institute, USDA-NRCS and Cornell Cooperative Extension for funding and support of the Cornell Soil Health program.

This fact sheet represents the best professional judgment of the authors and does not necessarily reflect the views of the funders or reviewers.

For more information contact:



Cornell University  
Soil Health Laboratory  
[bit.ly/SoilHealthContacts](http://bit.ly/SoilHealthContacts)

Harold van Es

Robert Schindelbeck

Aaron Ristow, Kirsten Kurtz and  
Lindsay Fennell

January 2017





## Common Soil Constraints

It is important to recognize soil constraints that limit crop productivity, farm sustainability, and environmental quality. Management practices can be adjusted to alleviate these problems. The following is some of the more common soil constraints commonly observed in the U.S., along with some contributing factors and resulting soil conditions.

### Soil compaction

Compaction can occur at the surface and subsurface soil profile. Be sure that a soil is ready for equipment prior to tilling.

#### Contributing factors:

- Traffic or tillage when soil is wet or ‘plastic’ (Fig. 1)
- Heavy equipment and loads
- Uncontrolled traffic patterns

#### Can result in:

- Reduced root growth in surface and subsurface soils
- Limited water infiltration resulting in runoff, erosion, ponding and poor aeration
- Drought sensitivity due to reduced water storage and rooting
- Reduced nutrient access due to poor root growth and restricted water flow
- Increased pathogen pressure due to poor drainage and plant stress
- Increased cost of tillage; lower yields



**FIGURE 1.** Tillage when the soil is too wet (plastic) resulting in clodding and compaction.



**FIGURE 2.** Surface crusting in mid-spring as a result of poor aggregation.

### Poor aggregation

Poorly aggregated soils are more susceptible to erosion and runoff which increases risk of lost productivity. Aggregates are formed whenever mineral and organic particles clump together.

#### Contributing factors:

- Intensive tillage; low active rooting density
- Limited use of soil building crops and soil cover
- Limited duration of root presence during the year
- Limited organic additions
- Low biological activity to stabilize aggregates

#### Can result in:

- Reduced drought resistance due to crusting and cracking (Fig. 2)
- Poor water infiltration and storage during rain events
- Increased occurrence of erosion and runoff
- Reduced aeration and root growth
- Poor seedling emergence and stand establishment
- Few number of and less active microbial communities

### Weed Pressure

When plants are unhealthy and “weak” they are less able to compete against weeds for water and nutrients and defend themselves against pests.

#### Contributing factors:

- Inadequate crop rotations and omission of cover crops
- Poor weed management; resistance to herbicides
- Poor timing of management practices

#### Can result in:

- Poor stand establishment and crop growth
- Poor crop quality and reduced yield
- Increased disease and pest damage
- Interference with cultural practices and harvest
- Increased cost of weed control

# Common Soil Constraints

## High pathogen pressure

Root pathogenesis negatively impacts plant growth and root effectiveness as well as minimizes contributions from microbiota in proper functioning of important soil processes.

### Contributing factors:

- Poorly planned crop rotations and low rotational diversity
- Ineffective residue management; poor sanitary practices
- Low microbial diversity, reduced pathogen suppression
- Poor physical soil functioning, particularly waterlogging, or other plant stress-inducing conditions.

### Can result in:

- Damaged and diseased roots (Fig. 3); uneven and poor growth
- Reduced yields, crop quality and profit

## Salinity and sodicity

Soil problems can be found in arid and semiarid regions, including soils that are high in salts (saline) and those that have excessive sodium (sodic) (Fig. 4).

### Contributing factors:

- Frequently found in semi-arid and arid climates, also under irrigated systems or closed, irrigated high tunnels and greenhouses (in the northeast).

### Can result in:

- Loss of crop yield and quality
- Loss of aggregation, infiltration and drainage functions

## Low water and nutrient retention

Lower organic matter in soils indicates poor structure and lower water holding capacity. Therefore nutrient mobility and plant growth will be limited.

### Contributing factors:

- Low organic matter and resulting poor structure, water holding capacity and reduced exchange capacity
- Poor retention and biological recycling of nutrients in biomass and soil organic matter
- Excessive tillage, insufficient use of soil building crops

### Can result in:

- Ground and surface water pollution; Reduced microbial community, nutrient deficiencies and poor plant growth



**FIGURE 3.** Symptoms of root rot diseases on pea roots.

## Heavy metal contamination

Contamination from past human activities, such as high traffic, commercial activity, spills, or pesticide application, can negatively impact soil and plant health.

### Contributing factors:

- Common in urban areas and other sites with past use of contaminants such as lead paint, fertilizers, pesticides (e.g., lead arsenate use on orchard land)
- Past activities such as high traffic, industrial or commercial activity, treated lumber, machine repair, junk vehicles, furniture refinishing, fires, landfills, or garbage dumps
- Naturally occurring high heavy metal concentrations (generally rare in the Northeast)

### Can result in:

- Higher risks of human exposure
- Plant toxicity; inhibition of soil biological activity
- Reduced yield and/or crop quality



**FIGURE 4.** Saline/sodic soil

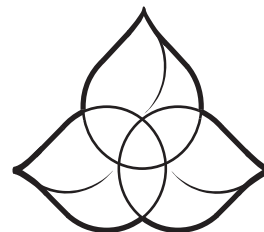
For a more comprehensive overview of soil health concepts including a guide on conducting in-field qualitative and quantitative soil health assessments, please download the Cornell Soil Health Manual at [bit.ly/SoilHealthTrainingManual](http://bit.ly/SoilHealthTrainingManual).

## Acknowledgement

Thanks to the NE Sustainable Agriculture Research & Education Program, New York Farm Viability Institute, USDA-NRCS and Cornell Cooperative Extension for funding and support of the Cornell Soil Health program.

This fact sheet represents the best professional judgment of the authors and does not necessarily reflect the views of the funders or reviewers.

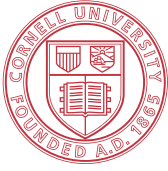
For more information contact:



Cornell University  
Soil Health Laboratory  
[bit.ly/SoilHealthContacts](http://bit.ly/SoilHealthContacts)

Harold van Es  
Robert Schindelbeck  
Aaron Ristow, Kirsten Kurtz and  
Lindsay Fennell  
January 2017

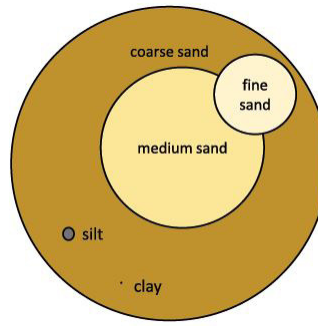




## Soil Texture

### What is soil texture?

Soil texture refers to a mixture of variously sized mineral particles (Fig. 1), which determine a soil's textural class. 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 below (Fig. 2). 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. 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.



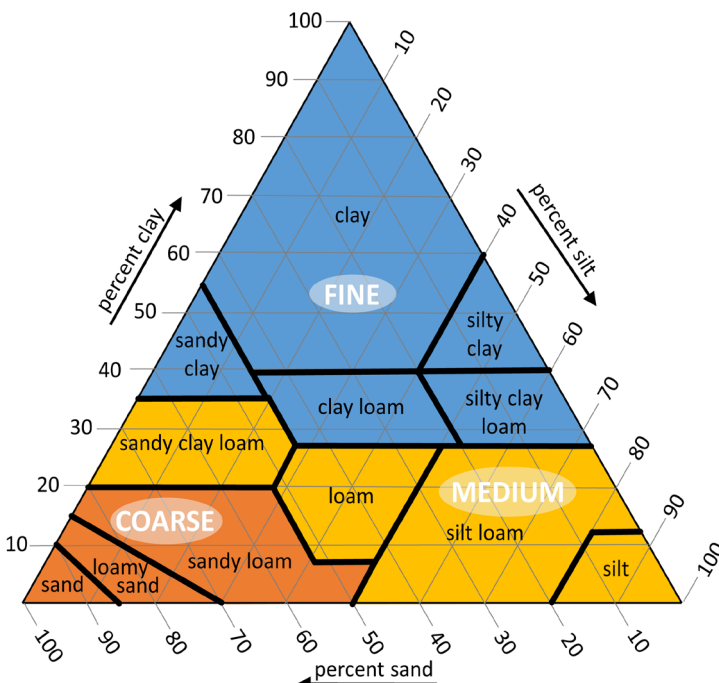
**FIGURE 1.** Relative size of soil particles.

### Relating texture 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 (finer soils) generally have higher ability to retain nutrients (more [cation exchange capacity](#), or CEC) 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. Aggregates

and inter-aggregate spaces are as important as the sizes of the particles themselves, because the relative quantities of variously sized pores—large, 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.



**FIGURE 2.** Textural triangle used in determining soil textural class.

# Soil Texture

## Using texture in developing scoring functions

Soil texture contributes to inherent soil quality, and is virtually unchangeable through soil management. However, most interpretations of soil health indicator scores are dependent on interactions with soil texture. Therefore texture is not given a soil health score. For example, given the same management, coarse textured soils generally have lower organic matter (OM) levels than fine-textured soils because they lack the ability to stabilize OM. Measured OM 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 (See textural triangle on the previous page).

## Basic protocol

- Air dry and sieve soil sample 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 (Fig. 3a). Sieve assembly consists of 0.053mm sieve on top of a 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 (3b).
- Silt and clay particles collected in the 1L beaker are re-suspended by stirring and allowed to settle for 2 hours (3c). The clay in suspension is then 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<sup>o</sup> C to constant weight before recording dry weight.
- Calculate percent sand, silt clay from:
  - Sand (%) = dry wt sand (g)/dry wt soil (g) added to centrifuge tube.
  - Silt (%) = dry wt silt (g)/dry wt soil (g) added to centrifuge tube.
  - Clay (%) = 100% - Sand (%) - Silt (%).



**FIGURE 3 a - c.** Steps to determine soil textural class.

NOTE: This is a rapid, but reliable and robust method to categorize sample soil particle size distribution. Once silt, sand and clay fractions are known, a sample is categorized as fine, medium or coarse, and the textural triangle is used to determine textural class (previous page).

Cornell Soil Health Laboratory Soil Texture [Standard Operating Procedures](#) (CSH 02) can be found under the 'Resources' tab on our website.

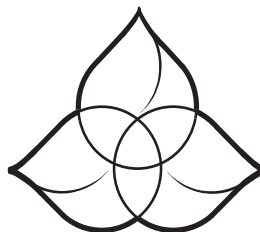
For a more comprehensive overview of soil health concepts including a guide on conducting in-field qualitative and quantitative soil health assessments, please download the Cornell Soil Health Manual at [bit.ly/SoilHealthTrainingManual](http://bit.ly/SoilHealthTrainingManual).

## Acknowledgement

Thanks to the NE Sustainable Agriculture Research & Education Program, New York Farm Viability Institute, USDA-NRCS and Cornell Cooperative Extension for funding and support of the Cornell Soil Health program.

This fact sheet represents the best professional judgment of the authors and does not necessarily reflect the views of the funders or reviewers.

For more information contact:



Cornell University  
Soil Health Laboratory  
[bit.ly/SoilHealthContacts](http://bit.ly/SoilHealthContacts)

Harold van Es

Robert Schindelbeck

Aaron Ristow, Kirsten Kurtz and  
Lindsay Fennell

January 2017





## Available Water Capacity

Available Water Capacity (AWC) is an indicator of the range of plant available water the soil can store. The upper end of the range is referred to as ‘*field capacity*’ or the condition where saturated soil ceases to drain freely from gravity after wetting. The lower end of the range is called the ‘*permanent wilting point*’, when only water unavailable to plants is left after free drainage (Fig. 1). 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.

### How AWC relates to soil function

Water is stored in medium and small sized soil pores and in organic matter. Available Water Capacity is an indicator of how much water per weight of soil can be stored in the field, and therefore how crops may fare in extremely dry conditions. Soils with lower storage capacity have greater risk of drought stress.

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 (Fig. 1). Therefore 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 clays 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 comes less frequently but more intensively. Note that total crop water availability is also dependent on rooting depth, which is considered in separate soil health indicators - surface and subsurface hardness.

A guide to demonstrating how soil structure can impact water storage is available under the ‘[Resources](#)’ tab on our website: [soilhealth.cals.cornell.edu/resources](http://soilhealth.cals.cornell.edu/resources).

### Managing constraints and maintaining optimal available water capacity

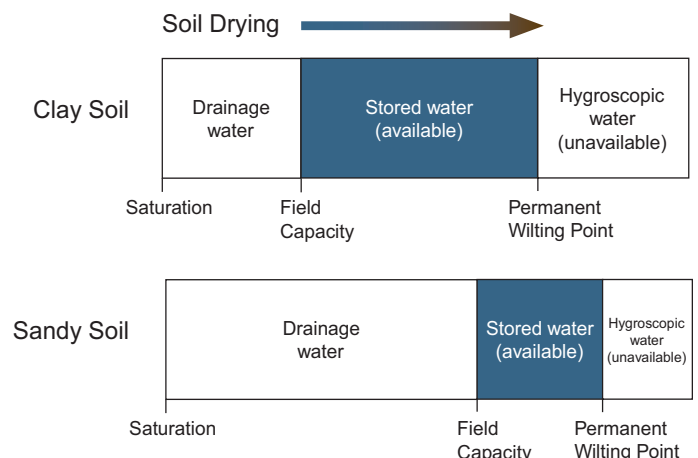
#### Short-term strategies:

- Adding stable organic materials, such as composts, that themselves can store larger amounts of water
- Use mulches to prevent water from evaporating from the surface

#### Long-term strategies:

- Build organic matter and aggregation to enhance porosity for water infiltration and storage
- Reduce tillage
- Long-term cover cropping
- Add amendments such as mulch
- Rotate annual crops with diverse perennials
- Keep actively growing roots in the system to build and maintain soil pores.

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 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.



**FIGURE 1.** Water storage for two soil textural groups. The blue shaded area represents water that is available for plant use.

