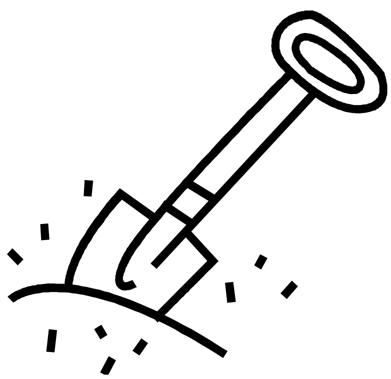
Cornell Soil Health Assessment Training Manual

B.K. Gugino, O.J. Idowu, R.R. Schindelbeck, H.M. van Es, D.W. Wolfe, B.N. Moebius-Clune, J.E. Thies, and G.S. Abawi

Second Edition

Cornell University
College of Agriculture and Life Sciences

Cornell Soil Health Assessment Training Manual



Edition 2.0, 2009

New York State Agricultural Experiment Station
(NYSAES)
630 West North Street
Geneva, New York 14456
http://www.nysaes.cornell.edu

ISBN 0-9676507-4-7

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Produced by Communications Services, NYSAES, Geneva, NY
Book design and layout: Beth K. Gugino
Printed by Cornell Digital Print Services, Ithaca, NY

Unless otherwise noted, the photos were taken by authors and soil health team members and collaborators.

Acknowledgements

The publication team:

George S. Abawi,
Dept. Plant Pathology, Geneva
Beth K. Gugino,
Dept. Plant Pathology, Geneva
Omololu J. Idowu,
Dept. Crop and Soil Sciences, Ithaca
Robert R. Schindelbeck,
Dept. Crop and Soil Sciences, Ithaca
Larissa L. Smith,
Dept. Crop and Soil Sciences, Ithaca
Janice E. Thies,
Dept. Crop and Soil Sciences, Ithaca
David W. Wolfe,
Dept. Horticulture, Ithaca
Harold M. van Es,
Dept. Crop and Soil Sciences, Ithaca

Funding for the preparation of this manual was provided by:

Northern New York Agricultural Development Program

Northeast Region SARE
Sustainable Agriculture Research and Education Program

IPM Integrated Pest Management

NY farm viability INSTITUTE

Cornell University Cooperative Extension

Thanks:

We would like to thank the Cornell Soil Health Team members (growers, extension educators, faculty and staff) for their many contributions to the research and outreach activities conducted since 2003. Their contributions provided the foundation on which this manual is based.

We would like to especially acknowledge the significant contributions of:

Carol MacNeil, Cornell Cooperative Extension (CCE)
John Ludwig, Research Assistant
Kate Duhamel, Research Assistant
Molly Shaw, CCE
Renuka Rao, Cornell Nutrient Analysis Laboratory
Ted Blomgren, Formerly of CCE
Dale Moyer, Formerly of CCE

We would also like to thank Fred Magdoff of the University of Vermont for his contributions to this manual. Excerpts from his book Building Soils for Better Crops 2nd Edition were used throughout the manual. We would also like to thank Rob Way for his technical assistance with the layout and design of this manual.

For additional information related to this project and the revision history for this manual please visit the Cornell Soil Health Team's website at:

http://soilhealth.cals.cornell.edu

Correct citation:

Gugino, B.K., Idowu, O.J., Schindelbeck, R.R., van Es, H.M., Wolfe, D.W., Moebius-Clune, B.N., Thies, J.E. and Abawi, G.S. 2009. Cornell Soil Health Assessment Training Manual, Edition 2.0, Cornell University, Geneva, NY.

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Purpose of this publication

- Provide an overview of the concept of soil health
- Describe soil constraints and soil quality issues common to soils in New York and the Northeast region, especially in vegetable and field crop production systems
- Provide guidelines on how to conduct in-field qualitative and quantitative soil health assessment
- Provide a how-to guide for proper soil sampling
- Provide an overview of laboratory methods used to assess the health status of soil, the soil health report and their interpretation
- Identify management strategies for improving soil health based on measured constraints and
- Provide links to additional soil health and soil management resources.

What is soil?

Briefly, soil is composed of four basic components: mineral solids, water, air and organic matter (including living biota). The ***mineral solids*** are stone fragments, sand, silt, and clay. It is the proportion of the latter three that determines the soil's texture. For example, a soil that is composed of 70% silt, 20% sand and 10% clay can be classified as a silt loam using the soil texture triangle (Figure 1). Soil texture contributes to the inherent soil quality, the characteristics of the soil that result from soil forming processes. These characteristics are difficult to change through soil management.

Water is essential for soil life. Water is the medium that facilitates nutrient transport through the soil and enables plant nutrient uptake. Water also enables/facilitates the movement of microbes such as nematodes and bacteria through the soil.

Air is constantly moving in and out of the soil. Air provides the oxygen required for cell functioning in aerobic organisms including plant roots. Both air and water occupy the pore spaces (Figure 2) created within and between soil aggregates (clusters of sand, silt and clay particles bound together by particle surface chemistry and microbial and plant exudates).

Organic matter is any material that is part of or originated from living organisms. Organic matter may be divided into three fractions, the living, the dead (active fraction) and the very dead (stable fraction). The living soil organic matter fraction includes microorganisms, soil-dwelling insects, microarthropods, animals and plants. The dead fraction consists primarily of fresh residues from crops, recently dead microorganisms and insects, sloughed-off root cells, leaf litter, and manure, etc. This fraction is considered active. The sugars, proteins, cellulose and other simple compounds are quickly broken down (degraded) by soil microbes and used as a food source which fuels the soil microbial population. The exudates (sticky substances) produced by the microbes (and roots) as well as the microbes themselves (e.g. fungi) help bind the mineral particles together to form soil aggregates. Good soil aggregation is

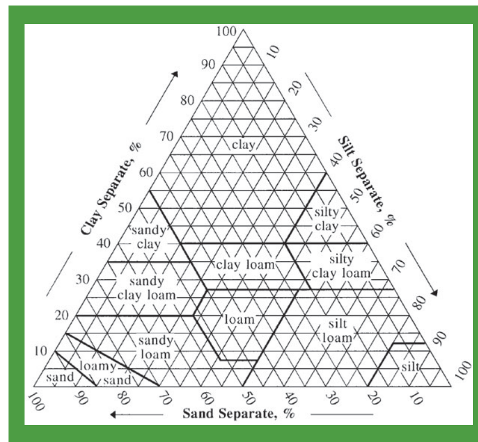


Figure 1. The soil textural triangle.

important for maintaining good (crumbly) soil structure and enabling adequate air exchange and water drainage. The very dead organic matter fraction is also called humus. Humus is very stable and resists further degradation. Although it is not an important food source for microbes, it is important for storing nutrients and water, binding toxic chemicals and contributing to improved aggregate stability.

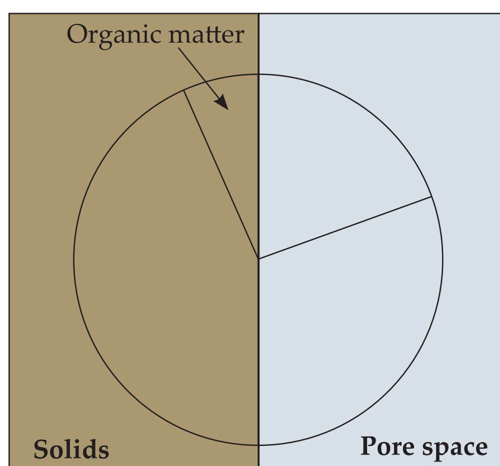
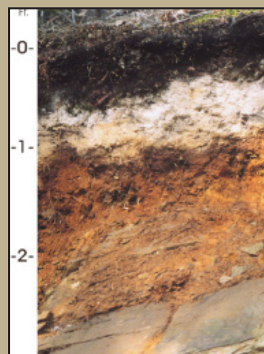


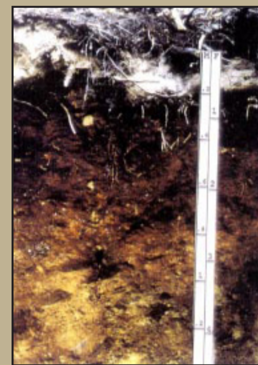
Figure 2. Distribution of solids and pores in the soil.

Representative and State Soils in the Northeast:

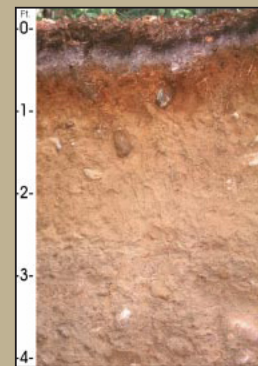
Honeoye (NY)



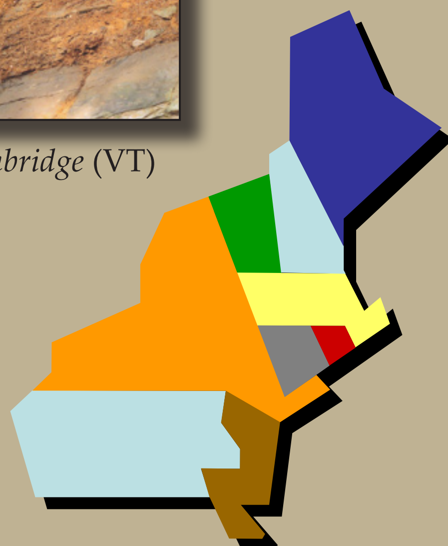
Tunbridge (VT)

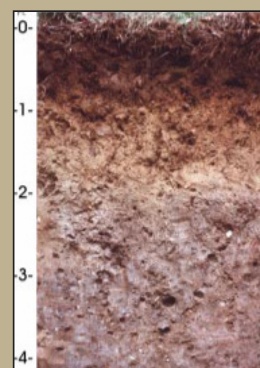


Marlow (NH)



Chesuncook (ME)





Paxton (MA)

Hazleton (PA)

Downer (NJ)

Windsor (CT)

Narragansett (RI)

According to the National Resources Conservation Service, a state soil is represented by a soil series that has special significance to a particular state. Each state has selected a state soil. Of those, 20 have been legislatively established as "Official State Soils" and share the same level of distinction as official state flowers and birds. Areas of similar soils are grouped and labeled as a soil series. The series name is usually derived from a town or landmark in the area where the soil was first recognized. Soil series are not bound by geographic boundaries, therefore a given soil series does not necessarily occur within the confines of only one state.

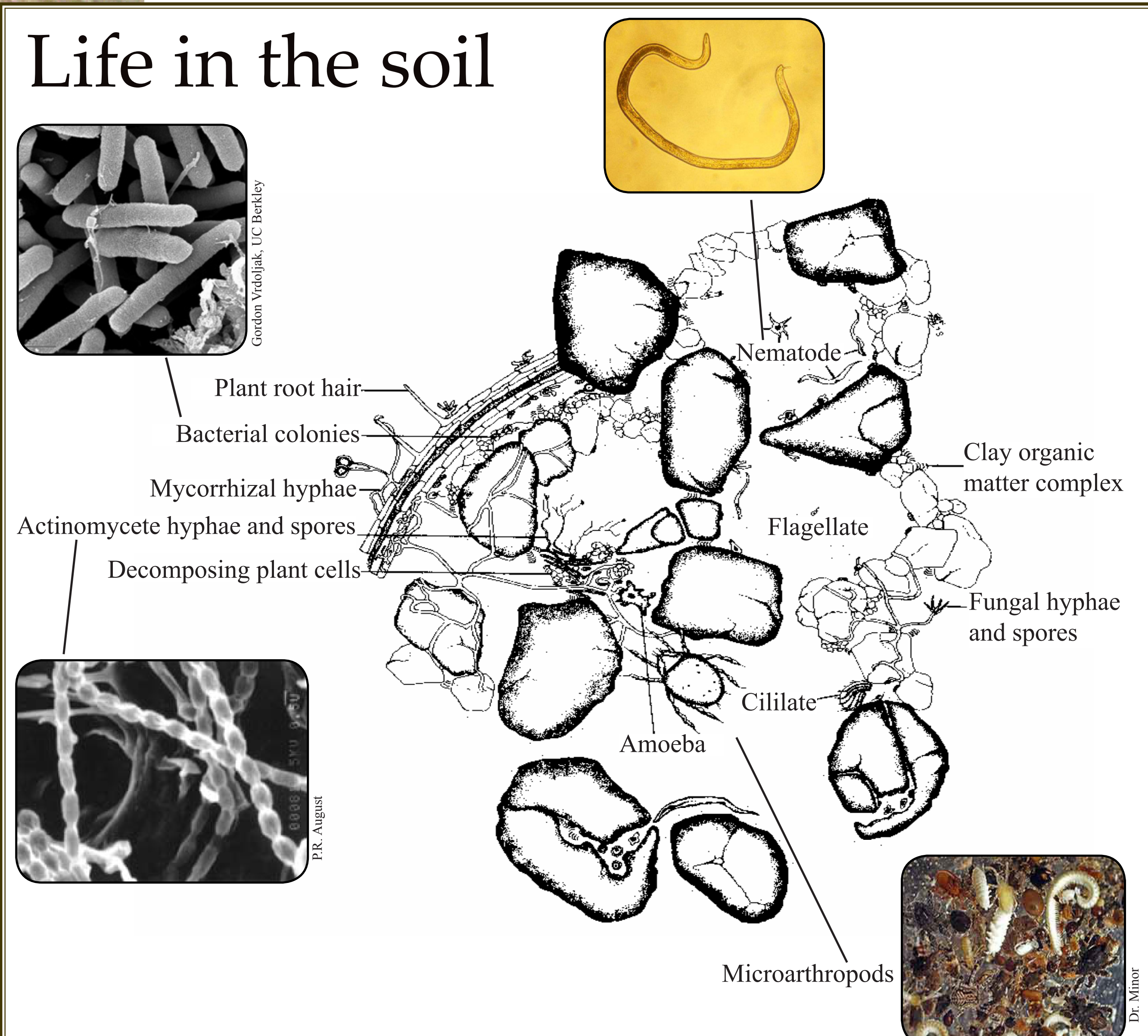
Information and soil profile images from USDA - NRCS

SOIL BIOLOGY

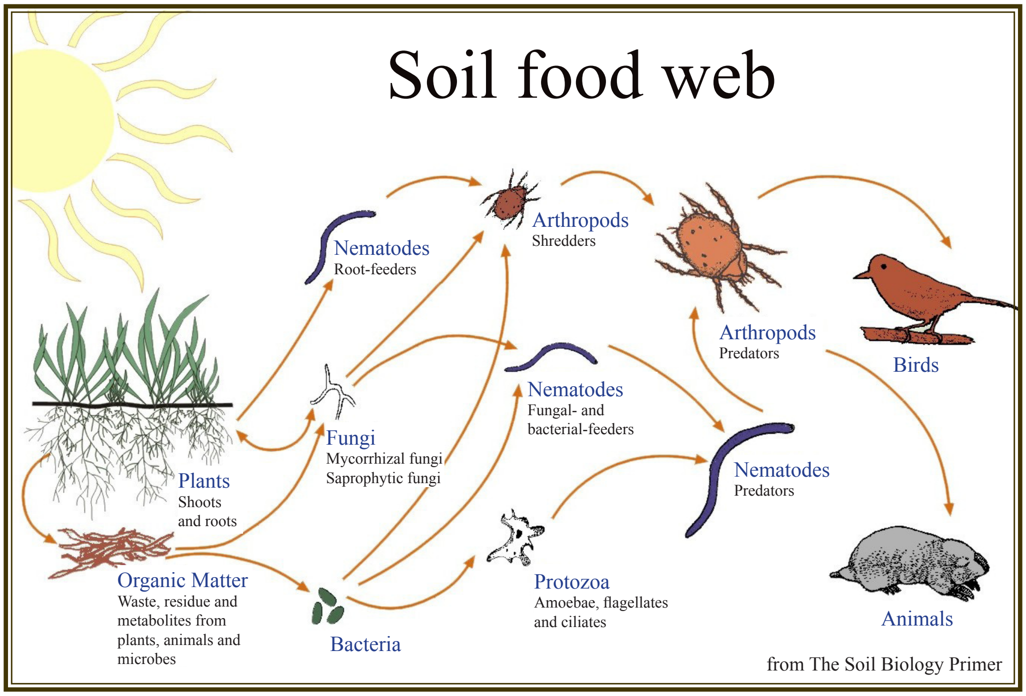
The soil is teeming with life. Soil microbes range from microscopic bacteria to macroscopic earthworms and microarthropods. Some soil scientists say that there are more species of organisms in a shovel full of garden soil than can be found above ground in the entire Amazon rain forest (NRCS).

B*acteria* are the most abundant cells in the soil. They can occur singly or join together in groups. The bacteria (as well as other organisms) in the soil are responsible for the decomposition of residues. They secrete enzymes that break down molecules such as sugars and starches into basic chemical components like carbon and nitrogen, which the bacteria can use for energy. If the nutrients are not needed by the bacteria (or other degrading organisms) then they are released into the soil and become available for plant uptake. Other types of bacteria such as rhizobia form specific associations with plants (e.g. legumes). The symbiotic relationship results in the formation of nodules by the plant. These bacteria fix nitrogen from the air and convert it to ammonium nitrogen, a form that can be used by the plant.

Actinomycetes, are another type of bacteria from which numerous antibiotics have been derived. They function to degrade the



Modified drawing by S. Rose and E.T. Elliott



larger lignin molecules in organic residues. They are also responsible for the “earthy” smell of the soil from the production of geosmin.

Fungi are also important in the decomposition of crop residues, especially the recalcitrant compounds such as hemicellulose and lignins. They are also less sensitive than bacteria to acidic conditions. Ninety percent of plants with the exception of those in the Brassica family and a few others form a symbiotic relationship with certain fungi called ***mycorrhizal fungi***. Mycorrhiza means fungus root. The fungus penetrates the root cells and forms specialized structures called arbuscules that are the site of nutrient exchange between the plant and fungus. The fungus also produces hyphae that grow out into the soil and absorb water and nutrients, especially phosphorus, and translocate them to the plant. In return, the fungus receives sugars from the plant that are used as a source of energy. Some soil-borne fungi are also pathogenic and cause diseases.

Nematodes are generally the most abundant multicellular organisms in soils. They are involved in organic matter decomposition and nutrient cycling, biological control of insects and other organisms, as well as serve as food for other soil organisms. A number are also parasites of plants and animals.

Algae are abundant in habitats with accessible light and adequate moisture. They can exist as single cells or can form long chains. Similar to plants, algae contains chlorophyll and therefore are able to convert sunlight into energy or form more complex compounds.

Protozoa are single celled animals that are classified based on their means of locomotion (cilia, flagella, etc.). They can feed directly upon microbial cells such as bacteria and fungi or they can adsorb solubilized organic and inorganic compounds. It is thought that through feeding on other soil microbes, protozoa are instrumental in mineralizing nitrogen in agricultural systems.

Large macroscopic organisms such as ***earthworms***, ***insects*** and ***millipeeds*** are important for improving aggregation, soil drainage, and aeration due to their burrowing/-channeling nature.

All the life in the soil interacts together in what is termed the **soil food web**. With organic matter as the initial primary food source the bacteria, fungi, actinomycetes and nematodes feed and release nutrients for plant uptake. Then they themselves are fed upon by larger soil organisms such as arthropods, earthworms and so on (see above diagram).

SOME KEY FUNCTIONS OF SOIL MICROBES INCLUDE:

- Decomposition of organic matter (crop residue)
- Mineralization and recycling of nutrients
- Fixation of nitrogen
- Detoxification of pollutants
- Maintenance of soil structure
- Biological suppression of plant pests
- Parasitism and damage to plants

What is soil health?

The terms soil health and soil quality are becoming increasingly familiar worldwide. Doran and Parkin (1994) defined soil quality as "the capacity of a soil to function, within ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health." In general, soil health and soil quality are considered synonymous and can be used interchangeably. The National Resources Conservation Service (NRCS) defines soil quality or soil health similarly, but add inherent and dynamic soil quality to the definition. The inherent soil quality is defined as "the aspects of soil quality relating to a soil's natural composition and properties influenced by the factors and processes of soil formation, in the absence of human impacts." While, dynamic soil quality "relates to soil properties that change as a result of soil use and management over the human time scale."

Important soil functions related to crop production include:

- infiltration and storage of water
- retention and cycling of nutrients
- pest and weed suppression
- detoxification of harmful chemicals
- sequestering of carbon
- production of food and fiber

When the soil is not functioning to its full capacity as a result of soil constraints (see page 8) then sustainable productivity and net farmer profits over the long term are jeopardized. Below are some examples of the economic benefits of maintaining and improving soil health:

-better plant growth and yield by compaction remediation;
-reduced risk of yield loss and/or better field access during periods of environmental stress (e.g., heavy rain, drought, pest or disease outbreak);
-reduced input costs by requiring less tillage;
-reduced input costs by reducing fertilizer, pesticide, and herbicide requirements.

CHARACTERISTICS OF A HEALTHY SOIL

1. Good soil tilth

Soil tilth refers to the overall physical character of the soil in the context of its suitability for crop production (Figure 3).

2. Sufficient depth

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

3. Sufficient but not excess supply 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. Excess 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.

4. Small population of plant pathogens and insect pests

In agricultural production systems, plant pathogens and pests can cause diseases and damage to the crop. In a healthy soil, the population of these organisms is low and/or inactive. This could result from direct competition from other soil organisms for nutrients or niche habitats, hyperparasitism, etc. Also, healthy plants are better able to defend themselves against a variety of pests (similar to the human immune system).

5. Good soil drainage

Even after a heavy rain, a healthy soil will drain more rapidly as a result of good soil structure and an adequate distribution of different size pore spaces, but also retain adequate water for plant uptake.

6. Large population of beneficial organisms

Soil microbes are important to the functioning of the soil. They help nutrient cycling, decomposition of organic matter, maintenance of soil structure, biological suppression of plant pests, etc. A healthy soil will have a high and diverse population of beneficial organisms to carry out these functions and thus help maintain a healthy soil status.

7. Low weed pressure

Weed pressure is a major constraint in crop production. Weeds compete with crops for water and nutrients that are essential for plant growth. Weeds can interfere with stand establishment, block sunlight, interfere with harvest and cultivation operations, and harbor disease causing pathogens and pests.

8. Free of chemicals and toxins that may harm the crop

Healthy soils are either devoid of harmful chemicals and toxins or can detoxify and/or bind such chemicals making them unavailable for plant uptake due to their richness in stable organic matter and diverse microbial communities.

9. Resistant to degradation

A healthy, well aggregated soil is more resistant to adverse events including erosion by wind and rain, excess rainfall, extreme drought, vehicle compaction, etc.

10. Resilience when unfavorable conditions occur

A healthy soil will rebound more quickly after a negative event such as harvesting under wet soil conditions or if land constraints restrict or modify planned rotations.

Figure 3. *The effect of organic matter on the same soil type managed using conventional plow tillage (left) or zone tillage for 10 years (right).*

Common soil constraints

It is important to define and characterize the major soil constraints that limit crop productivity, farm sustainability, and environmental quality. Below is a listing of soil constraints commonly observed in New York and the Northeast region of the U.S. Along with each constraint is a listing of some of the contributing factors and resulting soil conditions. Take note of where these constraints may be present on the farm or fields being monitored.

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

Soil Compaction

Ruts resulting from late fall harvest when soils are wet.

Contributing factors

- Traffic when soil is wet
- Tilling wet (plastic) soils
- Heavy equipment and loads
- Uncontrolled traffic

Can result in

- Reduced root growth
- Limited water infiltration, runoff, and erosion
- Ponding and poor aeration
- Drought sensitivity
- Increased cost of tillage
- Lower yields

Poor Aggregation and Crusting

Surface crusting in mid-spring.

Contributing factors

- Poor aggregate stability
- Low organic matter or limited organic additions
- Intensive tillage
- Limited use of soil building crops

Can result in

- Poor seedling emergence and stand establishment
- Poor water infiltration and increased occurrence of erosion and runoff
- Reduced root growth
- Less active microbial communities
- Reduced aeration
- Increased erosion

Weed Pressure

Weedy beet field.

Contributing factors

- Poor crop rotations
- Resistance to herbicides
- Poor weed management/ 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

High Population of Soilborne Pathogens and Root Diseases

Symptoms of root rot diseases on pea roots.

Contributing factors

- Poor crop rotations
- Poor sanitary practices (people and/or equipment)
- Ineffective/ poor timing of management practices
- Low organic matter, poor physical soil quality, low microbial diversity

Can result in

- Damaged and diseased roots
- Uneven and poor growth
- Reduced yields

Low Water and Nutrient Retention

Application of liquid manure.