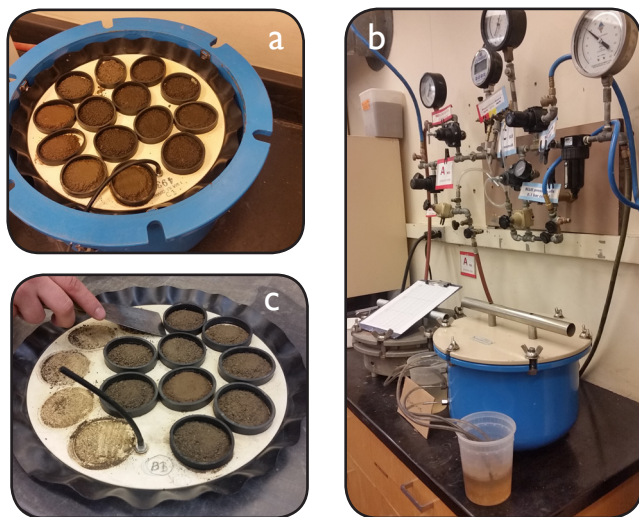
# Available Water Capacity



**ABOVE:** Residue mulch on the surface from reduced tillage. The cover prevents water from evaporating. *Source: USDA-NRCS*

## Basic protocol

- Soil is placed on two ceramic plates with known porosity, and wetted to saturation (Fig. 2a).
- The ceramic plates are inserted into two high pressure chambers to extract water to field capacity (10 kPa), and to the permanent wilting point (1500kPa) (2b).
- After the sample equilibrates at the target pressure, the sample is weighed (2c), then oven-dried at 105C 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.

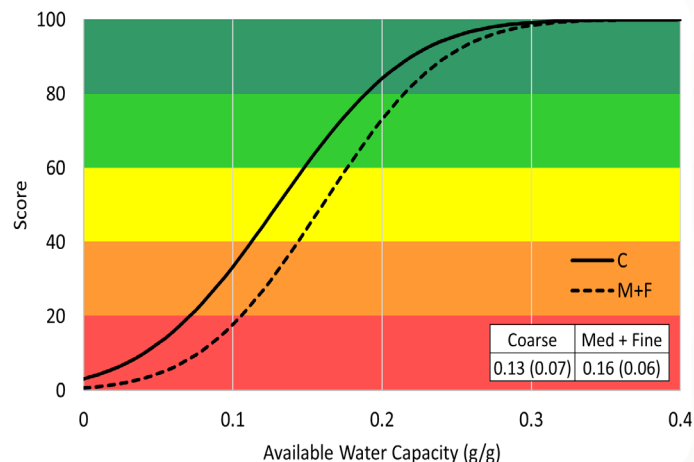


**FIGURE 2 a - c.** (a) Ceramic plates with soil are (b) inserted into high pressure chambers. (c) Equilibrated samples at target pressure. Samples are weighed, oven dried overnight, and weighed again.

## Scoring function

Figure 3 below depicts Available Water Capacity scoring functions and upper value limits for coarse, medium, and fine textured soils. 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.



**FIGURE 3.** 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.

Cornell Soil Health Laboratory AWC [Standard Operating Procedures](#) (CSH 05) can be found under the '[Resources](#)' tab on our website.

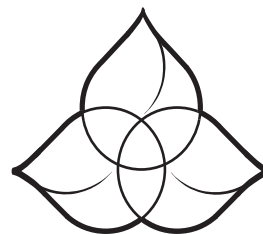
For a more comprehensive overview of soil health concepts including a guide on conducting in-field qualitative and quantitative soil health assessments, please download the Cornell Soil Health Manual at [bit.ly/SoilHealthTrainingManual](http://bit.ly/SoilHealthTrainingManual).

## Acknowledgement

Thanks to the NE Sustainable Agriculture Research & Education Program, New York Farm Viability Institute, USDA-NRCS and Cornell Cooperative Extension for funding and support of the Cornell Soil Health program.

This fact sheet represents the best professional judgment of the authors and does not necessarily reflect the views of the funders or reviewers.

For more information contact:



Cornell University  
Soil Health Laboratory  
[bit.ly/SoilHealthContacts](http://bit.ly/SoilHealthContacts)

Harold van Es  
Robert Schindelbeck  
Aaron Ristow, Kirsten Kurtz and  
Lindsay Fennell

January 2017





## Predicted Available Water Capacity

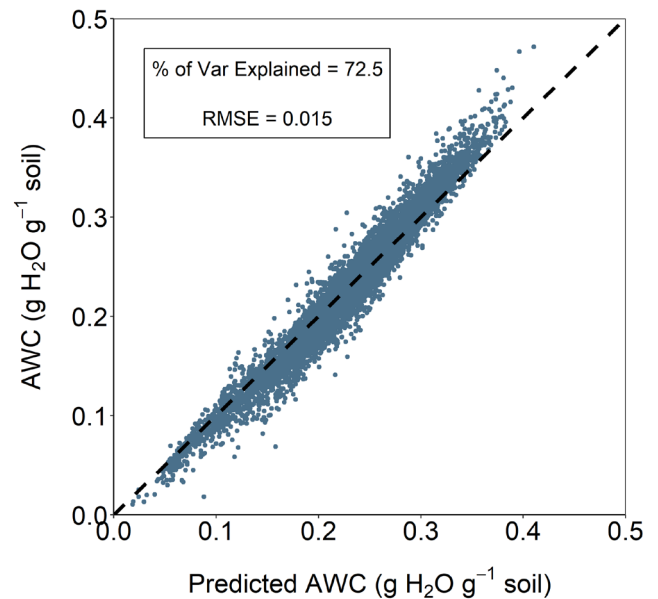
Available Water Capacity (AWC) is an indicator of the amount of plant available water a soil can store.

Beginning in 2019, the Cornell Soil Health Lab moved to **predict** AWC from a suite of measured sample parameters in the Standard comprehensive assessment of soil health (CASH) package. The laboratory measured AWC will remain available as an optional add-on to the CASH packages.

### Modeling AWC

In late 2018, the Cornell Soil Health lab determined that AWC, a valuable, but time-intensive measurement, could be accurately predicted. A CASH database containing 7,951 soil samples was used to develop a Random Forest model to predict AWC from a suite of measured parameters, including % sand, % silt, % clay, Organic Matter, Active Carbon, ACE Protein, Respiration, Wet Aggregate Stability, Potassium, Magnesium, Iron, and Manganese. The Random Forest (RF) model was able to explain more variation in AWC than alternative multiple linear regression models. Specifically, the RF model was able to explain 72.5 % of the variation in AWC with a low average root mean square error (RMSE) value (Fig. 1). RMSE is a measure of how much observed values deviate from the predicted values. The RMSE value was only 3% of actual AWC values, which is equivalent to the sensitivity of the laboratory method. Therefore, our predicted values had no more error than the original raw AWC data.

Random Forest is a robust machine learning algorithm that uses a decision tree approach to model variables. Machine learning algorithms such as RF have become increasingly popular techniques to model parameters that are difficult or costly to measure. For example, soil properties such as bulk density and hydraulic conductivity are expensive to measure and extremely variable, so environmental scientists have developed models to predict these variables from routinely measured parameters such as % sand, silt, clay, and organic carbon.



**FIGURE 1.** Predicted AWC vs. observed AWC for the CASH database (n=7,951).

### Managing constraints and maintaining optimal AWC

#### Short-term strategies:

- Adding stable organic materials, such as composts, that themselves can store larger amounts of water
- Use mulches to prevent water from evaporating from the surface

#### Long-term strategies:

- Build soil organic matter and aggregation to enhance porosity for water infiltration and storage
- Reduce tillage
- Long-term cover cropping
- Rotate annual crops with perennial species
- Keep actively growing roots in the system to build and maintain soil pores

In coarse textured soils, improving water holding capacity is more challenging than in finer textured soils that inherently store more water. Therefore, managing for increased AWC, and also for decreased evaporation through surface cover, is important in coarse textured soils.

# Predicted Available Water Capacity

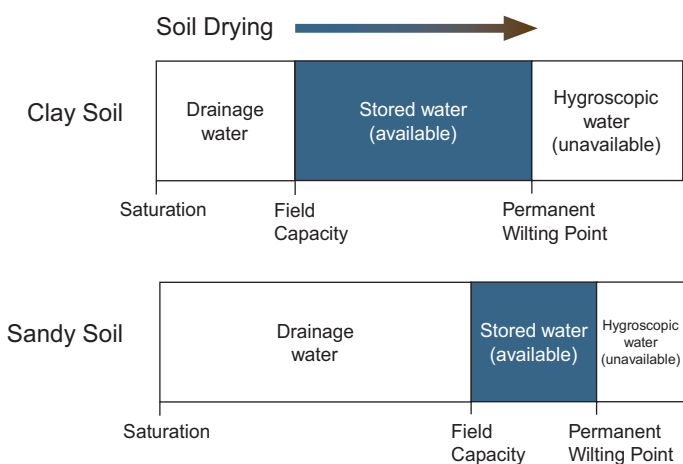
## How AWC relates to soil function

Water is stored in medium and small sized soil pores and in organic matter. AWC provides a measure of how much water will be available to plants in the field, and therefore how crops may fare in extremely dry conditions. In the field, a soil is at the upper end of soil wetness when water that it can't hold up 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 is plant available until it decreases to the permanent wilting point (Fig. 2).

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 (Fig. 2). Therefore, a common constraint of sandy (coarse textured) soils is their ability to store water for crops between rains, which is especially a concern during draughty 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 clays 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 water to infiltrate during intense rainfall events.

Note that total crop water availability is also dependent on rooting depth, which is considered in separate soil health indicators - surface and subsurface hardness.

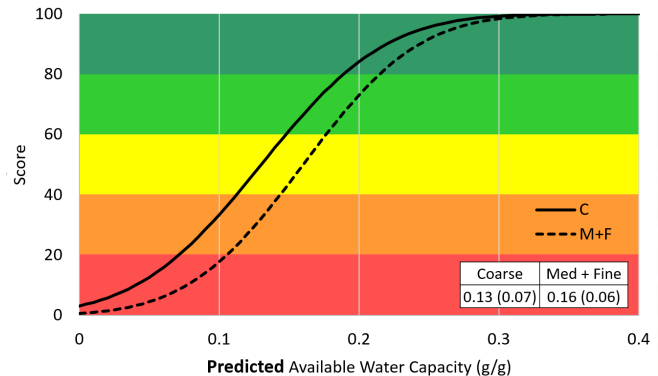


**FIGURE 2.** Water storage for two soil textural groups. The blue shaded area represents water that is available for plant use.

## Scoring function

Figure 3 below depicts the **Predicted** Available Water Capacity scoring functions and upper value limits for coarse, medium, and fine textured soils. Scoring functions were combined for medium and fine classes because no clear differences were observed between these texture groups.

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.



**FIGURE 3.** Predicted Available Water Capacity (AWC) scoring functions 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.

Note that the original AWC laboratory methodology is available in [Fact Sheet Number 16-05](#). In addition, the Cornell Soil Health Laboratory AWC [Standard Operating Procedures](#) (CSH 05) can be found under the 'Resources' tab on our website.

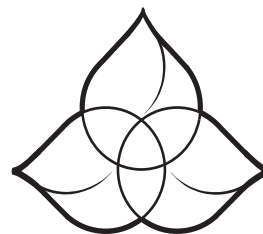
For a more comprehensive overview of soil health concepts including a guide on conducting in-field qualitative and quantitative soil health assessments, please download the Cornell Soil Health Manual at [bit.ly/SoilHealthTrainingManual](http://bit.ly/SoilHealthTrainingManual).

## Acknowledgement

Thanks to the NE Sustainable Agriculture Research & Education Program, New York Farm Viability Institute, USDA-NRCS and Cornell Cooperative Extension for funding and support of the Cornell Soil Health program.

This fact sheet represents the best professional judgment of the authors and does not necessarily reflect the views of the funders or reviewers.

For more information contact:



Cornell University  
Soil Health Laboratory  
[bit.ly/SoilHealthContacts](http://bit.ly/SoilHealthContacts)

Harold van Es  
Robert Schindelbeck  
Joseph Amsili and Kirsten Kurtz  
March 2019





## Surface and Subsurface Hardness

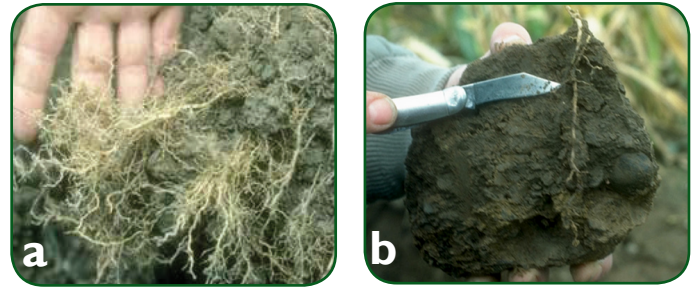
Surface and subsurface hardness are indicators of the soil compaction status, measured as field penetration resistance in pounds per square inch (psi). It is measured in the field using a penetrometer or soil compaction test pushed through the soil profile at two depth increments (surface: 0 – 6”, and subsurface: 6 – 18”). Measurements should be taken when the soil is friable, since moisture content influences the measurement. For a detailed guide on how to take penetrometer measurements please visit [bit.ly/SHPenetrometer](http://bit.ly/SHPenetrometer).

### How soil hardness relates to soil function

Field penetration resistance measures whether the soil is compacted. Compaction occurs when large pores are packed closer together through tillage or traffic with heavy equipment, particularly on wet soils. Large pores are necessary for water and air movement and to allow roots and organisms to explore the soil (Fig. 1). 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 (Fig 2). 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.

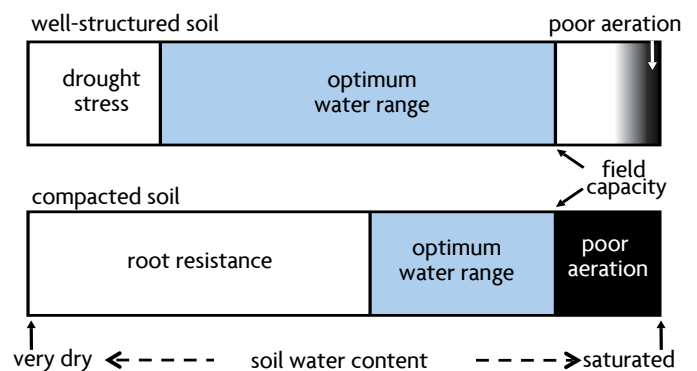


**FIGURE 1 a and b.** (a) Dense rooting allows for full soil exploration. (b) Surface compaction prevents root from accessing water and nutrients.

### Managing and preventing constraints

Compaction in surface and subsurface soil occurs when the soil is worked or trafficked while it is too wet, and it can be transferred deep into the soil even from surface pressure. Thus, compaction can be prevented:

- avoid soil disturbance, especially when the soil is wet
- maintain aggregation
- target mechanical surface loosening of the soil, followed by adding fresh organic matter and rooting cover/rotation crops to build aggregates
- use deep tillage or deep rooting crops
- reduce tillage, have soil cover with active rooting, use rotations and controlled traffic with minimized loads to maintain non-compacted soils in the long term.



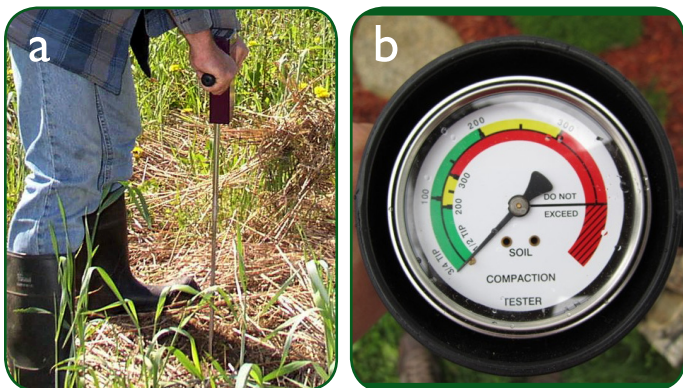
**FIGURE 2.** Compacted soils have greater root resistance, poorer water storage capacity and decreased infiltration compared to well-structured soils. *Source: Building Soils for Better Crops, 3rd edition.*

# Surface and Subsurface Hardness

## Basic protocol

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 (Fig. 3a).

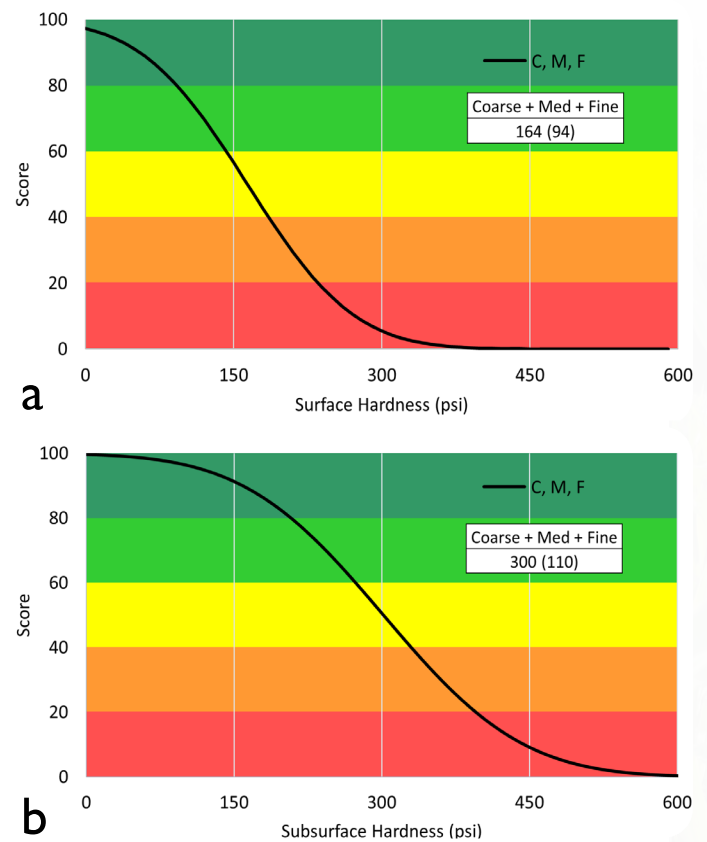
- Most penetrometers come with two different sized tips which correspond to two different gauge scales. The outer and inner scales correspond to the larger  $\frac{3}{4}$  inch and the smaller  $\frac{1}{2}$  inch diameter tips, respectively (3b). The  $\frac{1}{2}$ " tip should be used for our test. The  $\frac{3}{4}$ " 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). See Fact Sheet #5 for more detail on field capacity. If the soil conditions are not ideal, it is important to note these conditions at the time so that proper interpretation of the reading can be made.
- 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 for your own reference.
- 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. 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 3 a and b.** Measuring surface and subsurface hardness with a penetrometer. Source (b): [agricultureolutions.com](http://agricultureolutions.com)

## Scoring function

Figure 4 below depicts Surface (a) and Subsurface (b) Resistance scoring functions and upper value limits for coarse, medium, and fine textured soils.



**FIGURE 4 a and b.** Surface (a) and subsurface (b) scoring functions and upper value limits for Coarse (C), Medium (M) and Fine (F) textural classes.

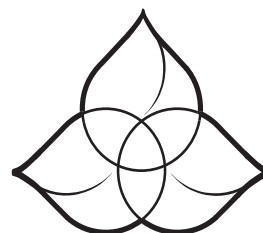
For a more comprehensive overview of soil health concepts including a guide on conducting in-field qualitative and quantitative soil health assessments, please download the Cornell Soil Health Manual at [bit.ly/SoilHealthTrainingManual](http://bit.ly/SoilHealthTrainingManual).

## Acknowledgement

Thanks to the NE Sustainable Agriculture Research & Education Program, New York Farm Viability Institute, USDA-NRCS and Cornell Cooperative Extension for funding and support of the Cornell Soil Health program.

This fact sheet represents the best professional judgment of the authors and does not necessarily reflect the views of the funders or reviewers.

For more information contact:



Cornell University  
Soil Health Laboratory  
[bit.ly/SoilHealthContacts](http://bit.ly/SoilHealthContacts)

Harold van Es  
Robert Schindelbeck  
Aaron Ristow, Kirsten Kurtz and  
Lindsay Fennell

January 2017





## Wet Aggregate Stability

Wet Aggregate Stability is a measure of the extent to which soil aggregates resist falling apart when hit by rain drops and wetted. It is measured using a Cornell Rainfall Simulator that steadily rains on a sieve containing a known weight of soil aggregates. 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 (see following page). For details on the Rainfall Simulator visit: [soilhealth.cals.cornell.edu](http://soilhealth.cals.cornell.edu).

### How aggregate stability relates to soil function

Stable aggregates are built by biological activity, as aggregates are largely “stuck” together by fungal hyphae, microbial colonies, and plant and microbial exudates. Aggregates can break down, however, in intensively managed and clean-tilled soils

Aggregate stability can be used as an indicator of both physical and biological health:

- 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 (Fig. 1) as well as a 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, potentially causing it to take longer before field operations are possible.
- Enhanced friability and crumbliness from aggregation in fine textured soils, 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 fissures between crumbs, while storing water for plant use within the stable aggregates.
- Good aggregation is critical for resilience to extreme weather.



**FIGURE 1.** Poor soil aggregation tends to form surface crusts and compacted surface soil. This can reduce water infiltration and storage and lead to excessive runoff and erosion.

Source: [indianapublicmedia.org](http://indianapublicmedia.org)

### Tips for managing constraints and maintaining optimal aggregate stability

We want soil to have favorable, stable structure (tilth) so that plant roots can fully develop with minimal effort while maximizing rainfall infiltration and water storage for later plant use. 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 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, diverse species and crop rotations with active living roots will build and maintain stable aggregates in the long term.

# Wet Aggregate Stability

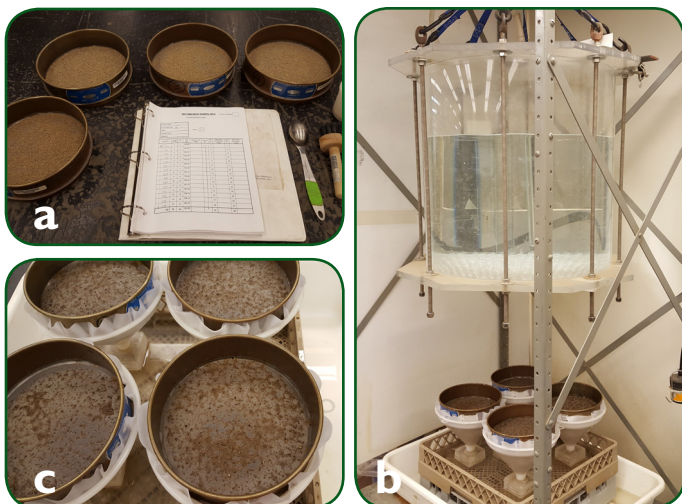
## Basic protocol

- Soil is air-dried and placed on stacked sieves of 2.0 mm, 0.25 mm and a catch pan. The 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 is spread on a 0.25 mm sieve (Fig. 2a).
- Sieves are placed at a distance of 500 mm (20 inches) below a rainfall simulator, which delivers individual drops of 4.0 mm diameter (2b).
- 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 (2c). A total of 0.74 J of energy thus impacts 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 simulation, 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:

$$WSA = W_{stable} / W_{total}$$

where:  $W_{stable} = W_{total} - (W_{slaked} + W_{stones})$

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.

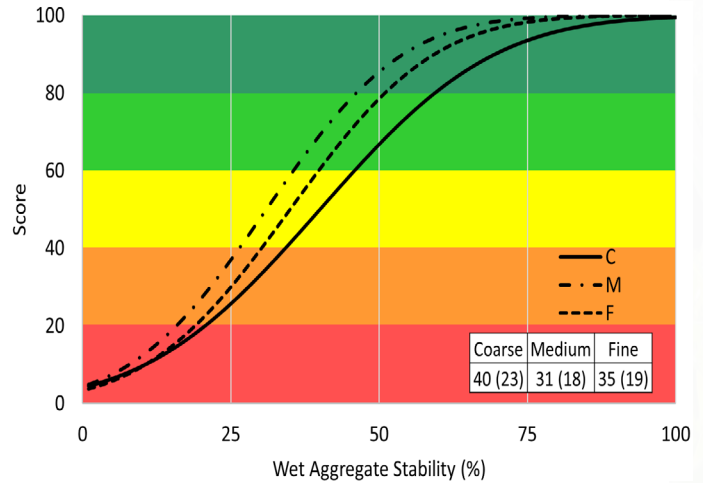


**FIGURE 2 a - c.** Aggregate Stability test. A rain simulator is used for 5 minutes on 4 sieves containing soil aggregates.

## Scoring function

Figure 3 below depicts Wet Aggregate Stability scoring functions and upper value limits for coarse, medium, and fine textured soils.

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.



**FIGURE 3.** 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.

Cornell Soil Health Laboratory Wet Aggregate Stability [Standard Operating Procedures](#) (CSH 03) can be found under the 'Resources' tab on our website.

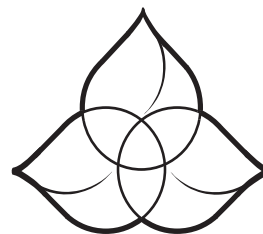
For a more comprehensive overview of soil health concepts including a guide on conducting in-field qualitative and quantitative soil health assessments, please download the Cornell Soil Health Manual at [bit.ly/SoilHealthTrainingManual](http://bit.ly/SoilHealthTrainingManual).

## Acknowledgement

Thanks to the NE Sustainable Agriculture Research & Education Program, New York Farm Viability Institute, USDA-NRCS and Cornell Cooperative Extension for funding and support of the Cornell Soil Health program.

This fact sheet represents the best professional judgment of the authors and does not necessarily reflect the views of the funders or reviewers.

For more information contact:



Cornell University  
Soil Health Laboratory  
[bit.ly/SoilHealthContacts](http://bit.ly/SoilHealthContacts)

Harold van Es

Robert Schindelbeck

Aaron Ristow, Kirsten Kurtz and  
Lindsay Fennell

January 2017





## Soil Organic Matter

Total soil organic matter (OM) consists of both living and dead material, including well decomposed, more stabilized materials. OM analysis is a measure of carbon containing material that is, or is derived from, living organisms, including plants and other soil dwelling organisms.

### 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 (Fig. 1).

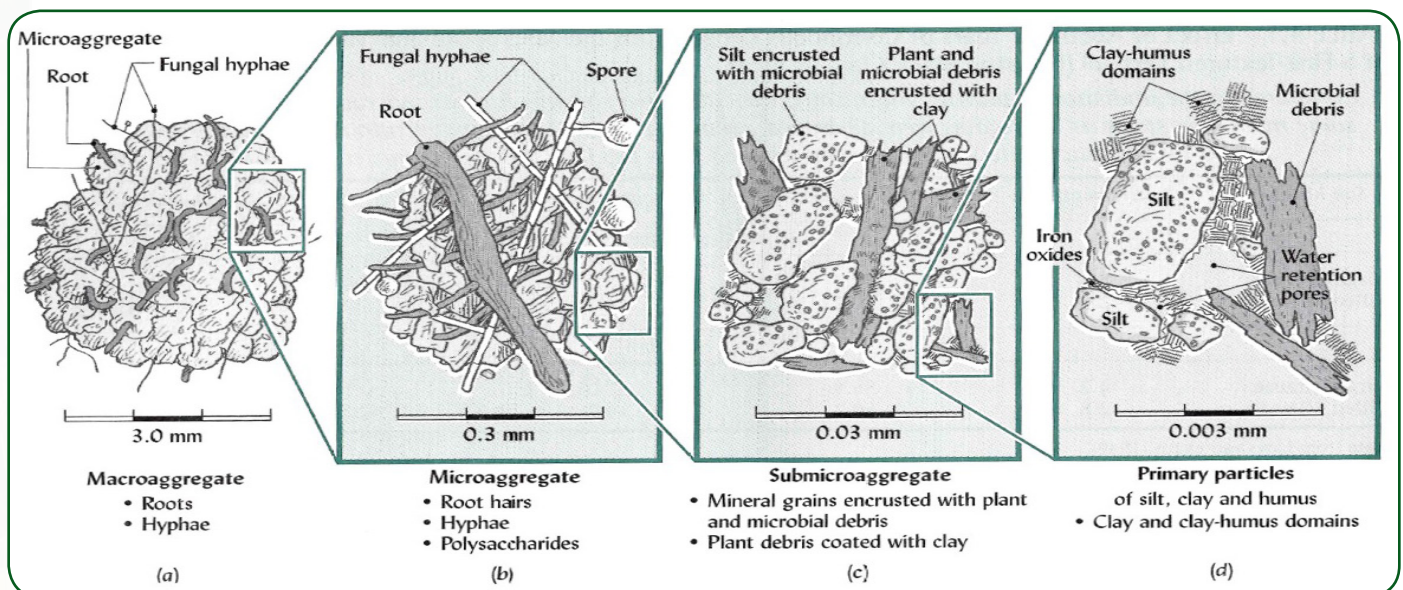
OM in its various forms greatly impacts the physical, biological and chemical properties of the soil. OM acts as a long-term carbon sink, and as a slow-release pool for nutrients. It contributes to ion exchange capacity (nutrient storage), nutrient cycling, soil aggregation, and water holding capacity, and it provides nutrients and energy to the plant and soil microbial communities. Soils with high organic matter tend to require lower farm inputs, and to be more resilient to drought and extreme rainfall events.