Contributing factors

- Low organic matter
- Poor retention/ recycling of nutrients
- Poor structure
- Excessive tillage
- Low water-holding capacity

Can result in

- Ground water pollution
- Reduced microbial community
- Nutrient deficiencies and poor plant growth
- Drought stress

Cornell Soil Health Team

Our definition of soil health...

Over the years the concepts and understanding of the importance of the soils' physical and chemical properties have been well accepted. However, it has not been until recently that the importance of understanding soil biology and biological properties has become a focus. It has been even more recent that researchers and growers have begun trying to manage the soil in a way to improve its biological properties. To us, soil health is a concept that deals with the integration and optimization of the physical, chemical and biological properties of soil for improved productivity and environmental quality (Figure 4).

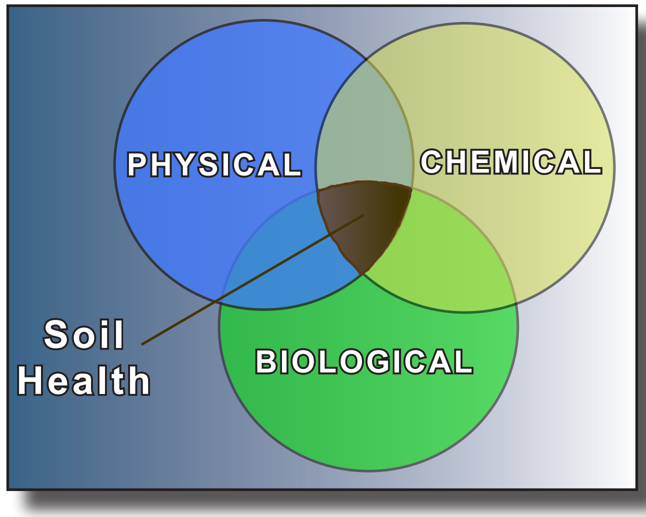


Figure 4. *The concept of soil health deals with integrating the physical, chemical and biological components of the soil (Adapted from the Rodale Institute).*

Our approach...

The Cornell Soil Health Team has been working to address soil degradation issues that have resulted in reduced soil quality, and lower crop productivity and farm profitability. Among the causes of soil degradation are soil compaction, surface crusting, low organic matter, increased pressure and damage from diseases, weeds, insects and other pests, as well as lower density and diversity of beneficial organisms. To address these issues, a group of interested growers, extension educators, researchers and private consultants established a Program Work Team with support from Cornell Cooperative Extension. One of the major accomplishments has been the development of a cost-effective protocol for assessing the health status of soils in New York and the Northeast region. The protocol is the outcome of an elaborate research process where 39 potential indicators (Table 1) were evaluated for their use in rapidly assessing soil health based on cost, response to management, etc.

Table 1. *Thirty-nine potential indicators evaluated for use in the soil health assessment protocol.*

	Physical		*Biological*		*Chemical*
1.	Bulk density	17.	Root health assessment	28.	Phosphorus
2.	Macro-porosity	18.	Beneficial nematode population	29.	Nitrate nitrogen
3.	Meso-porosity	19.	Parasitic nematode population	30.	Potassium
4.	Micro-porosity	20.	Potential mineralizable nitrogen	31.	pH
5.	Available water capacity	21.	Decomposition rate	32.	Magnesium
6.	Residual porosity	22.	Particulate organic matter	33.	Calcium
7.	Penetration resistance at 10 kPa	23.	Active carbon	34.	Iron
8.	Saturated hydraulic conductivity	24.	Weed seed bank	35.	Aluminum
9.	Dry aggregate size (<0.25 mm)	25.	Microbial respiration rate	36.	Manganese
10.	Dry aggregate size (0.25 - 2 mm)	26.	Glomalin	37.	Zinc
11.	Dry aggregate size (2 - 8 mm)	27.	Organic matter content	38.	Copper
12.	Wet aggregate stability (0.25 -2 mm)			39.	Exchangeable acidity
13.	Wet aggregate stability (2 - 8 mm)				
14.	Surface hardness with penetrometer				
15.	Subsurface hardness with penetrometer				
16.	Field infiltrability				

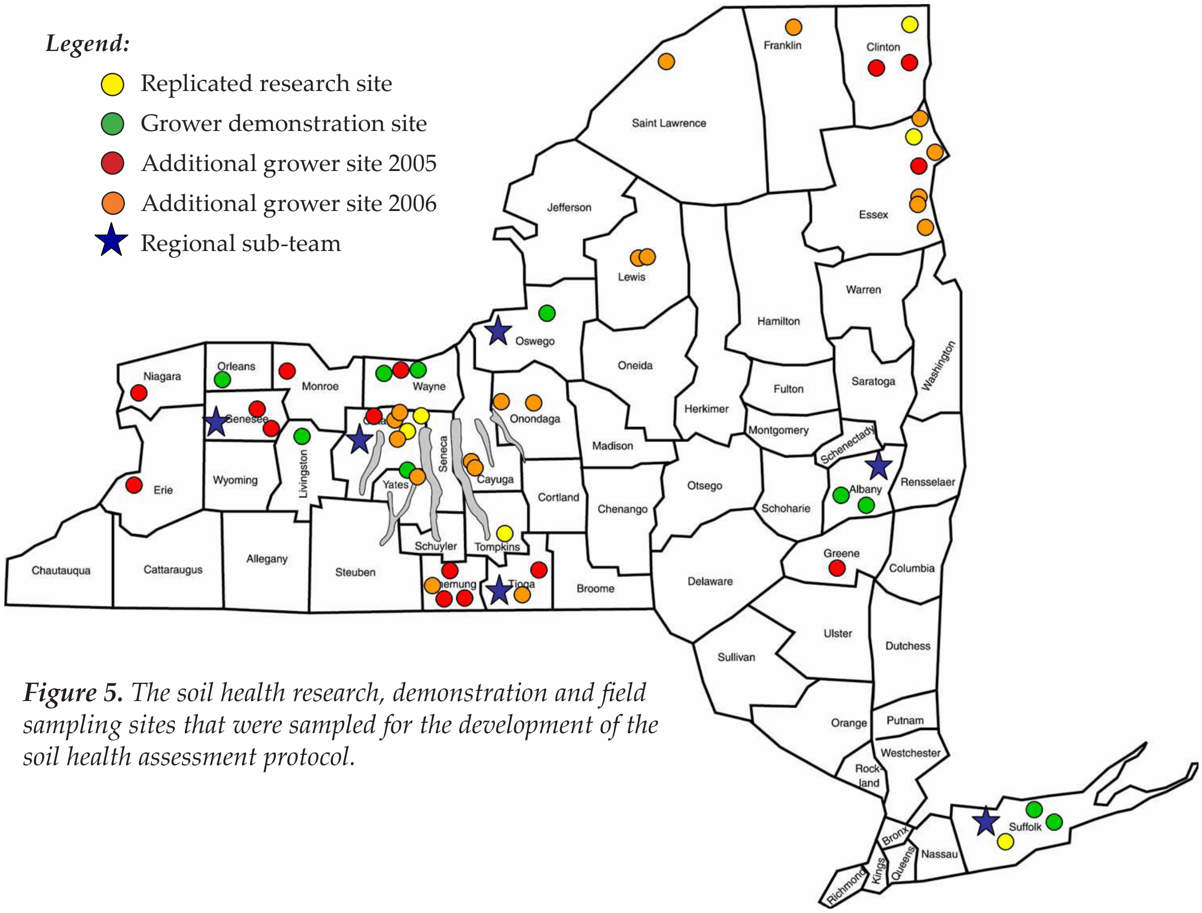


Figure 5. *The soil health research, demonstration and field sampling sites that were sampled for the development of the soil health assessment protocol.*

In order to evaluate the thirty-nine soil health assessment indicators, soil samples were collected from replicated research trials, grower demonstration trials and from fields of interested growers from across New York State (Figure 5) and also Pennsylvania, Vermont and Maryland. The replicated research sites represent different vegetable and field crop production systems being managed using different practices in various combinations. For example, the Gates Farm in Geneva, NY is a 14-acre research site that consists of a total of 72 plots which represent three tillage (no-till/ridge-till, strip-till, and conventional tillage), three cover crop (no cover, rye, and vetch), and two rotation treatments. One rotation emphasizes continuous high-value vegetable production, while the second rotation includes season long soil-building crops (Figure 6). The grower demonstration sites are side-by-side comparisons of different management practices such as the use of a winter rye cover crop versus no cover crop or using strip tillage versus conventional moldboard plowing prior to planting sweet corn. Numerous individual fields of interested growers have been sampled in cooperation with county educators in order to build a database on the health status of New York soils. The selection of the sub-set of indicators used in the soil assessment protocol is described further on page 14.

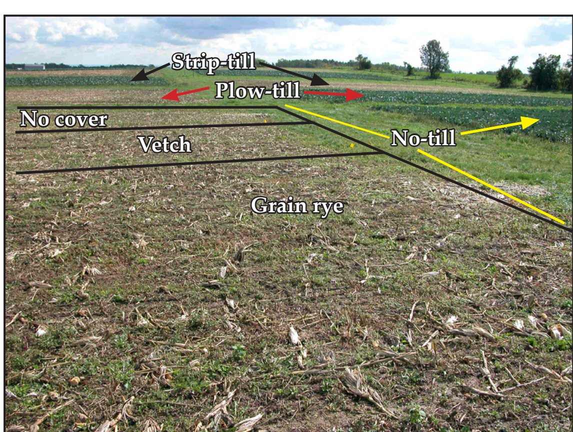


Figure 6. *The 14-acre long-term soil health research site at Gates Farm in Geneva, NY was established in 2003. The 72 plots represent three tillage systems, three cover crops and two rotation treatments replicated four times. One rotation (plots with green vegetation) emphasizes continuous high-value vegetable production and another rotation includes season long soil-building crops (plots with corn residue).*

In-field soil health assessment

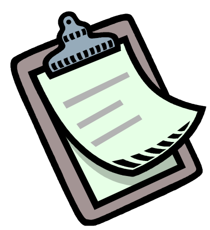
Qualitative on-farm, in-field measures of soil health involve no special analyses, only the informed scoring or rating of soil characteristics. This is usually done by visual assessment, but the smell and feel of soil may also be involved. While this approach is subjective and therefore can reflect user bias, when detailed guidelines and training have been provided the results can compare well to quantitative laboratory measurements. Some specific soil indicators, such as penetrometer resistance in the root zone, are always measured better directly in the field than in a laboratory.

Developing and using in-field assessments:

- A participatory process in developing qualitative soil health monitoring procedures locally has considerable educational value and opens up communication among farmers and between farmers and other agriculture professionals.

- Cards developed to date have utilized more than 30 physical indicators and more than 10 biological, chemical, and crop indicators of soil health. Soil physical characteristics might be scored for soil 'feel'; crusting; water infiltration, retention or drainage; and compaction. Soil biological properties might include soil smell (low score for sour, putrid or chemical odors vs. high score for 'earthy,' sweet, fresh aroma), soil color and mottling (which reflects balance of aerobic vs. anaerobic bacterial activity, among other things), and earthworm or overall biological activity.

- The rating scales used in soil health score cards vary from just a few categories ("poor, fair, or good") to scales of 1 to 10. The descriptions that define categories or rating scales are best based on local terminology and preferences. High quality photographs are an excellent way to train users and standardize scoring. See Figure 7 for an example.



POINTS TO REMEMBER:

- Training should include information on sampling, standardized verbal descriptions and/or photos that faciliate uniform scoring and keep users on track, and sufficient information regarding interpretation of results.
- To the extent possible, in-field measurements should be conducted at a similar time of year in relation to field operations, and at a similiar soil moisture and temperature.

Indicator Table

Indicator	Poor	Medium	Good
Earthworms	0-1 worms in shovelful of top foot of soil. No casts or holes.	2-10 in shovelful. Few casts, holes, or worms.	10+ in top foot of soil. Lots of casts and holes in tilled clods. Birds behind tillage.
Organic Matter Color	Topsoil color similar to subsoil color.	Surface color closer to subsoil color.	Topsoil clearly defined, darker than subsoil.
Organic Matter Roots/Residue	No visible residue or roots.	Some residue, few roots.	Noticeable roots and residue.
Subsurface Compaction	Wire breaks or bends when inserting flag.	Have to push hard, need fist to push flag in.	Flag goes in easily with fingers to twice the depth of plow layer.
Soil Tilth Mellowness Friability	Looks dead. Like brick or concrete, cloddy. Either blows apart or hard to pull drill through.	Somewhat cloddy, balls up, rough pulling seedbed	Soil crumbles well, can slice through, like cutting butter. Spongy when you walk on it.
Erosion	Large gullies over 2 inches deep joined to others, thin or no topsoil, rapid run-off the color of the soil.	Few rills or gullies, gullies up to two inches deep. Some swift runoff, colored water.	No gullies or rills, clear or no runoff.
Water Holding Capacity	Plant stress two days after a good rain.	Water runs out after a week or so.	Holds water for a long period of time without puddling.
Drainage Infiltration	Water lays for a long time, evaporates more than drains, always very wet ground.	Water lays for short period of time, eventually drains.	No ponding, no runoff, water moves through soil steadily. Soil not too wet, not too dry.
Crop Condition (How well it grows)	Problem growing throughout season, poor growth, yellow or purple color.	Fair growth, spots in field different, medium green color.	Normal healthy dark green color, excellent growth all season, across field.
pH	Hard to correct for desired crop.	Easily correctable.	Proper pH for crop.
Nutrient Holding Capacity	Soil tests dropping with more fertilizer applied than crops use.	Little change or slow down trend.	Soil tests trending up in relation to fertilizer applied and crop harvested.

Assessment Sheet

Date____________ Crop__________________
Farm/Field ID__________________________
Soil Quality Poor Medium Good

INDICATORS	1	2	3	4	5	6	7	8	9
Earthworms									
Organic Matter Color									
Organic Matter Roots/residue									
Subsurface Compaction									
Tilth/Friability Mellowness									
Erosion									
Water Holding Capacity									
Drainage Infiltration									
Crop Condition									
pH									
Nutrient Holding Capacity									
Other (write in)									
Other (write in)									

Assessment Guide

Indicator	Best Assessed
Earthworms	Spring/Fall Good soil moisture
Organic Matter Color	Moist soil
Organic Matter Roots/Residue	Anytime
Subsurface Compaction	Best pre-tillage or post harvest Good soil moisture
Soil Tilth Mellowness Friability	Good soil moisture
Erosion	After heavy rainfall
Water Holding Capacity	After rainfall During growing season
Drainage Infiltration	After rainfall
Crop Condition	Growing season Good soil moisture
pH	Anytime, but at same time of year each time
Nutrient Holding Capacity	Over a five year period, always at same time of year.

Figure 7. Example score card from the Maryland Soil Quality Assessment Book (1997) published by the Natural Resource Conservation Service (available online as a pdf file at http://soils.usda.gov/sqi/assessment/state_sq_cards.html.

Soil Health Testing

The Cornell soil health assessment protocol emphasizes the integration of soil biological measurements with soil physical and chemical measurements. These measurements include soil texture and stone content, wet aggregate stability, available water capacity, field penetrometer resistance, potentially mineralizable nitrogen, active carbon, organic matter content, root health assessment, and macro- and micro-nutrient level assessment. These measurements were selected from 39 potential soil health indicators (page 10, Table 1) that were evaluated for their:

- sensitivity to changes in soil management practices
- relevance to soil processes and functions
- consistency and reproducibility
- ease and cost of sampling
- cost of analysis.

Soil Health Testing **Page**

The results of these measurements have been synthesized into a grower-friendly soil health report that can initially be used by the grower as a baseline assessment. Subsequent sampling and analysis of the same field can be employed to determine the impact of implemented soil management practices on soil health. The report is explained in further detail on page 40. Table 2 provides a brief description of each indicator. More detailed descriptions as well as the basic protocol/ methodology, how each indicator relates to the functioning of the soil and the scoring function used to assign a rating score can be found on pages 22 though 39.

Strip tillage into a winter rye cover crop in spring prior to planting to snap bean.

Why assess soil health?

- **Target management practices to address soil constraints**
- **Quantify soil improvement from implementing new or modifying current soil management practices**
- **Facilitate applied research - compare management practices to develop a farm/field specific soil management program**
- **Land valuation - facilitate the pricing of soil health**

Table 2. Brief descriptions of the selected soil health assessment indicators	
PHYSICAL	**Aggregate Stability:** is a measure of the extent to which soil aggregates resist falling apart when wetted and hit by rain drops. It is measured using a rain simulation sprinkler that steadily rains on a sieve containing a known weight of soil aggregates between 0.5mm and 2.0mm. The unstable aggregates slake (fall apart) and pass through the sieve. The fraction of soil that remains on the sieve determines the percent aggregate stability.
	Available Water Capacity: reflects the quantity of water that a disturbed sample of soil can store for plant use. It is the difference between water stored at field capacity and the wilting point, and is measured using pressure chambers.
	Surface Hardness: is a measure the maximum soil surface (0 to 6 inch depth) penetration resistance (psi) determined using a field penetrometer.
	Subsurface Hardness: is a measure of the maximum resistance (in psi) encountered in the soil at the 6 to 18 inch depth using a field penetrometer.
BIOLOGICAL	**Organic Matter:** is any material that is derived from living organisms, including plants and soil fauna. Total soil organic matter consists of both living and dead material, including well decomposed humus. The percent OM is determined by loss on ignition, based on the change in weight after a soil is exposed to approximately 500˚C in a furnace.
	Active Carbon: is a measure of the fraction of soil organic matter that is readily available as a carbon and energy source for the soil microbial community (the fuel of the soil food web). Active carbon is a "leading indicator" of soil health response to changes in crop and soil management, usually responding much sooner than total organic matter content. The soil sample is mixed with potassium permanganate (deep purple in color) and as it oxidizes the active carbon, the color (absorbance) is measured using a spectrophotometer.
	Potentially Mineralizable Nitrogen: is the amount of nitrogen that is converted (mineralized) from an organic form to a plant-available inorganic form by the soil microbial community over seven days in an incubator. It is a measure of soil biological activity and an indicator of the amount of nitrogen that is rapidly available to the plant.
	Root Health Rating: is a measure of the quality and function of the roots as indicated by size, color, texture and absence of symptoms and damage by root pathogens such as *Fusarium*, *Pythium*, *Rhizoctonia*, and *Thielaviopsis*. Been seeds are grown in a portion of the soil sample in the greenhouse for four weeks. Low ratings (1 to 3) suggest healthy roots because pathogens are not present at damaging level and /or are being suppressed by the beneficial microorganisms in the soil.
CHEMICAL	**Soil Chemical Composition:** a standard soil test analysis package measures levels of pH, plant nutrients and toxic elements. Measured levels are interpreted in the framework of sufficiency and excess but are not crop specific.

Scoring Functions

To aid the interpretation of our soil health measurements, scoring functions were developed for the individual indicators, following work by Andrews et al. (2004)[1]. The scoring functions enable a value for a specific indicator to be converted to a rating and assigned a color (red, yellow, green) on the soil health report (Figure 10). In the context of our soil health assessment, a scoring function is a curve that assigns specific scores between 0 and 100 to the values measured for individual indicators. A score of 100 is the best (highest) while a score of 0 is the worst (poorest). For most of the indicators, scoring functions were developed separately for the major soil textural groups (sand, silt, and clay) based on data distributions. We used the data collected across the Northeastern United States to establish these scoring curves. The scoring functions for many indicators consist of the cumulative normal distribution (CND) curves normalized to a scale of 0-100 for scoring soil health indicators (Figure 9).

Figure 8 shows the distribution of active carbon in silt soils with the normal distribution curve drawn to fit the data. The data in Figure 8 have a mean of 612 ppm and a standard deviation of 187 ppm. Generating a CND from these data and normalizing the Y axis on a scale of 0-100 yields the scoring curve in Figure 9.

We used the following values to set the threshold for rating soil health indicators: i.) 0 - 30 (red) corresponds to deficiency of an indicator implying that it will constrain soil use; ii) >30 - <70 (yellow) corresponds to the intermediate region of the indicator and iii) 70 – 100 (green) indicates that the indicator value is at an optimal level.

The soil measurements that were scored in this way include aggregate stability, available water capacity, surface hardness, subsurface hardness, organic matter, active carbon and potentially mineralizable nitrogen.

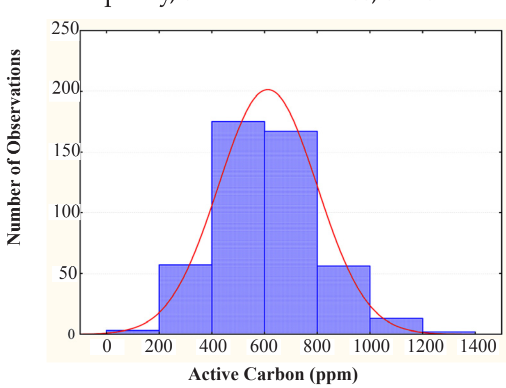


Figure 8. *Distribution of active carbon data in silt soils.*

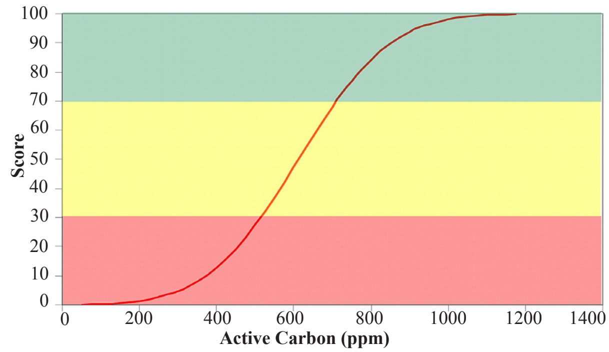
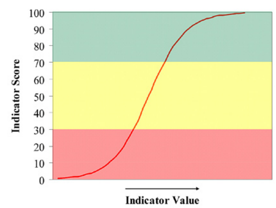
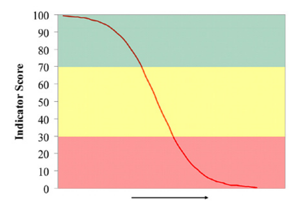


Figure 9. *Cumulative normal distribution for scoring active carbon in silt soils.*

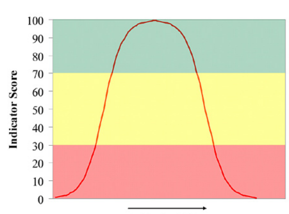
Our scoring curves for soil health assessment generally follow three types of functions which are:



a. **more is better:** In this situation, the higher the value of the indicator, the higher the score until a maximum level is attained. Indicators falling in this class include aggregate stability, available water capacity, organic matter content, active carbon content, potentially mineralizable nitrogen, and extractable potassium.



b. **less is better:** The scoring curve in this case gives higher scores to lower values of the indicator. Soil measurements in this group include surface hardness, subsurface hardness and root health assessment.



c. **optimum curve:** In this case, the curve rises to the highest level with increasing indicator values and remains stationary at the maximum score. As the indicator value increases, the scores start decreasing. Indicators that were scored this way are pH and extractable phosphorus.

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

Soil minor element and micronutrient values were scored based on the number of elements that are either deficient or excessive. A deficiency or excess of one element brings the indicator score down to 6, while a deficiency or excess of two elements brings the score down to 1.

Specific scoring functions for individual indicators used in our soil health assessment are shown in each section where they are discussed. An overall soil quality score is computed from the sum of all the individual indicator scores and is expressed on a percentage scale. The overall classification of the soil based on the percentage score is given as:

i.	> 85%	Very High
ii.	70 - 85%	High
iii.	55 - 70%	Medium
iv.	40 - 55%	Low
v.	< 40%	Very Low

Plant root growing down a worm channel in the soil profile.