As organic matter increases, soil tilth improves as soils become less compact and have more space for air passage and water storage. Good tilth also means that the soil is porous so root development is not restricted as they more easily move through the soil to access oxygen, water and nutrients.

### Managing constraints and maintaining optimal organic matter content

Intensive tillage and lack of carbon inputs decrease organic matter content and overall soil health over time. Likewise, increasing organic matter in the soil takes dedication, patience and time to rebuild. 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 improve water infiltration and retention in the short term.

Percent organic matter is determined by loss on ignition, based on the change in mass after a soil is exposed to high temperature in a furnace. At these temperatures, carbonaceous materials are burned off (oxidized to CO<sub>2</sub>), while other materials remain.



**FIGURE 1.** Each step (a–d) demonstrates the bonding agents and aggregation of soil as size decreases. An active microbial population will build and stabilize soil through production and interaction with adhesive by products. Adapted from *The Nature and Properties of Soils*, 12th ed., Brady and Weil (1999) Fig. 4.26 from p 150.



# Soil Organic Matter

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). These all stimulate both microbial community growth and the stabilization (sequestration) of carbon in aggregates.



Growing Aroostook cereal rye cover crop. Photo: Troy Bishopp

The appropriate selection of organic matter input will depend on the management goal(s) and other microbial activity and food source related constraints identified.

## Basic protocol

- A sample is dried at 105°C to remove all water.
- The sample is weighed (Fig. 2)
- 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 % OM using the following equation:

$$\% OM = (\% LOI * 0.7) - 0.23$$

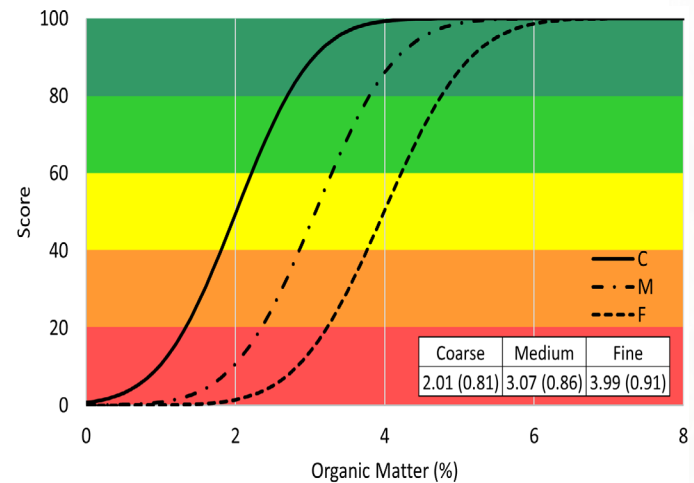
**FIGURE 2.** Soil mass is determined prior to being exposed to high temperature. Soil is weighed after being ashed to calculate the percentage of mass lost.



## Scoring function

Figure 3 below depicts Organic Matter scoring functions and upper value limits for coarse, medium, and fine textured soils.

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.



**FIGURE 3.** 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.

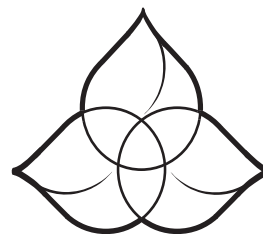
For a more comprehensive overview of soil health concepts including a guide on conducting in-field qualitative and quantitative soil health assessments, please download the Cornell Soil Health Manual at [bit.ly/SoilHealthTrainingManual](http://bit.ly/SoilHealthTrainingManual).

## Acknowledgement

Thanks to the NE Sustainable Agriculture Research & Education Program, New York Farm Viability Institute, USDA-NRCS and Cornell Cooperative Extension for funding and support of the Cornell Soil Health program.

This fact sheet represents the best professional judgment of the authors and does not necessarily reflect the views of the funders or reviewers.

For more information contact:



Cornell University  
Soil Health Laboratory  
[bit.ly/SoilHealthContacts](http://bit.ly/SoilHealthContacts)

Harold van Es  
Robert Schindelbeck  
Aaron Ristow, Kirsten Kurtz and  
Lindsay Fennell  
January 2017





## Total Carbon, Total Nitrogen

### Total Carbon (Tot C)

Total Carbon (Tot C) is a measure of both the organic and inorganic forms of carbon in soil. Carbon that is bound in soil organic matter is referred to as soil organic carbon (SOC), which includes relatively available organic carbon such as in fresh plant residues and more stable organic carbon that is protected in the soil.

Carbon can also be found in inorganic form as carbonate minerals such as calcium carbonate (lime). When soils have no carbonate minerals, Tot C is equivalent to SOC. However, in soils containing high levels of carbonates, a significant portion of Tot C may be in the inorganic (mineral) form. Soils with high levels of carbonates tend to have a soil pH above 7.2.

Important differences exist between measuring Tot C and measuring the percent organic matter (% OM) of a sample using the loss-on-ignition (LOI) procedure. The Tot C method directly measures the CO<sub>2</sub> released as the soil sample is combusted and is subject to less error than the LOI procedure. On the other hand, estimation of the % OM in a soil sample from Tot C may not be completely accurate if the soil contains large quantities of carbonates.

### How Tot C relates to soil function

Organic carbon greatly impacts the physical, biological and chemical properties of the soil. The Tot C measurement is an indicator of the OM in the soil sample. The total amount of all organic material in soil is commonly called soil organic matter (SOM). Carbon is the main element found in soil organic matter, comprising 48-58 % of its total dry weight (Nelson and Sommers, 1996). SOM acts as a long-term carbon sink, and as a slow-release pool for nutrients. Soils with high Tot C tend to require lower farm inputs, and to be more resilient to drought and extreme rainfall events.

### Total Nitrogen (Tot N)

Total Nitrogen (Tot N) exists in organic forms and inorganic (or mineral) forms such as plant available ammonium (NH<sub>4</sub><sup>+</sup>) and nitrate (NO<sub>3</sub><sup>-</sup>). The majority of Tot N is bound in soil organic matter.

Inorganic nitrogen is liberated from organic nitrogen sources in the soil, particularly proteins and amino sugars. This complex group of organic compounds accounts for roughly 30 % of the total nitrogen found in soil but this number can vary greatly based on soil management practices: crop rotation, tillage operations, and application of animal manures.

### How Tot N relates to soil function

Soil microorganisms decompose organic matter to liberate energy stored in chemical bonds to fuel their activity and to harvest carbon and nitrogen to build their biomass. Soil biota require nitrogen for the synthesis of their own proteins and other nitrogen containing organic molecules (ATP, DNA, etc.). As dynamic microbial populations grow, if there is insufficient nitrogen in the organic matter they are decomposing they can out-compete crop plants for inorganic nitrogen. This is called immobilization. Conversely, if the organic matter contains sufficient nitrogen to satisfy microbial demands, excess inorganic N is released to crop plants.



**FIGURE 1.** Example of soil with (a) low SOM and (b) high SOM from Tall Grass Prairie USA.

# Total Carbon, Total Nitrogen

## Managing constraints and maintaining optimal total C and total N content

Sustainable soil management seeks to increase the size and quality of the pool of total carbon and total nitrogen. Building Tot C and Tot N can be accomplished through incorporating organic matter in the forms of cover crops, crop residues, and manures. Retention of crop debris and reduced tillage practices have been shown to increase storage of carbon and nitrogen in the soil.

## Basic protocol

Precise measurement of the carbon and nitrogen in soil samples is accomplished using a temperature regulated dry combustion furnace with automatic control of gas flow and pressures (Figure 2).

After oven drying batches of crucibles containing about 0.3 g of soil, the autosampler delivers each sample in turn to the analyzer. The Tot C in a sample is obtained with the complete oxidation of carbon to  $\text{CO}_2$  using a high temperature combustion (1100 °C) and  $\text{CO}_2$  measurement using Non Dispersive Infrared Detection (NDIR).

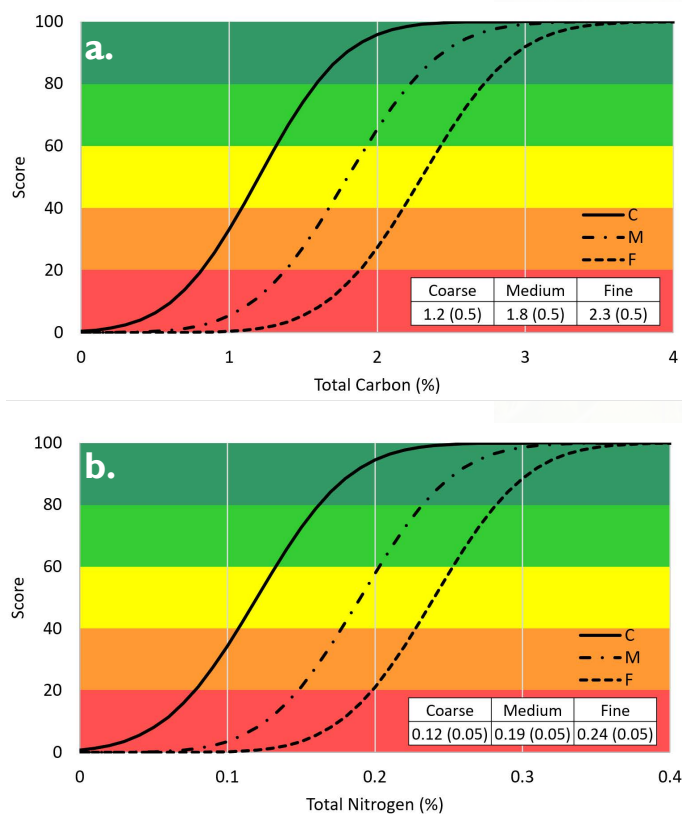
The Tot N in a sample is obtained following the Dumas Methodology. In this analysis, the sample is moved into the combustion furnace where all the Nitrogen is converted to  $\text{N}_x\text{O}_y$  using oxygen. Then the effluent gas is moved to the reduction furnace where all nitrogen is reduced to  $\text{N}_2$ . The  $\text{N}_2$  gas is measured by Thermal Conductivity Detection.



**FIGURE 2.** Primacs SNC-100 Carbon and Nitrogen Analyzer accepts soil or plant samples in small cuvettes placed on a carousel. Specialized software controls the insertion of each sample into the furnace, the application of combustion or purging gases, and the collection and routing of target gases to detectors for measurement.

## Scoring function

Figure 3 below depicts the (a) Total Carbon and (b) Total Nitrogen scoring functions and upper value limits for coarse, medium, and fine textured soils. 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.



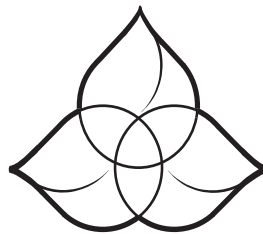
**FIGURE 3.** Tot C and Tot N scoring functions and upper value limits for Coarse (C), Medium (M) and Fine (F) textural classes. Mean and standard deviation (in parenthesis) for each class are provided. In this case more is better.

## Acknowledgment

Thanks to the New York Soil Health program, funded by the New York State Environmental Protection Fund, USDA-NRCS, New York Agriculture and Markets, and Cornell Cooperative Extension for funding and support of the Cornell Soil Health program.

This fact sheet represents the best professional judgment of the authors and does not necessarily reflect the views of the funders or reviewers.

For more information contact:



Cornell University  
Soil Health Laboratory  
[bit.ly/SoilHealthContacts](https://bit.ly/SoilHealthContacts)  
Harold van Es, Robert Schindelbeck  
Joseph Amsili and Kirsten Kurtz  
March 2020





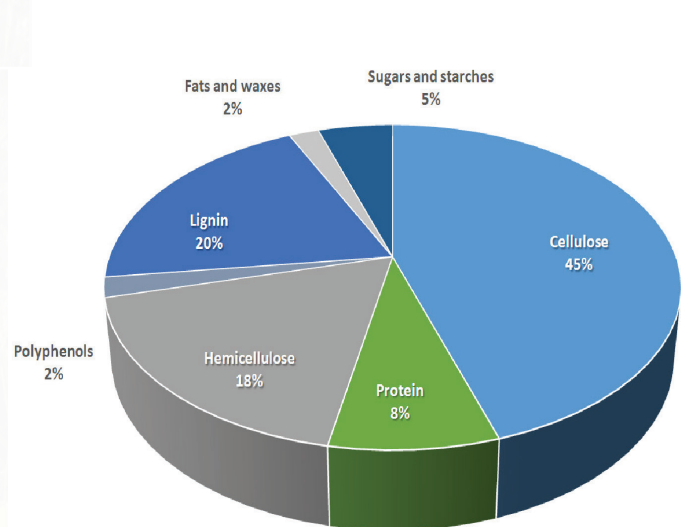
## Soil Protein

The Autoclaved Citrate Extractable (ACE) Protein Index is an indicator of the amount of protein-like substances that are present in the soil organic matter. ACE 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 well associated with overall soil health status because of its indication of biological and chemical soil health, in particular, the *quality* of the soil organic matter (SOM).

### How soil protein relates to soil function

Plant residues are ultimately the source of much of the SOM. Microbial biomass builds up as plant residues and other organic matter amendments decompose in the soil. Residues are made up of several types of compounds that are largely similar in composition (Fig. 1). Of these compounds, protein contains the largest fraction of N.