CORNELL SOIL HEALTH TEST REPORT (COMPREHENSIVE)

Name of Farmer: Chazy Plots	Sample ID: E147
Location:	Agent: Bob Schindelbeck, Cornell University
Field/Treatment: CH 14	Agent's Email: 0
Tillage: 7-9 INCHES	Given Soil Texture: SILTY
Crops Grown: COG/COG/COG	Date Sampled: 4/25/2007

	Indicators	Value	Rating	Constraint
PHYSICAL	Aggregate Stability (%)	22	25	aeration, infiltration, rooting
PHYSICAL	Available Water Capacity (m/m)	0.18	63	
PHYSICAL	Surface Hardness (psi)	107	78	
PHYSICAL	Subsurface Hardness (psi)	400	13	Subsurface Pan/Deep Compaction
BIOLOGICAL	Organic Matter (%)	2.1	14	energy storage, C sequestration, water retention
BIOLOGICAL	Active Carbon (ppm) [Permanganate Oxidizable]	462	21	Soil Biological Activity
BIOLOGICAL	Potentially Mineralizable Nitrogen (µgN/ gdwsoil/week)	2.0	0	N Supply Capacity
BIOLOGICAL	Root Health Rating (1-9)	2.3	88	
CHEMICAL	*pH	8.3	0	Toxicity, Nutrient Availability (for crop specific guide, see CNAL report)
CHEMICAL	*Extractable Phosphorus (ppm) [Value <3.5 or >21.5 are downscored]	9.5	100	
CHEMICAL	*Extractable Potassium (ppm)	20	11	Plant K Availability
CHEMICAL	*Minor Elements		56	
	OVERALL QUALITY SCORE (OUT OF 100):		39.1	Very Low

Measured Soil Textural Class:==> silt loam

SAND (%): 17.0 *SILT (%): 77.0* *CLAY (%): 6.0*

Location (GPS): Latitude=> 0 Longitude=> 0

* See Cornell Nutrient Analysis Laboratory report for recommendations

Figure 10. *Example of the color coded ratings for continuous corn grain on a silt loam soil, managed using conventional plow tillage in a long-term soil management research trial in Chazy, NY. The reports are described further on page 40.*

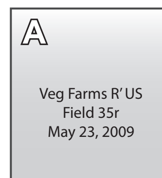
Soil Sampling Protocol

Materials needed for one sample:

- 2 5-gallon buckets/containers (one for soil, one for supplies)
- 1 zip-loc bag (large 1-gallon)
- 1 600 ml plastic beaker (3 cup capacity)
- Permanent marker and pen
- Trowel or shovel
- Penetrometer
- Grower and field information sheet (pages 20-21)
- Clipboard (if desired)

Steps for soil sampling:

1. Label the zip-loc bag with **field name/ID** and **date** (A).
2. **For each bulk sample** (B): scrape off the surface debris (or the top 1-inch if field was left fallow) and use a trowel or shovel to mix the top 6-inches of soil and place approximately one cupful into the sample bucket. It is important to collect the same amount of soil from all soil depths so the sample is not biased with more soil from the top 2 inches compared to the bottom 2 inches especially since soil biological properties vary with depth. Instead of a trowel, a standard soil probe may be used but more cores will need to be collected to obtain the necessary amount of soil for analysis.
3. Once all the bulk samples have been collected (5 stops, 10 sub-samples, see page 19), **thoroughly mix** the sub-samples in the bucket and place at least **1.5 quarts** (6 full cups) of soil into the **labeled zip-loc bag** (C). The total sample volume submitted will be about 1.5 quarts (6 full cups). The remaining soil in the bucket can be discarded.
4. **Penetrometer readings:** each penetrometer reading is taken thru 2 depths (0-6 and 6-18 inches). For each depth, the highest/maximum measured penetrometer reading is recorded on the Grower and Field Information Sheet (see page 20). When finished, penetrometer readings will have been recorded at 10 locations in the field, each at 2 depths. For additional information on measuring penetration resistance see page 28.
5. The sample should be kept out of the direct sun and placed in a cooler with ice packs. The microorganisms in the soil are very sensitive to heat.



A complete sample will consist of: *a labeled bag containing 6 full cups of composited soil and a completed grower and field information sheet with penetrometer readings recorded at the bottom of the page.*

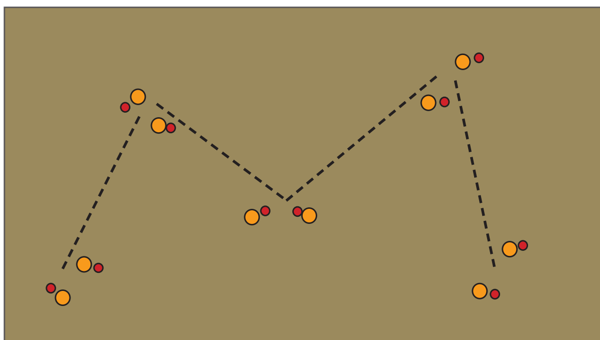
Field sampling design:

Prior to sampling a field it is important to determine whether the field should be divided up for multiple samples or one sample will accurately represent the entire field. The recommended guidelines are similar to sampling for nutrient analysis. Irregular areas in the field such as the low spot in *Example 2* should be avoided. Fields should be divided into sampling units when there are differences in:

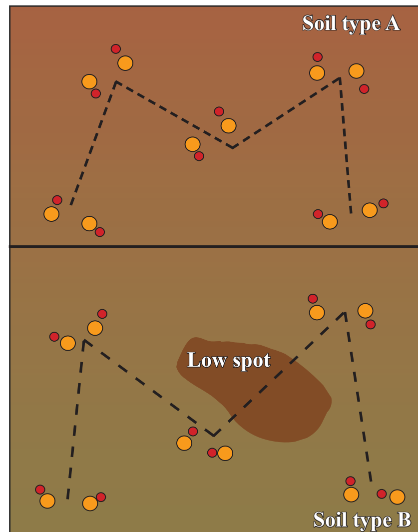
- soil type,
- management practices and
- crop growth and yield.

At each of the five stops, collect two bulk soil samples at least 15 feet apart and take one penetrometer reading at two depths at each bulk sample location (see field diagrams below).

Example 1: Uniform field (1 sample)



Example 2: Uneven field - 2 soil types (2 samples)



Sample portions:

● Bulk soil sample (placed in bucket) ● Penetrometer reading (each at 2 depths)

Soil sample storage and transportation requirements:

- Always keep samples out of direct sunlight and preferably in a cooler in the field
- Upon returning from the field, store samples in refrigerator or cold room as soon as possible

Recommended shipping guidelines:

- Use overnight or 2-day shipping
- Package sample with blue ice
- Each sample will weigh approximately 4 lbs (depending on soil moisture) plus packaging

Send or drop-off samples and completed information sheets to:

Bob Schindelbeck
1003 Bradfield Hall
Cornell University
Ithaca, NY 14853-1901
Cell phone: (607) 227-6055

Alternate drop-off site:

Dr. George Abawi
Department of Plant Pathology
NYS Agricultural Experiment Station
A111 or A113 Barton Laboratory
Geneva, NY 14456
Phone: (315) 787-2374 (office)
(315) 787-2407 (lab)
(315) 787-2331 (dept. main office)

PLEASE DOWNLOAD THE NEWEST VERSION OF THIS SUBMISSION FORM AT:
http://soilhealth.cals.cornell.edu/extension/test.htm

SH

Cornell Soil Health Assessment

Physical Chemical Biological

1003 Bradfield Hall, Ithaca, NY 14853
Lab Coordinator Bob Schindelbeck (607) 227-6055, rrs3@cornell.edu
E-mail: soilhealth@cornell.edu **Website: http://soilhealth.cals.cornell.edu**

NOTE: NO NUTRIENT RECOMMENDATIONS WILL BE PROVIDED WITHOUT THE SOIL NAME
For soil maps and soil names visit http://websoilsurvey.nrcs.usda.gov/app/

Grower	**Commercial representative**
Grower name: ____________	Representative name: ____________
Address: ____________	Address: ____________
____________	____________ **County:**
____________	____________ Email for extra recipient:
Phone: ____________	Phone: ____________
Email:	Email: **Cropware data: ____ Yes _____No**

Soil Health Analysis Cost

Basic Package* $40./ sample
Comprehensive Package* $65./ sample

[ ] Check enclosed (to: CORNELL UNIV.)
[ ] Paid Agent (name):
[ ] Bill Me:

* **See Back of Sheet (top) for Listing of Tests Performed in each Soil Health Package**

SOIL INFORMATION

LAB ID (*Lab Use Only*)	Field Identification	Date Sampled	Other Chemical/ Nutrient Tests
			(see Back of Sheet, bottom)

SOIL NAME (*REQUIRED*)	Tillage Depth	Artificial Drainage	Manure / Organic Additions
(ex. LIMA silt loam)	**2008** **2009** **2010** **1** = no till, **2** = 1-7 inch, **3** =7-9 inch, **4** = >9 inch	**1** = none, **2** = Inadequate, **3** =Adequate, **4** =Excellent	Type/ Animal Amount/ Acre [ ] 2008 [ ] 2009 [ ] 2010

CROP INFORMATION (see back of this sheet for Crop Codes)

% Legume Last Year	Cover Crop	Past Year Crops			Future Crops		
		3 yrs ago	2 yrs ago	Last yr	This yr	Next yr	Third yr
1 = 0%, **2** = 1-25%, **3** = 26-50%, **4** = 51-100%	**1** = Before next crop, **2** = Before 2nd years crop, **3** =Before 3rd years crop, **4** =Before all years crop						

FIELD PENETROMETER DATA COLLECTION (use SMALL 1/2" tip)

PENETRATION RESISTANCE	location 1		location 2		location 3		location 4		location 5	
	push 1	push 2	push 3	push 4	push 5	push 6	push 7	push 8	push 9	push 10
0-6 INCH										
6-18 INCH										

Depth to Hardpan or a Restrictive Layer (inches):

Record the highest resistance value encountered in each depth range

GPS coordinates here:

CORNELL SOIL HEALTH TEST INFORMATION

Basic Package Analyses $40./ sample	**Comprehensive Package Analyses $65./ sample**
Soil Texture	Basic Package
Wet Aggregate Stability	PMN (Potentially Mineralizable N)
Available Water Capacity	Root Bioassay
Surface/ sub-surface Hardness	
Organic Matter	
Active Carbon	
Standard Fertility Test and Recommendations (see below)	

Please see the website http://soilhealth.cals.cornell.edu for specific field sampling and sample handling instructions.

STANDARD SOIL FERTILITY TEST INFORMATION

Agro-One will be performing Soil Fertility tests and will send results directly to the names listed on this submission form.

Standard Fertlity Test Package includes: pH, Modified Mehlich Buffer pH (lime requirement), organic matter and Morgan equivalent extractable phosphorus, potassium, calcium, magnesium, aluminum, iron, zinc,and manganese.

1) You will receive the soil Chemical results and nutrient guidelines within 2 weeks of sample submission directly from Agro-One, 730 Warren Rd., Ithaca, NY 14850.

2) The complete Cornell Soil Health Test Report, which includes the test results from the Basic Package or Comprehensive Package listed above require about 4-6 weeks for completion and will be sent from the Cornell Soil Health Lab, 1003 Bradfield Hall, Cornell University, Ithaca, NY 14853.

PERENNIAL AGRONOMIC CROPS

CODE	INITIAL ESTABLISHMENT	CODE	TOPDRESSING ESTAB. STANDS	CODE	INITIAL ESTABLISHMENT	CODE	TOPDRESSING ESTABLISHED STANDS
ALE	Alfalfa	ALT	Alfalfa	CVE	Crownvetch	CVT	Crownvetch
AGE	Alfalfa-grass	AGT	Alfalfa-grass	GRE	Grasses	GRT	Grasses (brome, timothy)
ABE	Alfalfa-trefoil-grass	ABT	Alfalfa-trefoil-grass	GIE	Grass-intensive mgmt.	GIT	Grass-intensive management
BTE	Birdsfoot-trefoil	BTT	Birdsfoot-trefoil	PIE	Pasture-rotation grazed	PIT	Pasture-intensive management
BGE	Birdsfoot-trefoil-grass	BGT	Birdsfoot-trefoil-grass	PGE	Pasture w/improv. grazing	PNT	Pasture w/native grass
BCE	Birdsfoot-trefoil-clover	BCT	Birdsfoot-trefoil-clover-grass	PLE	Pasture with legumes	PGT	Pasture w/improved grass
BSE	Birdsfoot-trefoil-seed	BST	Birdsfoot-trefoil-seed	WPE	Waterways, pond dikes	PLT	Pasture w/legumes
CLE	Clover	CLT	Clover			WPT	Waterways, pond dikes
CGE	Clover-grass	CGT	Clover-grass				
CSE	Clover-seed production	CST	Clover-seed production				

ANNUAL AGRONOMIC CROPS

CODE	INITIAL ESTABLISHMENT	CODE	TOPDRESSING ESTAB. STANDS	CODE	INITIAL ESTABLISHMENT	CODE	TOPDRESSING ESTABLISHED STANDS
BSP	Barley-spring	BUK	Buckwheat	RYC	Rye-cover crop	SOY	Soybeans
BSS	Barley-spring w/legume	COG	Corn-grain	RYS	Rye-seed production	SUN	Sunflower
BWI	Barley-winter	COS	Corn-silage	SOG	Sorghum-grain	TRP	Triticale, Peas
BWS	Barley-winter w/legume	MIL	Milet	SOF	Sorghum-forage	WHT	Wheat
BDR	Beans-dry	OAT	Oats	SSH	Sorghum-sudan hybrid	WHS	Wheat w/legume
		OAS	Oats seeded w/legume	SUD	Sudangrass		

MISCELLANEOUS CROPS- Results only. No interpretations or nutrient guidelines are provided for IDL or OTH.

CODE	CROP	CODE	CROP
TRT	Christmas Tree, Topdress	IDL	Idle Land
TRE	Christmas Tree, Establishment	OTH	Crops not listed

NOTE: The complete list of crop codes can be found at http://www.dairyone.com/AgroOne/Agro_One_Crop_Codes.pdf

VEGETABLE CROPS

CODE	CROP	CODE	CROP	CODE	CROP	CODE	CROP
ASP	Asparagus	CFS	Cauliflower-seeded	MML	Muskmelon	RAD	Radishes
BND	Beans-dry	CEL	Celery	MUS	Mustard	RHU	Rhubarb
BNS	Beans-Snap	CRD	Chard	ONP	Onion-transplanted	SPS	Spinach-spring
BET	Beets	CHC	Chinese cabbage	ONS	Onion-seeded	SPF	Spinach-fall
BRP	Broccoli-transplanted	CKP	Cucumber-transplanted	PSL	Parsley	SQS	Squash-summer
BRS	Broccoli-seeded	CKS	Cucumber-seeded	PSN	Parsnips	SQW	Squash-winter
BUS	Brussels Sprouts	EGG	Eggplant	PEA	Peas	SWC	Sweet corn
CBP	Cabbage-transplanted	END	Endive/Escarole	PEP	Peppers	TME	Tomato-early
CBS	Cabbage-seeded	GAR	Garlic	POP	Popcorn	TOM	Tomato-all others
CAR	Carrots	LET	Lettuce	POT	Potatoes	TUR	Turnips
CFP	Cauliflower-transplanted	MIX	Mixed vegetables	PUM	Pumpkins	WAT	Watermelon

OPTIONAL TESTS* (*Please enclose check for the cost of additional tests*)

Test	Cost per sample($)
[ ] (836) pH in 0.01M $CaCl_2$	$5.00
[ ] (837) Soluble salts	$5.00
[ ] (838) No-till pH (0-1 inch)	$5.00
[ ] (839) Nitrate	$5.00
[ ] (840) Boron (Hot water)	$10.00

* *No interpretations or recommendations will be provided for optional tests.*

EXTRA PAYMENT

[ ] Check enclosed

[ ] Paid Cooperative Extension

[ ] Account Number:

Soil Texture

Soil particles are the building blocks of the soil skeleton. Most of a soil's particles are a mixture of variously sized minerals that define its texture. A soil's textural class—such as a clay, clay loam, loam, sandy loam, or sand—is perhaps its most fundamental inherent characteristics. It affects many of the important physical, biological, and chemical processes in a soil and changes little over time. 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. Particles that are larger than 2 mm are rock fragments (pebbles, cobbles, stones, and boulders), which are not considered in the textural class because they are relatively inert. Also, organic matter is not considered in the determination of soil texture, although it is very important for soil functioning, as discussed later.

Basic Protocol:

Basic Protocol[2]:

- A portion of the soil sample is oven-dried at 60 C and sieved past 2mm.
- About 14g (+/- 0.1g) of sieved soil is added to a 50ml centrifuge tube containing 42ml of 3% soap (sodium hexametaphosphate) solution.
- Shake vigorously on reciprocating shaker for 2 hours to fully disperse soil into suspension.
- Wash entire contents of centrifuge tube onto a 0.053mm soil sieve assembly. Sieve assembly consists of 0.053mm sieve on top of a plastic funnel above a 600ml beaker. Rinse all material through the sieve using fingers or rubber policeman. Sand captured on top of the sieve is washed into a tared metal can and set aside.
- Silt and clay particles collected in the 600ml beaker are re-suspended by stirring and allowed to settle for 2 hours. The clay in suspension is then carefully decanted. The settled silt at the bottom of the beaker is washed into a second tared can. Both tared cans (one containing the sand fraction and the other the silt fraction) are dried overnight at 105 C to constant weight before weighing.
- Calculate percent sand, silt clay from:

Sand (%) = dry wt sand (g) / dry wt (g) soil added to centrifuge tube

Silt (%) = dry wt silt (g) / dry wt (g) soil added to centrifuge tube

Clay (%) = 100% - Sand (%) - Silt (%)

[2]Kettler, T. A., J. W. Doran, and T. L. Gilbert. 2001. Simplified method for soil particle-size determination to accompany soil-quality analyses. Soil Science Society of America Journal 65:849–852.

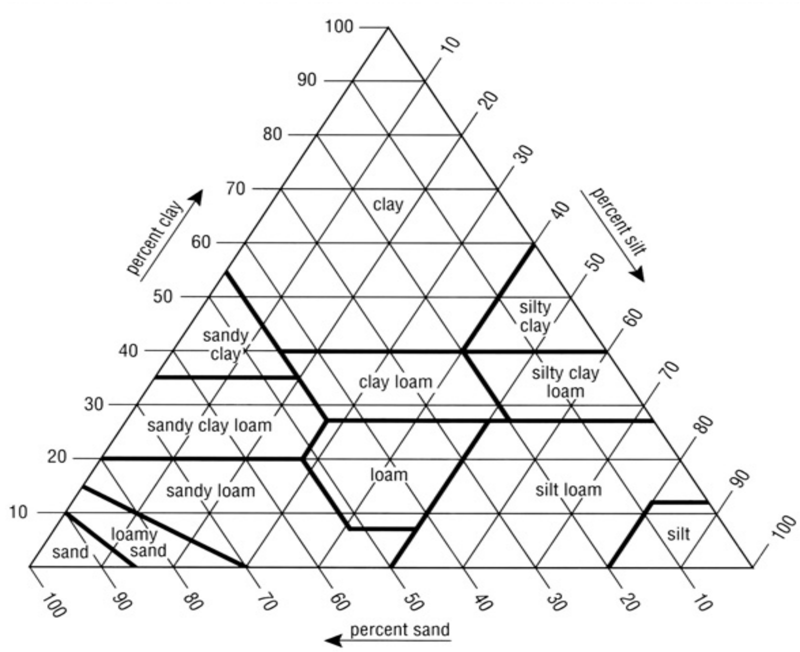
How soil texture relates to soil function:

Texture affects many basic properties. Soils with higher clay contents generally have higher ability to retain nutrients (more cation exchange capacity, or CEC) and can bind more organic matter. The size distribution of the particles also defines the size of the pore spaces between the particles and also between aggregates. These are just 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 retention, aeration, nitrate leaching, and denitrification. Also, soil organisms and plant roots live and function in pores. When the soil lacks small pores, roots cannot grow and many organisms have 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).

The pore sizes are affected not only by the relative amounts of sand, silt, and clay in a soil, but also by the amount of aggregation. On the one extreme, we see that beach sands have large particles (in relative terms) and no 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 change over time, the total amount of pore space and the relative amount of variously sized pores are strongly affected by management practices—aggregation and structure may be destroyed or improved.

Scoring function:

Soil texture is virtually unchangeable for a particular soil and is therefore not scored as part of a soil health assessment. Information on soil texture, however, is very valuable by itself for improving management practices. Moreover, soil textural information is being used to score most of the other soil health indicators, because interpretations cannot be made without correcting for soil texture. For example, coarse textured soils like loamy sands generally have lower organic matter levels than fine-textured clay loams because they lack the ability to stabilize organic matter through organo-mineral bonds. The measured organic matter contents are therefore adjusted to better reflect the health status of a soil. Similarly, a clayey soil is expected to have higher aggregate stability than a sandy soil and the measured values of aggregate stability are scored accordingly. 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, clay).



Aggregate Stability

Aggregate stability is a measure of the extent to which soil aggregates resist falling apart when wetted and hit by rain drops. It is measured using a rain simulation sprinkler that steadily rains on a sieve containing known weight of soil aggregates between 0.5 mm and 2 mm. The unstable aggregates slake (fall apart) and pass through the sieve. The fraction of soil that remains on the sieve is used to calculate the percent aggregate stability.

Basic Protocol:

- A portion of the soil is oven-dried at 40 ºC.
- Using stacked sieves of 2.0 mm and 0.25 mm with a catch pan, the dried soil is shaken for 10 seconds on a Tyler Coarse Sieve Shaker to separate it into different size fractions; small (0.25 - 2.0 mm) and large (2.0 - 8.0 mm).
- A single layer of small aggregates (0.25 - 2.0 mm) is spread on a 0.25 mm sieve (sieve diameter is 200 mm (8 inches)) (A).
- Sieves are placed at a distance of 500 mm (20 inches) below a rainfall simulator, which delivers individual drops of 4.0 mm diameter (B).
- The test is run for 5 minutes and delivers 12.5 mm depth of water (approximately 0.5 inches) as drops to each sieve. This is equivalent to a heavy thunderstorm. See soils starting to wet in (C). A total of 0.74 J of energy thus impact each sieve over this 5 minute rainfall period. Since 0.164 mJ of energy is delivered for each 4.0 mm diameter, it can be calculated that 15 drops per second impact each sieve.
- The slaked soil material that fell through the during the simulated rainfall event, and any stones remaining on the sieve are collected, dried and weighed, and the fraction of stable soil aggregates is calculated using the following equation:

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

where

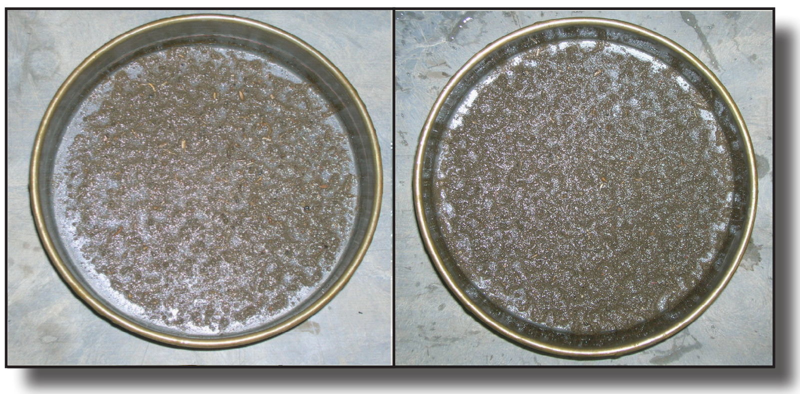
$$W_{stable} = W_{total} - (W_{slaked} + W_{stones})$$

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.

How aggregate stability relates to soil function:

This method tests the soil's physical quality with regard to its capacity to sustain its structure during most impactful conditions: a heavy rain storm after surface drying weather. Soils with low aggregate stability tend to form surface crusts which can reduce both water infiltration and air exchange. This poor soil aggregation also makes the soil more difficult to manage, and reduces its ability to dry off quickly. In heavy soils, enhanced friability and crumbliness from good aggregation makes the soil seem lighter. Growing a green manure cover crop or adding animal manure can stabilize soil aggregates.

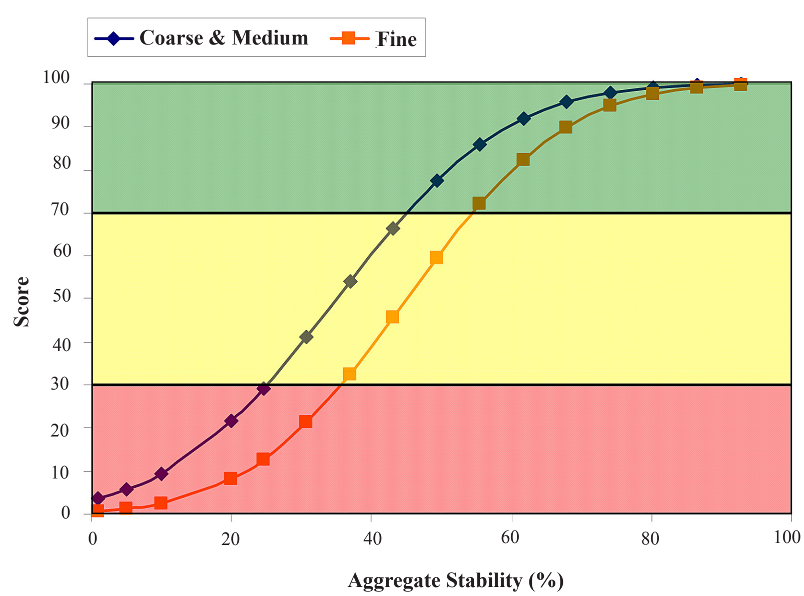
Over the long term, repeated tillage of soil can reduce soil tilth and break down stable soil aggregates. Such soils can be so degraded that they become addicted to tillage and crop establishment requires a soil loosening operation. A successful transition to reduced tillage and planting operations often requires significant green or animal manuring and/or focused tillage.