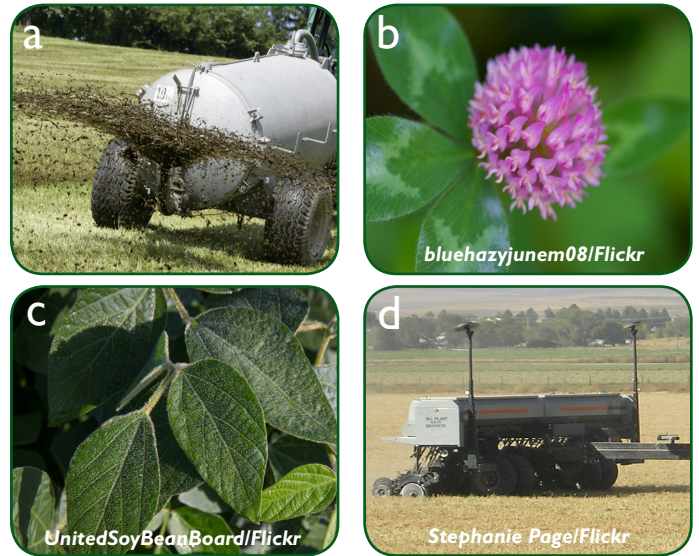
Protein content, as organically bound N, influences the ability of the soil to store N, and make it available by mineralization during the growing season. Soil protein content has also been associated with soil aggregation and thus water storage and movement.



**FIGURE 1.** Types of compounds in plant residues. Proteins are found in high abundance and contain the largest N fraction.

### Managing constraints and maintaining optimal soil protein content

To store and maintain N in SOM, 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. Building and maintaining healthy, biologically active soil with large reserves of decomposing plant tissue in organic form is a good approach to provide a crop with its N needs over time as opposed to applying soluble forms of N that plants may not use immediately and be lost. Organic forms of N reserves are built over years and should be maintained to the extent possible.



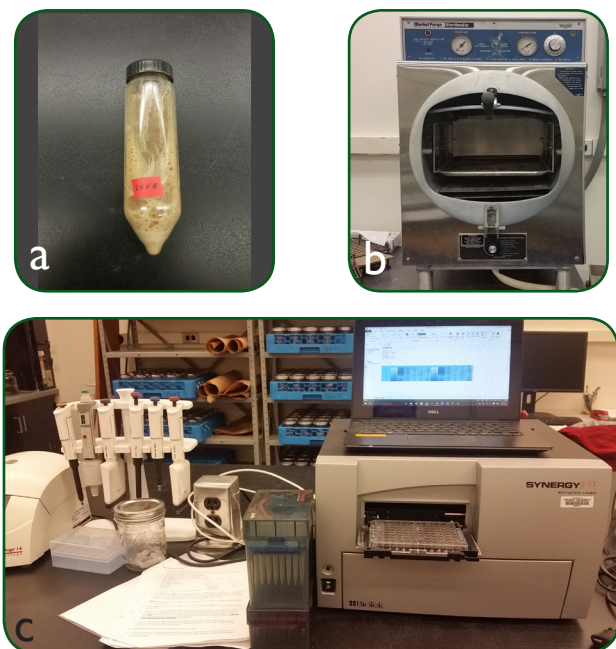
**FIGURE 2 a - d.** SOM building practices. (a) Manure (amendment), (b) Red clover (green manure), (c) Soybeans (crop rotation), (d) No-till drill (reduced tillage).

Protein content can be increased by adding biomass such as manure, fresh green biomass, well finished compost high in N, and by growing biomass in place to maintain the presence of living, actively growing roots – particularly legumes that are well nodulated – and soil microbes (Fig. 2). Most of these sources are slow to release N over time. Protein content tends to decrease with increasing soil disturbance such as tillage.

# Soil Protein

## Basic protocol

- 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) (Fig. 3a).
- The tubes are autoclaved for 30 min (121° C, 15 psi) and then cooled (3b).
- 2 ml of the slurry is withdrawn to a smaller micro-centrifuge tube, 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), 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, and read color development in a BioTek spectrophotometric plate reader (3c).
- 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.

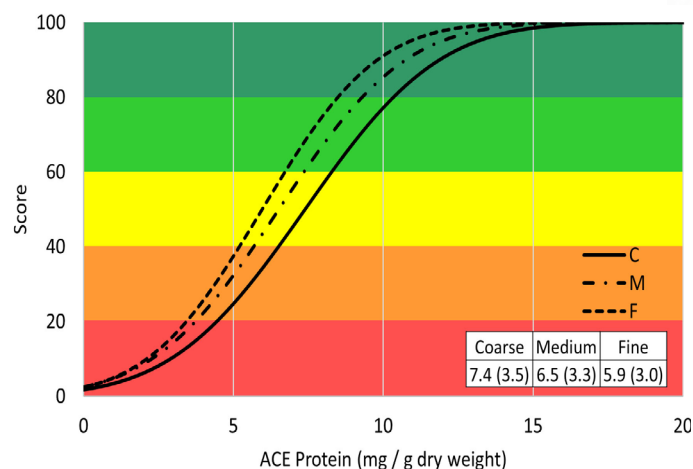


**FIGURE 3 a - c.** Lab procedure for the Autoclaved Citrate Extractable (ACE) Protein Index.

## Scoring function

Figure 4 below depicts ACE Soil Protein Index scoring functions and upper value limits for coarse, medium, and fine textured soils. 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.



**FIGURE 4.** 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 soil N.

Cornell Soil Health Laboratory ACE Protein [Standard Operating Procedures](#) (CSH 07) can be found under the '[Resources](#)' tab on our website.

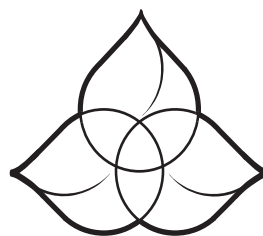
For a more comprehensive overview of soil health concepts including a guide on conducting in-field qualitative and quantitative soil health assessments, please download the Cornell Soil Health Manual at [bit.ly/SoilHealthTrainingManual](http://bit.ly/SoilHealthTrainingManual).

## Acknowledgement

Thanks to the NE Sustainable Agriculture Research & Education Program, New York Farm Viability Institute, USDA-NRCS and Cornell Cooperative Extension for funding and support of the Cornell Soil Health program.

This fact sheet represents the best professional judgment of the authors and does not necessarily reflect the views of the funders or reviewers.

For more information contact:



Cornell University  
Soil Health Laboratory  
[bit.ly/SoilHealthContacts](http://bit.ly/SoilHealthContacts)

Harold van Es  
Robert Schindelbeck  
Aaron Ristow, Kirsten Kurtz and  
Lindsay Fennell  
January 2017





## Predicted Soil Protein

The Autoclaved Citrate Extractable (ACE) Protein Index (Soil Protein) is an indicator of the amount of protein-like substances that are present in the soil organic matter. Soil protein represents the largest pool of organically bound nitrogen (N) in the soil organic matter, which microbes can mineralize and make available for plant uptake.

Beginning in 2020, the Cornell Soil Health Lab moved to **predict** Soil Protein from a suite of measured parameters in the Standard comprehensive assessment of soil health (CASH) package. The laboratory measured ACE Soil Protein assay will remain available to researchers and others as an optional add-on to the Standard CASH package.

### Modeling Soil Protein

In 2020, the Cornell Soil Health lab determined that soil protein, a valuable, but time-intensive measurement, could be accurately predicted. A Predicted Soil Protein relationship was developed using a Random Forest model to predict soil protein level from a suite of measured parameters, including % sand, % silt, % clay, Organic Matter, Active Carbon, Total Carbon, Total Nitrogen, Tot C/Tot N, and pH. This model was able to explain 82.5% of the variation in protein with a low average root mean square error (RMSE) value (Fig. 1).

Random Forest (RF) is a robust machine learning algorithm that uses a decision tree approach to model variables. Machine learning algorithms such as RF have become increasingly popular techniques to model parameters that are difficult or costly to measure. Environmental scientists have developed models using routinely measured parameters to predict difficult or costly to measure soil properties such as soil nitrogen availability to crop plants.

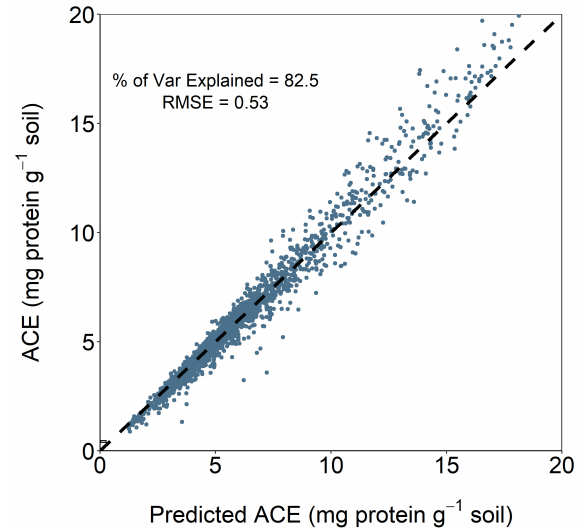


FIGURE 1. Predicted Protein content vs. observed Protein content for the CASH database (n=2,798).

### How soil protein relates to soil function

Plant residues are ultimately the source of much of the soil organic matter. Residues are made up of several types of compounds that are largely similar in composition (Fig. 2). Of these compounds, protein contains the largest fraction of N.

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. An active microbial population is responsible for for this change from organic N to plant available N. Soil protein content has also been associated with soil aggregation and thus water storage and movement.

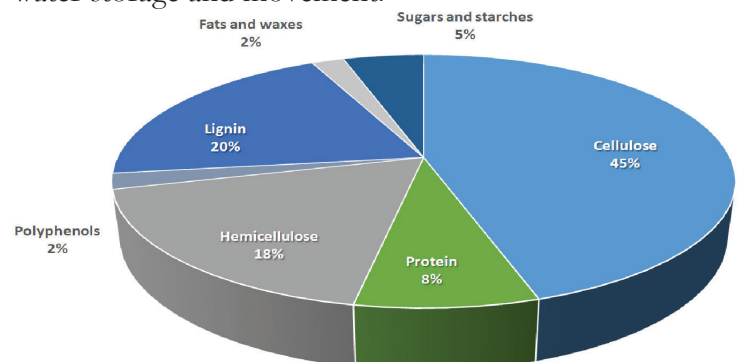


FIGURE 2. Types of compounds in plant residues. Proteins are found in high abundance and contain the largest N fraction. Modified from Brady and Weil (2002)

# Predicted Soil Protein

## Managing constraints and maintaining optimal soil protein content

To store and maintain N in 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 (Fig. 3). Building and maintaining healthy, biologically active soil with large reserves of decomposing plant tissue in organic form is a good approach to provide a crop with its N needs over time as opposed to applying soluble forms of N that plants may not use immediately and be lost. Organic forms of N reserves are built over years and should be maintained to the extent possible.

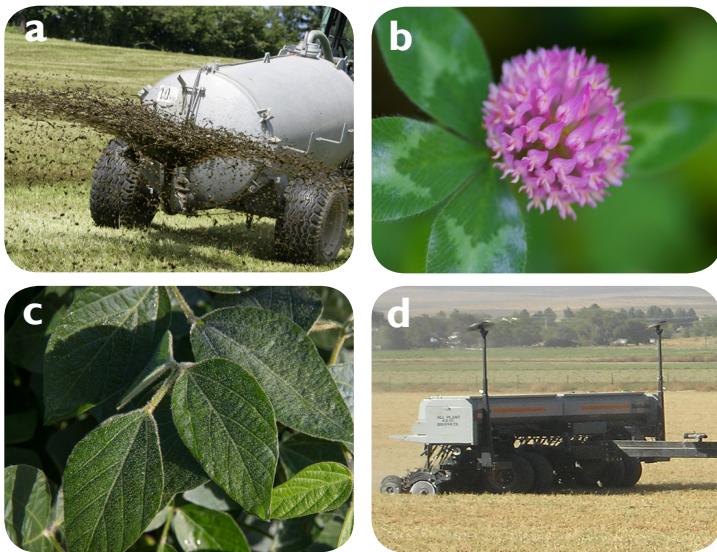


FIGURE 3. a - d. SOM building practices. **Short term strategies:** (a) Manure (amendment), (b) Red clover (green manure cover crop), **Long term strategies:** (c) Soybeans (crop rotation), (d) No-till drill (reduced tillage). Photo source: Flickr

Protein content can be increased by adding organic amendments directly such as manure and well-finished compost high in N (Fig. 3). Cover crop mixtures using diverse species with useful root architecture provides green biomass grown in place to maintain the presence of living, actively growing roots. Well nodulated legumes are important sources of root zone N to sustain a large microbial population. Most of these sources are slow to release N over time which can reduce environmental losses. Use careful planning to reduce tillage intensity and to enable timely no-till drilling of cover crops. Protein content tends to decrease with increasing soil disturbance such as tillage.

## Scoring function

Figure 4 below depicts the **predicted** Soil Protein scoring functions and upper value limits for coarse, medium, and fine textured soils. 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.

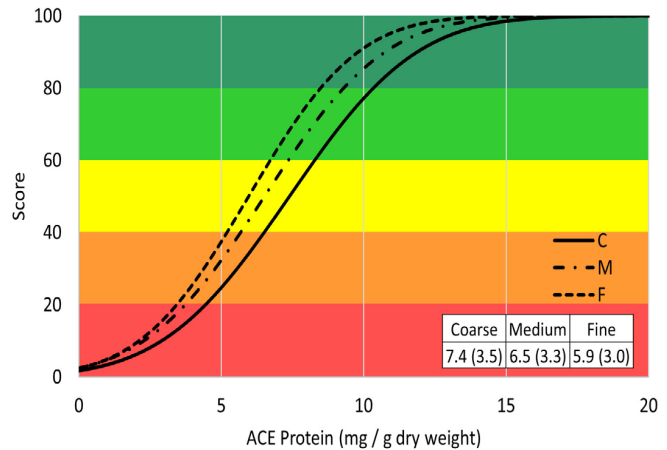


FIGURE 4. **Predicted** Soil Protein Index scoring functions and upper value limits for Coarse (C), Medium (M) and Fine (F) textural classes. Mean and standard deviation (in parenthesis) for each class are provided. In this case more is better. Higher protein index scores indicate a larger pool of organically-bound soil N.

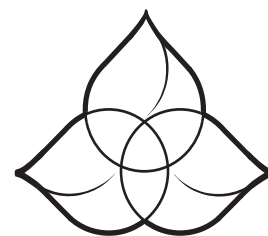
Cornell Soil Health Laboratory ACE Protein [Standard Operating Procedures](#) (CSH 07) can be found under the 'Resources' tab on our website.