A Lima silt loam soil from a long-term tillage experiment. The moldboard plow treatment on the left has 34% water stable aggregates while the soil under zone-till management on the right has 56% water stable aggregates (0.25 mm sieve).

Scoring function:

To the right is the scoring functions graph for aggregate stability for silt, sand and clay textured soils. The red, yellow and green shading reflects the color coding used for the ratings on the soil health report (see page 40).

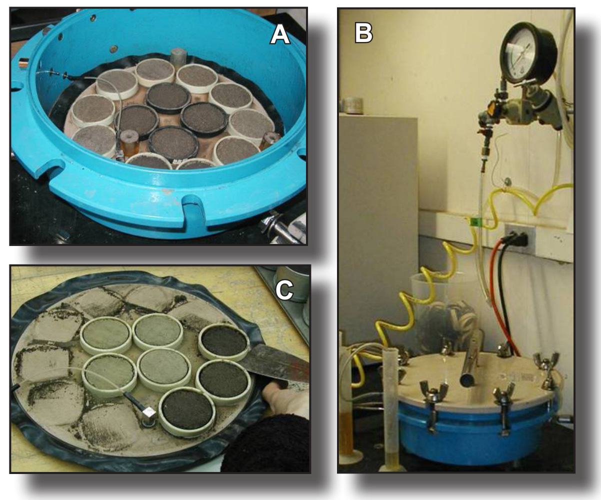


Available water capacity

Water storage in soil is important for plant growth. Water is stored in soil pores and in organic matter. In the field, the moist end of water storage begins when gravity drainage ceases (field capacity). The dry end of the storage range is at the 'permanent wilting point'. Water held in soils that is unavailable to plants is called hygroscopic water. Clay soils tend to hold more water than sandy soils. Sandy soils tend to lose more water to gravity than clays (see Figure 11.

Basic Protocol:

- Soil is placed on ceramic plates that are inserted into high pressure chambers to extract the water at field capacity (10 kPa) and at the permanent wilting point (1500 kPa) (A and B).
- After the sample equilibrates at the target pressure, the sample is weighed and then oven-dried at 105°C overnight (C).
- The sample dry weight is then determined and soil water content at each pressure is calculated. The available water capacity is the soil water loss between the 10 and 1500 kPa pressures.



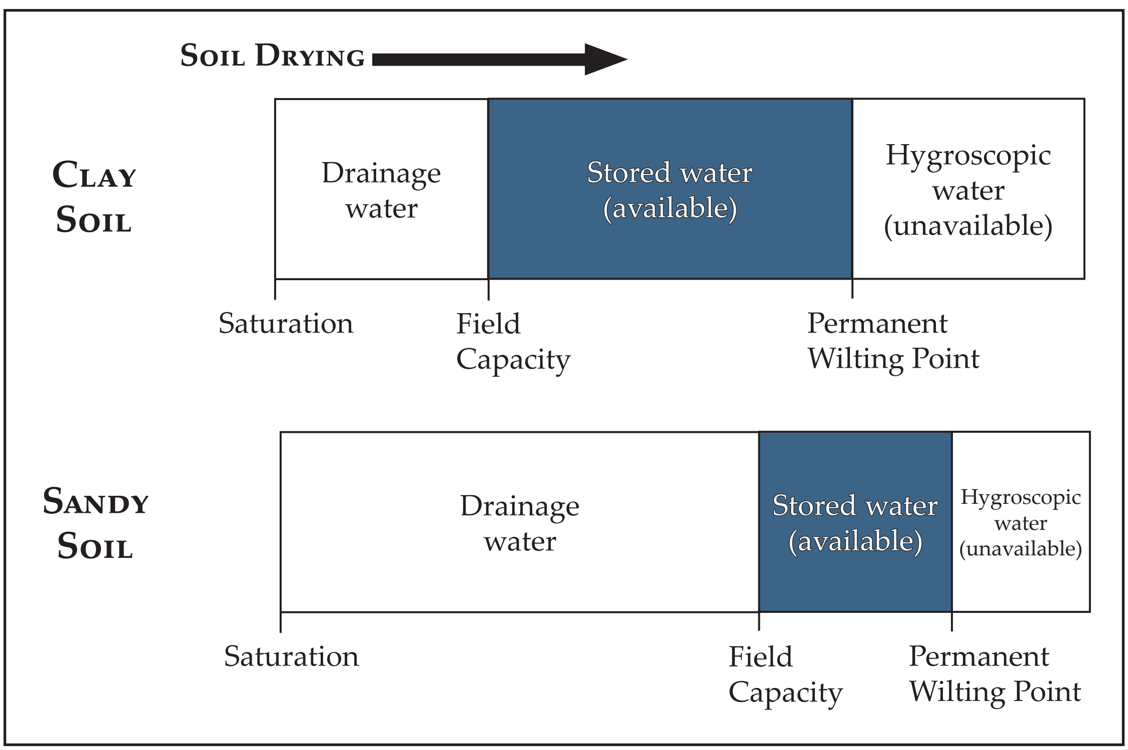


Figure 11. *Water storage for two soil types. The blue shaded area represents water that is available for plant use.*

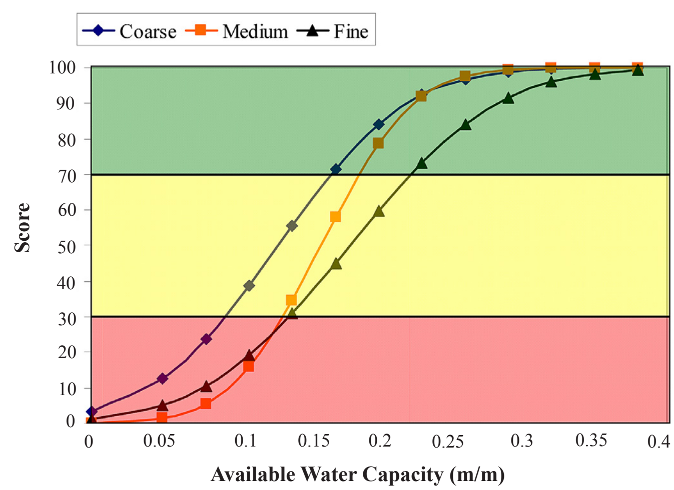
How AWC relates to soil function:

The available water capacity is an indicator of a soil's water storage capacity in the field. A common constraint of sandy soils is their ability to store water for crops between rains. The addition of composts or manures (green or animal) adds to the water storage, which is especially important during droughty periods. Note that total crop water availability is also dependent on rooting depth, which is considered in a separate indicator, penetration resistance

In heavier soils, the available water capacity is less critical because they naturally have high water retention ability. Instead, they are typically more limited in their ability to supply air to plant roots during wet periods. These soils often respond favorably to the addition of composts or manures (green or animal) but not in the same manner as the coarser textured soils above.

Scoring function:

To the right is the scoring function graph for available water capacity for sand, silt and clay textured soils. The red, yellow and green shading reflects the color coding used for the ratings on the soil health report (see page 40).



Field penetration resistance

Field penetration resistance is a measurement of the soil's strength measured (in psi) with a field penetrometer pushed through the soil profile. Measurements should be taken when the soil is near field capacity. It is measured for two depth increments in the field (0 to 6 in. and 6 to 18 in.) and used to assess surface and subsurface soil compaction.

Basic Protocol (guidelines for use):

- Penetration resistance is measured using a penetrometer, an instrument that measures the soil resistance to penetration. It consists of a cone-tip, a metal shaft, and a gauge that measures resistance in pounds per square inch (psi, A).

- Most penetrometers come with two different sized tips which correspond to two different gauge scales. The outer and inner scales correspond to the larger ¾ inch and the smaller ½ inch diameter tips, respectively (A). Be sure to use the scale appropriate for the size tip used.

- The level of soil moisture can greatly affect the ease with which the probe penetrates the soil. It is recommended that penetration reading be taken when the soil is at field capacity (several days after free drainage). If the soil conditions are not ideal, it is important to note conditions at the time of measurment so 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 on the grower and field information sheet (see page 20).

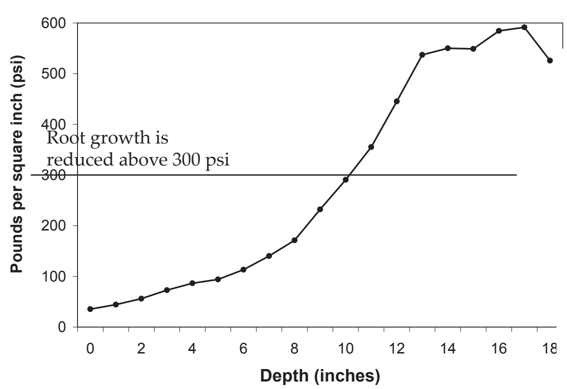


Figure 12. *Soil compaction graph for a field in intensive vegetable production in 2005 (Courtesy of C.R. MacNeil).*

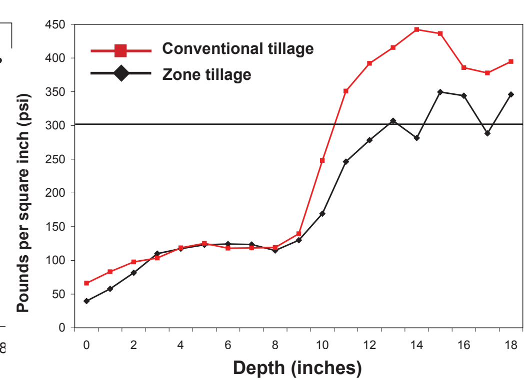


Figure 13. *Soil compaction graph for a conventionally plow tilled field and zone-till field with deep ripping on the same farm in spring of 2005 (Courtesy of C.R. MacNeil).*

How penetration resistance relates to soil function:

Field penetration resistance is a measure of soil compaction. The amount of pressure needed to push the probe through the soil can be measured at any desired depth but is most useful for identifying the depth of the compaction layer, if present. Roots can not penetrate the soil with penetrometer readings above 300 psi. Field profiles of penetration resistance can be created by recording the measured psi every inch through the soil profile and then plotting them on a chart (Figures 12 and 13). These charts can be used to identify various layers of compaction, if present (Figure 14). For the soil health test, however, we only target two depths.