For a more comprehensive overview of soil health concepts including a guide on conducting in-field qualitative and quantitative soil health assessments, please download the Cornell Soil Health Manual at [bit.ly/SoilHealthTrainingManual](http://bit.ly/SoilHealthTrainingManual)

## Acknowledgment

Thanks to the New York Soil Health program, funded by the New York State Environmental Protection Fund, USDA-NRCS, New York Agriculture and Markets, and Cornell Cooperative Extension for funding and support of the Cornell Soil Health program.

This fact sheet represents the best professional judgment of the authors and does not necessarily reflect the views of the funders or reviewers.



For more information contact:

Cornell University  
Soil Health Laboratory

[bit.ly/SoilHealthContacts](http://bit.ly/SoilHealthContacts)

Harold van Es, Robert Schindelbeck,  
Joseph Amsili and Kirsten Kurtz  
April 2022







## Soil Respiration

Respiration is a measure of the metabolic activity of the soil microbial community (Fig. 1). It is measured by capturing and quantifying carbon dioxide ( $\text{CO}_2$ ) released from a re-wetted sample of air dried soil held in an airtight jar for 4 days. Greater  $\text{CO}_2$  release is indicative of a more active soil microbial community.

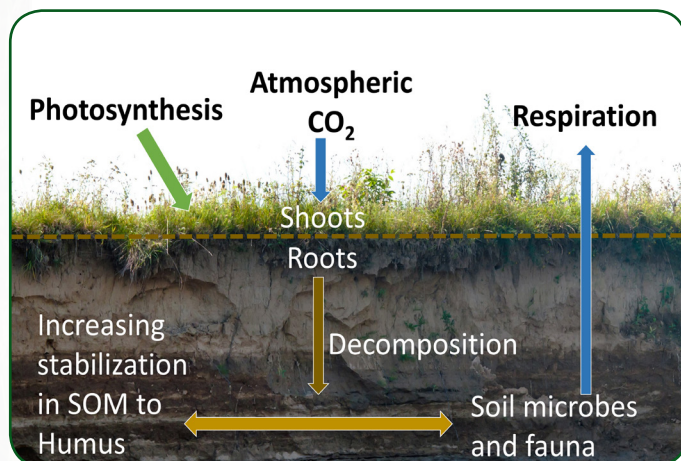
### How soil respiration relates to soil function

Respiration is a direct measurement of biological activity, integrating abundance and activity of microbial life. Thus, it 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. Soil biological activity 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  $\text{CO}_2$  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 (Fig. 2). 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.



**FIGURE 1.** The soil respiration measurement is an indicator of soil microbial abundance and activity. A larger, more active community will maximize soil functioning such as accepting and using residues and making nutrients readily available for plants.

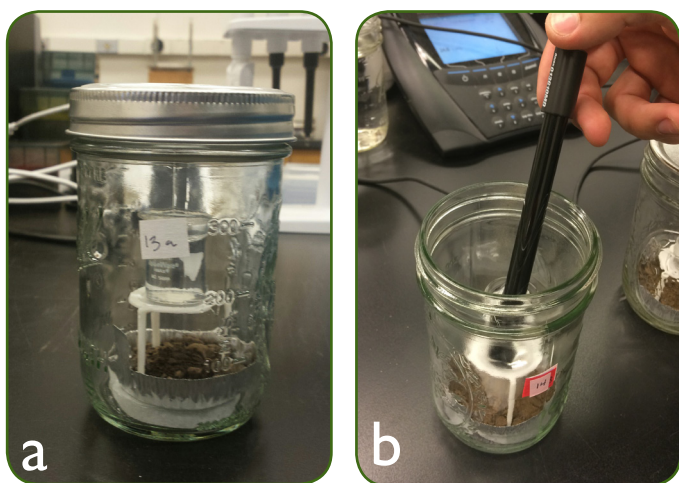


**FIGURE 2.** Mix of winter rye, wheat, barley, and hairy vetch. Cover crop mixes are an excellent way of accumulating plant biomass to build organic matter, alleviate compaction problems, feed soil microbes and suppress disease. Photo: Dom Cox

# Soil Respiration

## Basic protocol

- 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.
- 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 CO<sub>2</sub> trapping solution (9 ml of 0.5 M KOH) (Fig. 3a).
- 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 CO<sub>2</sub> absorption, as OH<sup>-</sup> concentration in the trap declines and CO<sub>3</sub><sup>2-</sup> concentration in the trap increases.
- After incubation, the jar is opened and the conductivity of the trap solution is measured (3b).
- CO<sub>2</sub> respired is calculated by comparison with the conductivities of the original trap solution, and a solution representing the trap if saturated with CO<sub>2</sub> (0.25 M K<sub>2</sub>CO<sub>3</sub>).

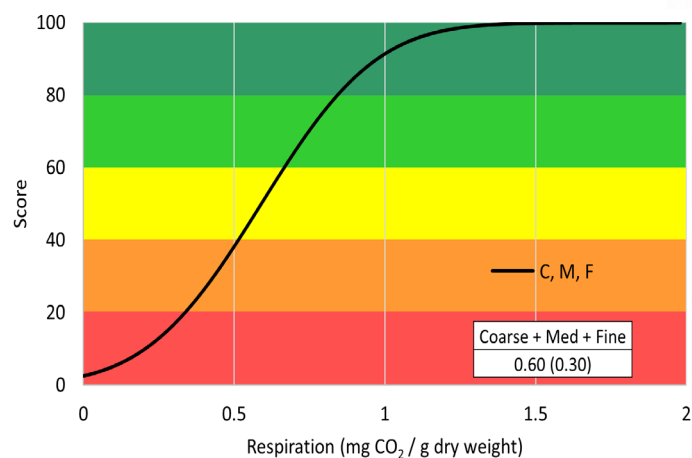


**FIGURE 3 a and b.** Soil Respiration is measured by capturing and quantifying CO<sub>2</sub> released from samples.

## Scoring function

Figure 4 below depicts Soil Respiration scoring functions and upper value limits for coarse, medium, and fine textured soils. 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.



**FIGURE 4.** 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.

Cornell Soil Health Laboratory Soil Respiration [Standard Operating Procedures](#) (CSH 06) can be found under the [Resources](#) tab on our website.

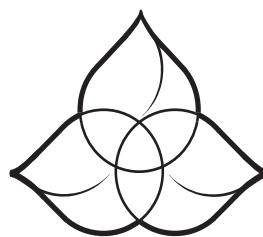
For a more comprehensive overview of soil health concepts including a guide on conducting in-field qualitative and quantitative soil health assessments, please download the Cornell Soil Health Manual at [bit.ly/SoilHealthTrainingManual](http://bit.ly/SoilHealthTrainingManual).

## Acknowledgement

Thanks to the NE Sustainable Agriculture Research & Education Program, New York Farm Viability Institute, USDA-NRCS and Cornell Cooperative Extension for funding and support of the Cornell Soil Health program.

This fact sheet represents the best professional judgment of the authors and does not necessarily reflect the views of the funders or reviewers.

For more information contact:

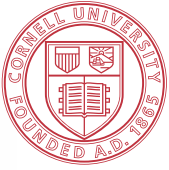


Cornell University  
Soil Health Laboratory  
[bit.ly/SoilHealthContacts](http://bit.ly/SoilHealthContacts)

Harold van Es  
Robert Schindelbeck  
Aaron Ristow, Kirsten Kurtz and  
Lindsay Fennell

January 2017





## 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.

### How active carbon relates to soil function

Active carbon is highly correlated with and similar to particulate 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.

### 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 (Fig. 1).

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.



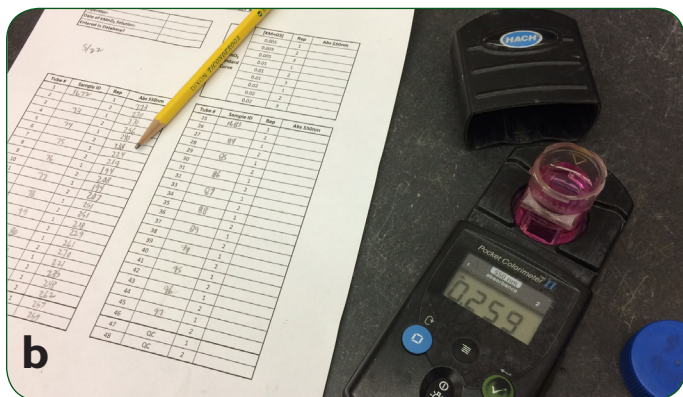
**FIGURE 1 a - b.** (a) Reducing tillage and (b) using cover crops with living roots provide the residues and labile carbon necessary to increase soil OM and promote soil microbial diversity and activity. Photo credit: (a) Jeff Vanuga, USDA-NRCS; (b) Dorn Cox, Greenstart.



# Active Carbon

## Basic protocol

- 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 ( $\text{KMnO}_4$ ) solution, which is deep purple in color (Fig. 2a).
- The soil and  $\text{KMnO}_4$  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 (2b).
- The absorbance of a standard dilution series of the  $\text{KMnO}_4$  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.

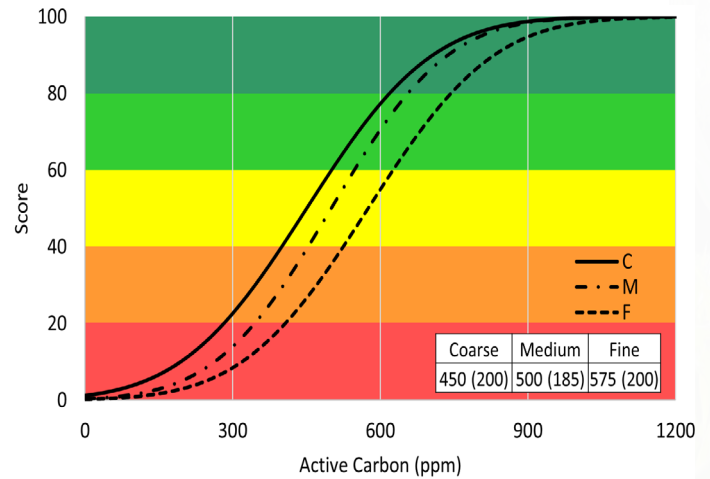


**FIGURE 2 a - b.** (a) Extracts before and after dilution. The samples on the left are after they have been weighed, shaken, and settled. The samples on the right show the dilution as they are prepared to be (b) measured for absorbance at 550 nm.

## Scoring function

Figure 3 below depicts active carbon scoring functions and upper value limits for coarse, medium, and fine textured soils.

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.



**FIGURE 3.** 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.

Cornell Soil Health Laboratory Active Carbon [Standard Operating Procedures](#) (CSH 04) can be found under the [‘Resources’](#) tab on our website.

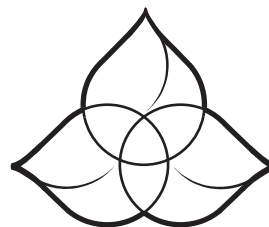
For a more comprehensive overview of soil health concepts including a guide on conducting in-field qualitative and quantitative soil health assessments, please download the Cornell Soil Health Manual at [bit.ly/SoilHealthTrainingManual](http://bit.ly/SoilHealthTrainingManual).

## Acknowledgement

Thanks to the NE Sustainable Agriculture Research & Education Program, New York Farm Viability Institute, USDA-NRCS and Cornell Cooperative Extension for funding and support of the Cornell Soil Health program.

This fact sheet represents the best professional judgment of the authors and does not necessarily reflect the views of the funders or reviewers.

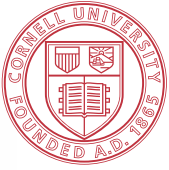
For more information contact:



Cornell University  
Soil Health Laboratory  
[bit.ly/SoilHealthContacts](http://bit.ly/SoilHealthContacts)

Harold van Es  
Robert Schindelbeck  
Aaron Ristow, Kirsten Kurtz and  
Lindsay Fennell  
January 2017





## Standard Nutrient Analysis

The Comprehensive Assessment of Soil Health (CASH) measures pH and extracts plant macro- and micronutrients to estimate plant nutrient availability using a traditional soil fertility analysis package for the Northeast. Measured levels are interpreted in our framework for sufficiency and excess but are not crop specific. The measured values for pH, extractable phosphorus and potassium are scored and integrated into the CASH report. Selected secondary nutrients and micronutrient (magnesium, iron, manganese, and zinc) analyses are combined into one rating for the report.

### How nutrient analysis relates to soil function

Nutrient availability is critical to crop production. Of the eighteen elements needed by plants, only three—nitrogen (N), phosphorus (P), and potassium (K)—are commonly deficient in soils. Deficiencies of micronutrients such as magnesium (Mg), sulfur (S), boron (B), manganese (Mn) and zinc (Zn) can occur, but are not common. Crops do not grow well if nutrients are not present at the right time of the season in sufficient quantities and in reasonable balance to one another. When plants are unhealthy they are more susceptible to disease, loss of yield, and poor crop quality which leads to reduced economic returns.

Likewise, excessive nutrient application may create problems that lead to poor plant growth and environmental degradation. These concerns have resulted in more emphasis on better management of N and P as their excessive use contributes to surface and groundwater pollution and to greenhouse gas emissions.

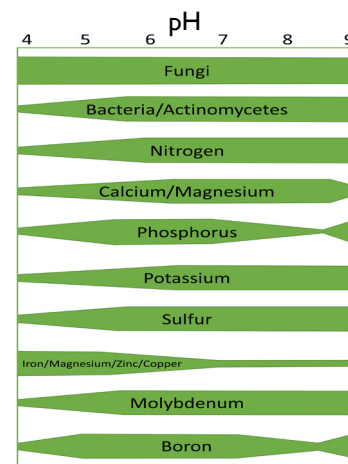
In particular, management of soil N can be challenging as its availability in the soil changes rapidly as influenced by weather, physical soil condition, microbial activity, and the abundance of organic materials. Therefore N is not included in the CASH report as N's availability is dynamic and changes rapidly throughout the season.

Conventional soil nutrient analyses are based solely on chemical extraction and are used to recommend the type and quantity of nutrients to add through amendments as well as whether pH needs to be adjusted for improved nutrient availability from the soil. This approach has been used to guide farmers since the middle of the last century. Until very recently, the influence of physical and biological processes on plant nutrient availability have not been taken into account.

### Managing constraints and maintaining optimal nutrient availability

Managing nutrients on the farm is critical to general plant health and pest management. If a soil has good tilth, drainage, adequate amounts of organic matter (OM), limited subsurface compaction, and sufficient water, plants should be healthy and have expansive root systems. This enables plants to efficiently take up nutrients and water from the soil and to use those nutrients to produce higher yields.

#### Generalized effective pH on bacteria growth and solubility of plant nutrients



**FIGURE 1.** Relationship between soil pH and availability of nutrients and optimal bacteria growth in the soil solution. Modified from Brady and Weil (1999).

The best single strategy for nutrient management is to build OM in a soil in order to realize the cascading positive effects on a range of physical, biological and chemical properties. Specific examples of management that promote nutrient availability (solubility) includes maintaining optimal pH (Fig. 1) through lime or wood ash applications, and adding organic material to help immobilize (make less soluble) aluminum and heavy metals. Cover crops can be used to make P more available to the following crop. Another option is to grow plants which can associate with mycorrhizal fungi to facilitate increased P availability as well as other nutrients and water. In general, improved understanding of the suite of soil fertility factors that can limit crop productivity is important to realize appropriate soil and nutrient management decisions.

# Standard Nutrient Analysis

## Basic protocol

**Analysis Method:** For extractable phosphorus (P) and potassium (K) and for magnesium (Mg), iron (Fe), manganese (Mn) and zinc (Zn), nutrients are extracted from soil by shaking the sample with [Modified Morgan's solution](#). After shaking, the extraction slurry is paper filtered, and the filtrate is analyzed on an inductively coupled plasma emission spectrometer (ICP, Spectro Arcos). CASH does not produce a traditional Land Grant University nutrient recommendation. Instead P, K, Mg, Fe, Mn, and Zn are scored for sufficiency or excess to identify potential constraints.

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

## Scoring function

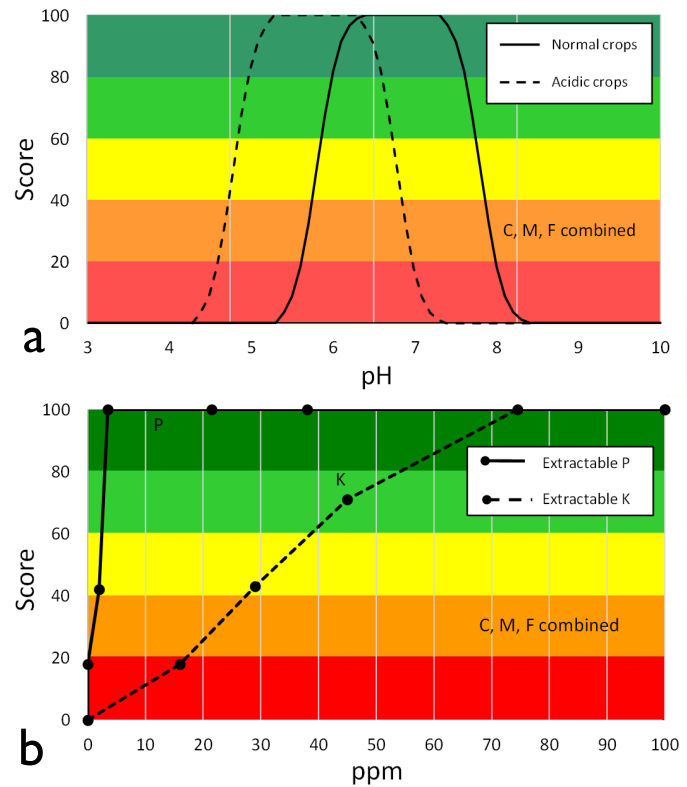
Scoring function graphs are shown to the right for pH, (Fig. 2a) and extractable phosphorus (P) and potassium (K) (Fig. 2b) on coarse, medium, and fine textured soils. Scoring functions were combined for all classes because no effects due to texture were observed in the data set. For pH, a score of 100 is assigned for values between 6.4-7.3 and 5.3-6.3 for normal and acidic crops, 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. Scores are not crop specific.

The micronutrient rating in the CASH Summary Report is reported as one score from determining the mean of the four sub-scores for Mg, Fe, Mn and Zn. To begin, each individual micronutrient value is assigned a sub-score of either '0' (sub-optimal) or '100' (optimal), independent of texture (Table 1a). Next (1b), if the mean of all four micronutrient subscores are adequate the subscore is 100 which also equates to an overall micronutrient score of 100 (excellent). However, if one micronutrient is deficient or excessive, the mean of all four subscores is 75 which equates to an overall micronutrient score of 56 (moderate). If a combination of two, three, or four micronutrients are deficient or excessive, the mean subscore is 50, 25 or 0, respectively, and equates to an overall score of 11, 4 or 0.

**TABLE 1 a - b.** The optimal ranges for secondary nutrients and micronutrients for all soil textural classes.

MICRO-NUTRIENT	SUBSCORE (ppm)		MEAN OF MICRO-NUTRIENT SUB-SCORES	OVERALL MICRO-NUTRIENT SCORE
	0	100		
Magnesium	< 33	$\geq 33$	100 (all adequate)	100
Iron	> 25	$\leq 25$	75 (3 of 4)	56
Manganese	> 50	$\leq 50$	50 (2 of 4)	11
Zinc	< 0.25	$\geq 0.25$	25 (1 of 4)	4
			0 (0 of 4)	0

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



**FIGURE 2 a - b.** Scoring function graphs for pH (a) and extractable phosphorus and potassium (b) 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.

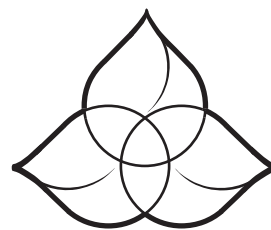
For a more comprehensive overview of soil health concepts including a guide on conducting in-field qualitative and quantitative soil health assessments, please download the Cornell Soil Health Manual at [bit.ly/SoilHealthTrainingManual](http://bit.ly/SoilHealthTrainingManual).

## Acknowledgement

Thanks to the NE Sustainable Agriculture Research & Education Program, New York Farm Viability Institute, USDA-NRCS and Cornell Cooperative Extension for funding and support of the Cornell Soil Health program.

This fact sheet represents the best professional judgment of the authors and does not necessarily reflect the views of the funders or reviewers.

For more information contact:



Cornell University  
Soil Health Laboratory  
[bit.ly/SoilHealthContacts](http://bit.ly/SoilHealthContacts)

Harold van Es

Robert Schindelbeck

Aaron Ristow, Kirsten Kurtz and  
Lindsay Fennell

June 2017





## Add-on Test: Root Health Bio-assay

The Root Health Bio-assay test 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. It is assessed by visual inspection for root size, color, texture and the absence or presence of damage potentially from root pathogens. Pathogen pressure is given a rating from 2 to 9, with higher numbers indicating greater pathogen-induced damage.

Commonly found soil pathogens include the fungi *Fusarium*, *Rhizoctonia*, and *Thielaviopsis*, and the oomycete *Pythium*. High pathogen pressure identified by the assay indicates that disease-causing organisms are present, and that other members of the microbial community are not successfully suppressing 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.

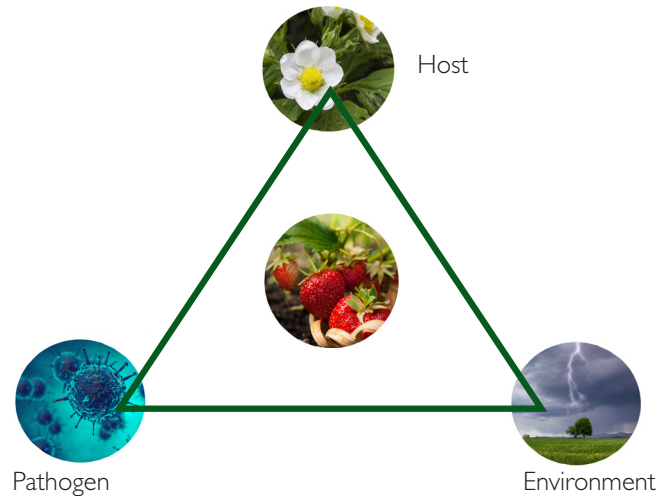
### How root pathogen pressure relates to soil function

Pathogen pressure refers to the degree to which plants encounter potentially growth-limiting attack by disease causing organisms. Known as the disease triangle (Fig. 1), it is a function of the presence of pathogens; the compatibility between pathogens and the plants that are growing; and the environmental conditions including soil physical and chemical characteristics, weather and local microbial communities.

Healthy roots are essential for vigorous plant growth and high yield as a large root mass can efficiently obtain nutrients and water from soil. Root pathogenesis negatively impacts plant growth and root effectiveness, as well as limiting interaction with beneficial root associated microbiota.



**FIGURE 2 a and b.** Root Pathogen Pressure test using (a) 'Hystyle' snap bean seed, (b) grown in the greenhouse.



**FIGURE 1.** Disease Triangle, illustrating the interaction between susceptible host, compatible pathogen, and conducive environmental conditions necessary for the development of plant disease.

### 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 effectiveness as hosts for various pests. Some produce compounds that inhibit or suppress pathogens, or may stimulate microbial communities that are hostile 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 such as poor drainage, high compaction, poor irrigation practices, or nutrient deficiencies.

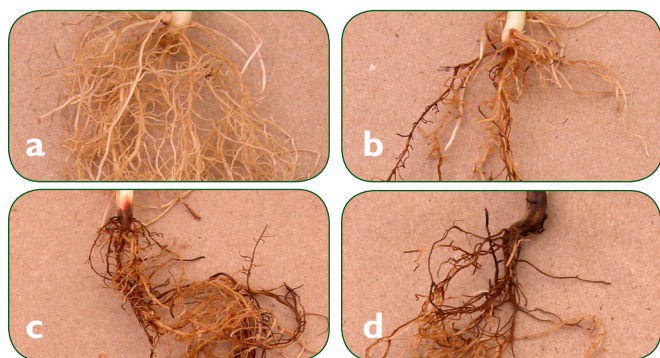
# Add-on Test: Root Health Bio-assay

## Add-on tests

The suite of soil analyses in the [Cornell Assessment of Soil Health packages](#) are all available as individual tests. Certain analysis, such as the Root Health Bio-assay, are not part of the Basic or Standard packages but are available as add-ons or as individual tests. A complete list of the packages we offer in addition to the add-on tests is available on our website at [bit.ly/CSHLPackages](http://bit.ly/CSHLPackages).

## Basic protocol

- 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.
- Each tube is planted with one green bean (Hystyle) seed (Fig. 2a). Commercially available, treated seeds are used to more closely represent on-farm conditions.
- 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 (2b).
- The plants are removed from their containers and the roots are washed and rated as described in the examples shown below:



**FIGURE 3 a - d.** Root Pathogen Pressure Rating System.

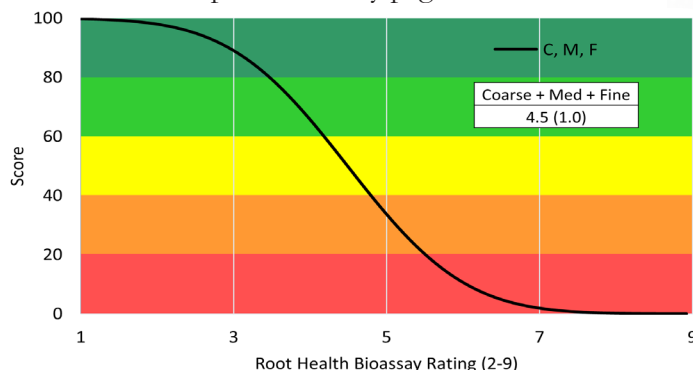
## Rating system

- 2 = White and coarse textured hypocotyl and roots; healthy (Fig. 3a).
- 4 = Light discoloration, with lesions covering up to a maximum of 10% of hypocotyl and root tissues (3b).
- 6 = Moderate damage, with lesions covering approximately 25% of hypocotyl and root tissue, with tissues remaining firm (3c).
- 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 (3d).

## Scoring function

Figure 4 below depicts the Root Health Bio-assay rating scoring function and upper value limits for coarse, medium, and fine textured soils. 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.



**FIGURE 4.** The Root Health Bio-assay 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.

Our Root Health Bio-assay Rating [Standard Operating Procedures](#) (CSH 09) can be found under the 'Resources' tab on our website.

**NOTE:** Due to APHIS regulations we cannot perform the bio-assay in certain areas of the country. Please visit [bit.ly/CASHRegulatedCounties](http://bit.ly/CASHRegulatedCounties) for a complete list of states and counties that fall into this category.

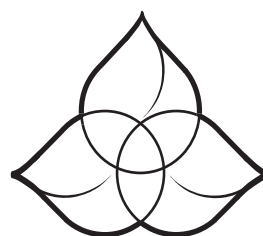
For a more comprehensive overview of soil health concepts including a guide on conducting in-field qualitative and quantitative soil health assessments, please download the Cornell Soil Health Manual at [bit.ly/SoilHealthTrainingManual](http://bit.ly/SoilHealthTrainingManual).

## Acknowledgement

Thanks to the NE Sustainable Agriculture Research & Education Program, New York Farm Viability Institute, USDA-NRCS and Cornell Cooperative Extension for funding and support of the Cornell Soil Health program.

This fact sheet represents the best professional judgment of the authors and does not necessarily reflect the views of the funders or reviewers.

For more information contact:



Cornell University  
Soil Health Laboratory  
[bit.ly/SoilHealthContacts](http://bit.ly/SoilHealthContacts)

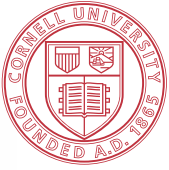
Harold van Es

Robert Schindelbeck

Aaron Ristow, Kirsten Kurtz and  
Lindsay Fennell

March 2017





## Add-on Test: Heavy Metal Contamination

Heavy metal testing is available for situations where contamination is suspected, or as a precaution by identifying whether contamination from past human activities (such as high traffic, industrial or commercial activity, spills, or pesticide application) is affecting the site. Heavy metals such as arsenic, barium, cadmium, chromium, copper, lead, nickel, zinc as well as other elements are measured. 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 [cwmi.css.cornell.edu/guidetosoil.pdf](http://cwmi.css.cornell.edu/guidetosoil.pdf)).

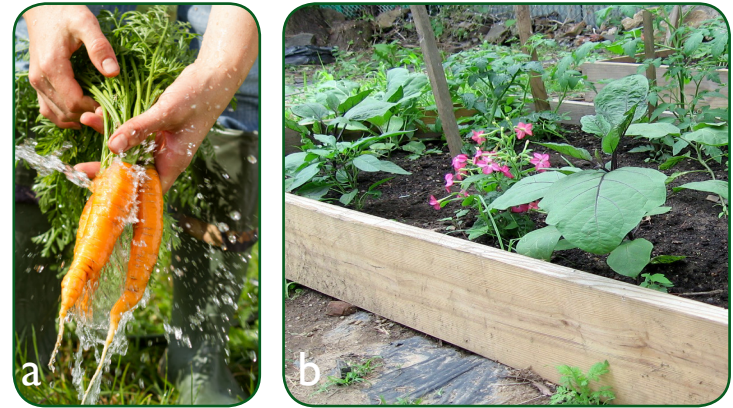
### How heavy metals relate to soil function

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 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. 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.

### Managing heavy metals in soil

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

Using plants to remove heavy metals from soil (a type of phytoremediation) is generally not effective for reducing metal 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).



**FIGURE 1 a and b.** Strategies to help reduce risk of heavy metal contamination in urban soils. (a) Wash garden-grown vegetables. (b) Garden in raised beds with clean soil and landscape fabric barrier.

Plants that readily take up metals (such as cadmium, copper, nickel, and zinc) are also relatively small in stature, slow growing and will take many years to "clean up" soils. Furthermore, 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.

### Additional risk-minimizing strategies

- If needed, add clean soil or organic matter; adjust soil pH; promote good drainage.
- Wash hands/wear gloves when working with soil.
- Keep soil from coming indoors on shoes, pets, or clothing.
- Keep an eye on children.
- Wash produce well, using soap, (Fig. 1a) to remove soil particles from plant surfaces, and peel root crops.
- Avoid or contain contaminated areas: use raised beds where appropriate for growing edible crops (Fig. 1b); mulch, plant ground cover, or otherwise cover bare soil areas to reduce dust.
- 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.

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.

# Add-on Test: Heavy Metal Contamination

## Add-on tests

The suite of soil analyses in the [Cornell Assessment of Soil Health packages](#) are all available as individual tests. Certain analyses, such as Heavy Metal Contamination, are not part of the Basic or Standard packages but are available as add-ons or as individual tests. A complete list of the packages we offer in addition to the add-on tests is available on our website at [bit.ly/CSHLPackages](http://bit.ly/CSHLPackages).

## Basic protocol

- A dried soil sample is digested in concentrated acid at high temperature.
- Particulates in the digestate are removed by filtration, centrifugation, or by allowing the sample to settle.
- The sample is analyzed by an inductively coupled plasma (ICP) instrument that identifies and quantifies individual elements accurately and precisely (Fig. 2).

## Interpreting heavy metals results

Laboratories report concentrations of measured elements in mg/kg or ppm. 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. Yet, understanding heavy metal 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.

Guidance values are given outside of the CASH report. This guidance was developed by the NYSDEC and the NYS DOH for environmental remediation programs (Table 1).

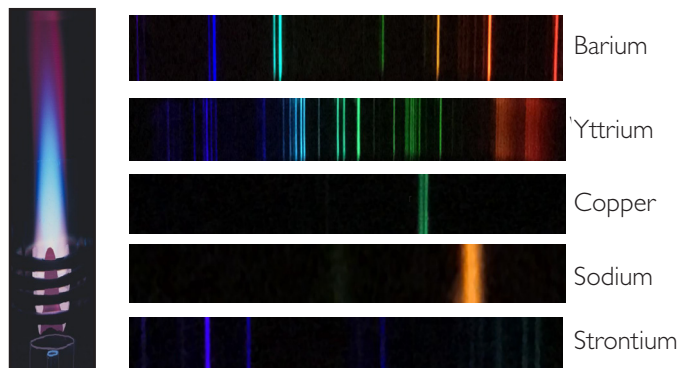
**TABLE 1.** Guidance values and background levels of metals commonly found in garden soils\*. See Healthy Soils, Healthy Communities resource [Metals in Urban Garden Soils\\*\\*](#) for more information.

Metal	Level in soil (parts per million [ppm])		
	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	1 - 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 NYSDOH 2005, Retec Group, Inc. 2007

\*\* [http://cwmi.css.cornell.edu/Metals\\_Urban\\_Garden\\_Soils.pdf](http://cwmi.css.cornell.edu/Metals_Urban_Garden_Soils.pdf)

\*\*\* Can be toxic to plants below health-based guidance values



**FIGURE 2.** (Left) Heavy metal samples are analyzed by an inductively coupled plasma (ICP) instrument. (Right) Every element has a unique spectrum that can be identified and quantified.

Although the values were developed by New York State, they can be used elsewhere as a guide 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 others.

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 risks.

Regarding plant health, some heavy metals (such as Zn) can be toxic to plants (phytotoxic) at levels below human health-based guidance values. In contrast, some heavy metals (e.g. Cd or Pb) do not adversely affect the health of the plant at levels that would be a concern for human health.

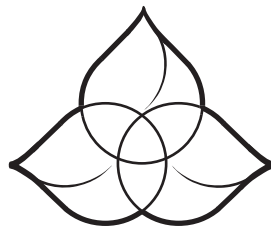
For a more comprehensive overview of soil health concepts including a guide on conducting in-field qualitative and quantitative soil health assessments, please download the Cornell Soil Health Manual at [bit.ly/SoilHealthTrainingManual](http://bit.ly/SoilHealthTrainingManual).

## Acknowledgement

Thanks to the NE Sustainable Agriculture Research & Education Program, New York Farm Viability Institute, USDA-NRCS and Cornell Cooperative Extension for funding and support of the Cornell Soil Health program.

This fact sheet represents the best professional judgment of the authors and does not necessarily reflect the views of the funders or reviewers.

For more information contact:



Cornell University  
Soil Health Laboratory  
[bit.ly/SoilHealthContacts](http://bit.ly/SoilHealthContacts)

Harold van Es  
Robert Schindelbeck  
Aaron Ristow, Kirsten Kurtz  
M. McBride, H. Shayler and the  
[Cornell Waste Management Institute](#)  
March 2017





## 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 seven 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. However, PMN is available as an add-on test.

### How PMN relates to soil function

Nitrogen is the most limiting nutrient for plant growth and yield in most agricultural situations (Fig. 1). 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. 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 1.** Nitrogen is the most limiting nutrient in crop production. The center two rows of sweet corn are severely nitrogen deficient.



**FIGURE 2 a and b.** SOM building practices. (a) Rolling cover crop with a roller - crimper (green manure) and (b) applying manure (amendment).

### Managing constraints and maintaining optimal nitrogen mineralization

Building and maintaining healthy, biologically active soil with large reserves of decomposing plant tissue in organic form is a good approach to provide a crop with its N needs over time. In contrast, plants may not immediately use soluble forms of applied N and it may be lost to the environment. Soils with high levels of nitrogen-rich organic matter tend to have the highest populations of microbes involved in nitrogen mineralization and the highest PMN rates. Organic forms of N reserves are built over years and should be maintained to the extent possible.

Accumulation and retention of N in organic matter as well as stimulation of a soil's biological activity is improved by:

- Keeping the soil covered with plants or residues throughout the season.
- Increasing diversity of species in the system through rotations, interseeding, or intercropping (Fig. 2a).
- Adding fresh, microbially degradable amendments (Fig. 2b).
- Growing biomass in place by maintaining living roots for as much of the year as possible.
- Reducing the use of biocides such as pesticides, fungicides, and herbicides.

Beneficial soil biological activity tends to decrease with increased 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.

# Add-on Test: Potentially Mineralizable Nitrogen

## Add-on tests

The suite of soil analyses in the [Cornell Assessment of Soil Health packages](#) are all available as individual tests. Certain analyses, such as Potentially Mineralizable Nitrogen, are not part of the Basic or Standard packages but are available as add-ons or as individual tests. A complete list of the packages we offer in addition to the add-on tests is available on our website at [bit.ly/CSHLPackages](http://bit.ly/CSHLPackages).

## Basic protocol

- 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 (N<sub>2</sub>) 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 (Fig. 3).
- The difference between the pre-incubation and post-incubation measurements is used as an indicator of N mineralization.

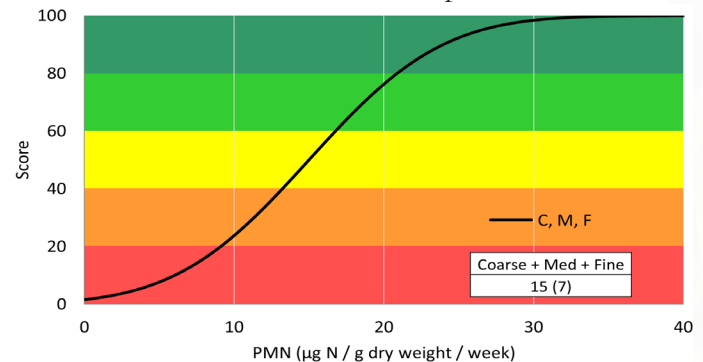


**FIGURE 3.** Potentially Mineralizable Nitrogen (PMN) processed in the lab. The difference between pre-incubation and post-incubation measurements of ammonium is used as an indicator of N mineralization.

## Scoring function

Results of the Potentially Mineralizable Nitrogen analysis are provided in a table sent as a separate file outside of the CASH report. However, measured values are scored using the scoring function in Figure 4 below. 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 scoring PMN results. It should be noted that extremely high N mineralization could increase losses of N to the environment, but this is not included in our interpretation.



**FIGURE 4.** 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 [Standard Operating Procedures](#) (CSH 08) can be found under the ‘[Resources](#)’ tab on our website.

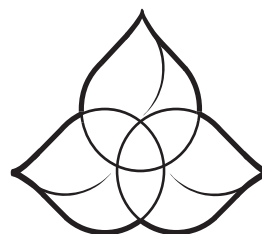
For a more comprehensive overview of soil health concepts including a guide on conducting in-field qualitative and quantitative soil health assessments, please download the Cornell Soil Health Manual at [bit.ly/SoilHealthTrainingManual](http://bit.ly/SoilHealthTrainingManual).

## Acknowledgement

Thanks to the NE Sustainable Agriculture Research & Education Program, New York Farm Viability Institute, USDA-NRCS and Cornell Cooperative Extension for funding and support of the Cornell Soil Health program.

This fact sheet represents the best professional judgment of the authors and does not necessarily reflect the views of the funders or reviewers.

For more information contact:



Cornell University  
Soil Health Laboratory  
[bit.ly/SoilHealthContacts](http://bit.ly/SoilHealthContacts)

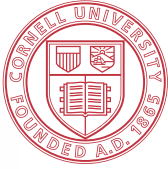
Harold van Es

Robert Schindelbeck

Aaron Ristow, Kirsten Kurtz and  
Lindsay Fennell

March 2017





## Add-on Test: Salinity

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. These conditions may occur together or separately.

The sodium adsorption ratio is not currently available from the CSHL. Although salinity and sodicity are often mistaken as the same thing, they are in fact quite different from each other. We include the comparison between salinity and sodicity here for clarification.

### How salinity and sodicity relate 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 1 A). 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.



Salt affected corn. Photo credit: University of Delaware



Crusting in a saline-sodic urban soil.

**FIGURE 1 A and B.** Management challenges in saline and sodic soils.

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 (B). 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.

# Add-on Test: Salinity

## 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.

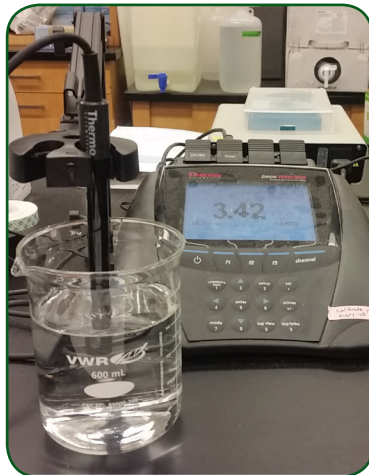
Sodicity is often addressed through the application of gypsum, where calcium substitutes for the sodium on the soil exchange complex, thereby improving soil aggregation and reducing pH. It is then important to leach the sodium out of the surface soil to prevent the reoccurrence of sodicity.

## Basic Protocol

### 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 (Fig. 2).



**FIGURE 2.** Electrical conductivity (EC) meter used to measure salinity.

## Interpretation

Tables 1 A and B to the right show 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.

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

DEGREE OF SALINITY	CROP RESIDUE	EC (mmhos cm <sup>-1</sup> ) BY SOIL TEXTURE			
		COARSE SAND TO LOAMY SAND	LOAMY FINE SAND TO LOAM	SILT LOAM TO CLAY LOAM	SILTY CLAY 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	1.4 - 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 1 B.** 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

	ECe	pH
<b>SALINE</b>	> 4 mmho cm <sup>-1</sup>	< 8.5
<b>SODIC</b>	< 4 mmho cm <sup>-1</sup>	> 8.5
<b>SALINE - SODIC</b>	> 4 mmho cm <sup>-1</sup>	> 8.5

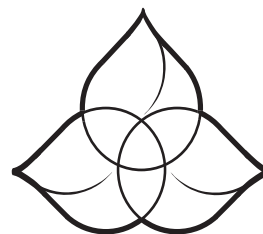
For a more comprehensive overview of soil health concepts including a guide on conducting in-field qualitative and quantitative soil health assessments, please download the Cornell Soil Health Manual at [bit.ly/SoilHealthTrainingManual](http://bit.ly/SoilHealthTrainingManual).

## Acknowledgement

Thanks to the NE Sustainable Agriculture Research & Education Program, New York Farm Viability Institute, USDA-NRCS and Cornell Cooperative Extension for funding and support of the Cornell Soil Health program.

This fact sheet represents the best professional judgment of the authors and does not necessarily reflect the views of the funders or reviewers.

For more information contact:



Cornell University  
Soil Health Laboratory  
[bit.ly/SoilHealthContacts](http://bit.ly/SoilHealthContacts)

Harold van Es

Robert Schindelbeck

Aaron Ristow, Kirsten Kurtz and  
Lindsay Fennell

May 2017