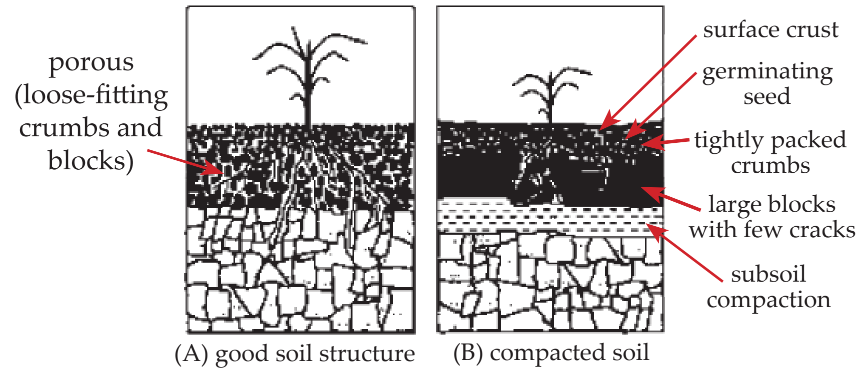
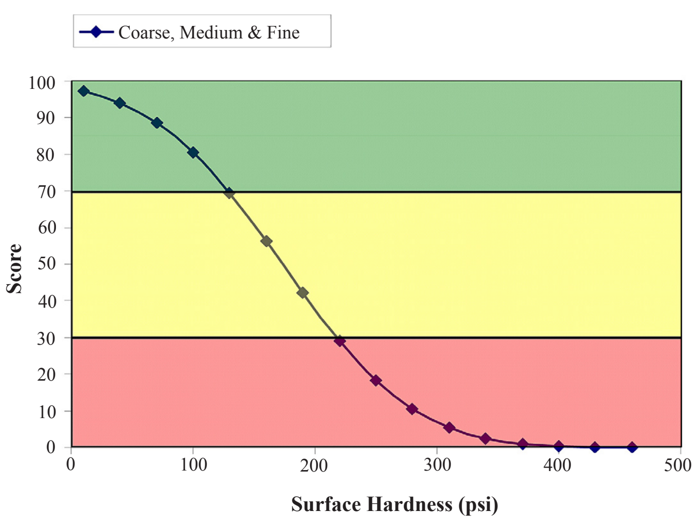
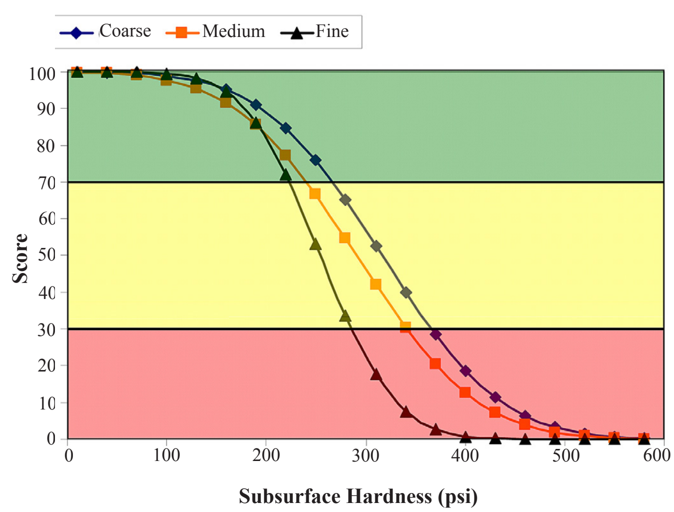


***Figure 14.** Plants growing is soil with good tilth (A) or three types of compaction (B). Source: Building Soils for Better Crops, 2nd edition, Sustainable Agriculture Network - USDA).*

Scoring function:

Below are the scoring function graphs for surface and subsurface resistance on sand, silt and clay textured soils. The red, yellow and green shading reflects the color coding used for the ratings on the soil health report (see page 40).





Organic matter

Organic matter is any material that is derived from living organisms, including plants and soil fauna. Total soil organic matter consists of both living and dead material, including well decomposed humus. The percent organic matter is determined by loss on ignition, based on the change in weight after a soil is exposed to approximately 950°F in a furnace. Organic matter content is often provided by soil analysis laboratories in conjunction with the analysis of major and minor nutrients.

Corn residue on the soil surface is a source of organic matter. (Photo courtesy of USDA-NRCS).

Basic Protocol:

- The Cornell Nutrient Analysis Laboratory measures the percent organic matter using loss on ignition.
- A sample is dried at 105°C to remove all water.
- The sample is then ashed for two hours at 500°C and the percent of weight lost is calculated.
- The % loss on ignition (LOI) is converted to % organic matter (OM) using the following equation:

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

How organic matter relates to soil function:

As discussed earlier, soil organic matter in its various forms greatly impacts the physical, chemical and biological properties of the soil. It contributes to soil aggregation, water-holding capacity, provides nutrients and energy to the plant and soil microbial communities, etc (Figure 16). It has been argued that organic matter management is soil health management!

Increasing the percent organic matter in the soil takes time and patience. It is unlikely that a single incorporation of a green manure or compost will noticeably increase the percent organic matter. However repeated use of organic amendments in combination with reduced tillage (depending on the constraints of the production system) will build soil organic matter levels. The selection of organic matter will depend on the management goal(s).

The addition of fresh organic matter that is easily degradable by the soil microbial population will lead to improvements in soil aggregate stability, nutrient cycling, and increased microbial diversity and activities.

The addition of more stable organic matter such as compost will improve water infiltration and retention. Also, organic matter in the form of rotational and cover crops, green manures, and composts have a major impact on the population and damage of soilborne pathogens, plant-parasitic

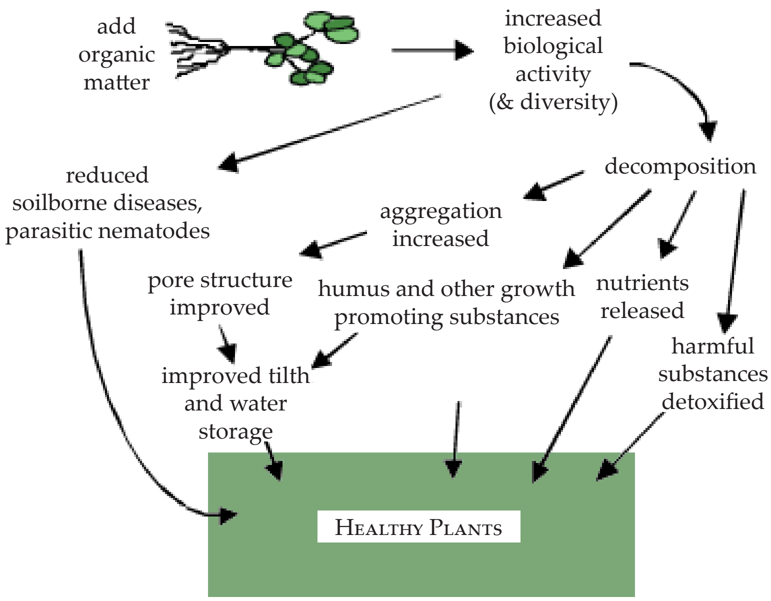


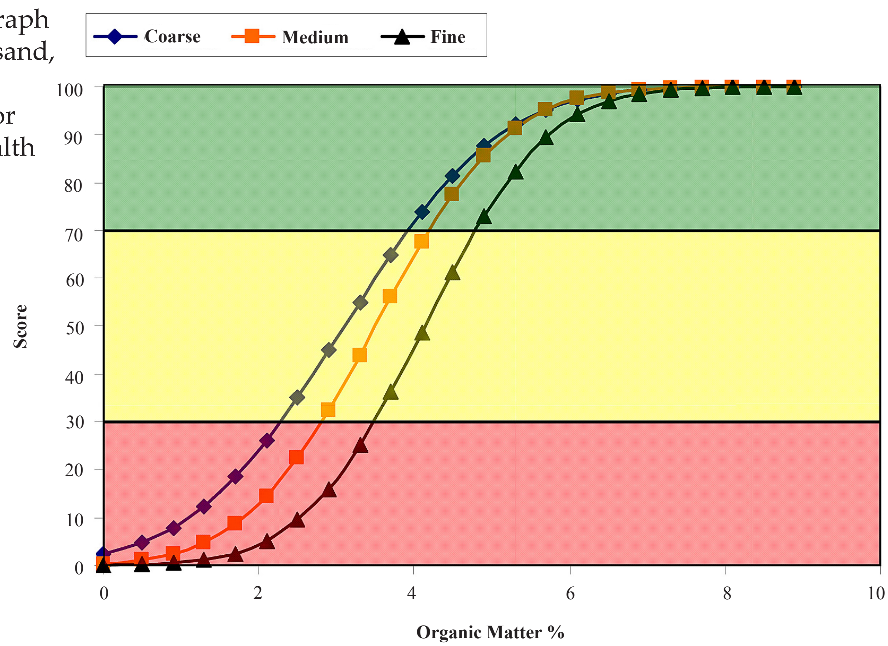
Figure 16. *Adding organic matter results in a cascade of changes within the soil. (Source: Building Soils for Better Crops, 2nd edition, Sustainable Agriculture Network - USDA).*

nematodes and other pests. Plants differ in their efficiency as hosts to various pests. They might produce products that inhibit or suppress pests and/or may stimulate microbial communities that are antagonistic or parasitic to crop pests.

Additional information on organic matter amendments and other resources can be found on pages 46-47 and 56-58, respectively.

Scoring function:

To the right is the scoring function graph for total organic matter content on sand, silt and clay textured soils. The red, yellow and green shading reflects the color coding used for the ratings on the soil health report (see page 40).



Active carbon

Active carbon is an indicator of the fraction of soil organic matter that is readily available as a carbon and energy source for the soil microbial community (i.e., food for the soil food web). The soil is mixed with potassium permanganate (deep purple in color) and as it oxidizes, the active carbon the color changes (becomes less purple), which can be observed visually, but is very accurately measured with a spectrophotometer.

Basic Protocol:

- From the larger thoroughly mixed composite bulk soil, a subsample is collected and allowed to air dry. The soil is ground 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 ($KMnO_4$) solution, which is deep purple in color
- The soil and $KMnO_4$ 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.
- The sample is centrifuged for 5 minutes, and the supernatant is diluted with distilled water and measured for absorbance at 550 nm.
- The absorbance of a standard dilution series of the $KMnO_4$ 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.

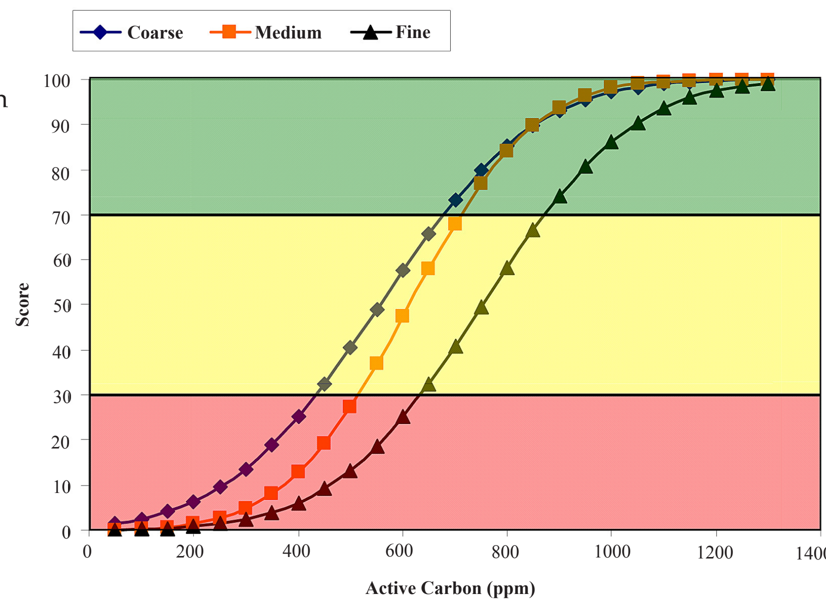
How active carbon relates to soil function:

Research has shown that active carbon is highly correlated with and similar to "particulate organic matter", which is determined with a more complex and labor-intensive wet-sieving and/or chemical extraction procedure. Active carbon is positively correlated with percent organic matter, aggregate stability, and with measures of biological activity such as soil respiration rate.

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. Thus, monitoring the changes in active carbon can be particularly useful to farmers who are changing practices to try to build up soil organic matter (e.g., reducing tillage, using new cover crops, adding new composts or manures).

Scoring function:

To the right is the scoring function graph for active carbon for sand, silt and clay textured soils. The red, yellow and green shading reflects the color coding used for the ratings on the soil health report (see page 40).



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 incubated for 7 days and the amount of ammonium produced in that period reflects the capacity for nitrogen mineralization.

Basic Protocol:

- As soon as possible after sampling, the mixed composite bulk soil sample (stored at 40°F) is sieved and two 8-g soil samples are removed and placed into 50 ml centrifuge tubes.
- 40 ml of 2.0 M potassium chloride (KCl) is added to one of the tubes, shaken on a mechanical shaker for 1 hour, centrifuged for 10 minutes, and then 20 ml of the supernatant is collected and analyzed for ammonium concentration ("time 0" measurement).
- 10 ml of distilled water is added to the second tube, it is hand shaken and stored (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 on a mechanical shaker for 1 hour, centrifuged for 10 minutes, and then 20 ml of the supernatant is collected and analyzed for ammonium concentration ("time 7 days" measurement).
- The difference between the time 0 and time 7-day ammonium concentration is the rate at which the soil microbes are able to mineralize organic nitrogen in the soil sample. Results are reported in units of micrograms nitrogen mineralized per gram dry weight of soil per week.

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

How PMN relates to soil function:

Nitrogen is the most limiting nutrient for plant growth and yield in most agricultural situations. 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 a handful of microbial species to convert this organic nitrogen into the ammonium and nitrate forms that plant roots can utilize (Figure 15).

The PMN test provides us with an indication of the capacity of the soil (the soil microbes) to recycle organic nitrogen into the plant available forms. Soils with high levels of nitrogen-rich organic matter (e.g., soils where legumes are in rotation) tend to have the highest populations of microbes involved in nitrogen mineralization and the highest PMN rates. We have found that soils with high PMN also are soils with high active C, high organic matter, and high aggregate stability.

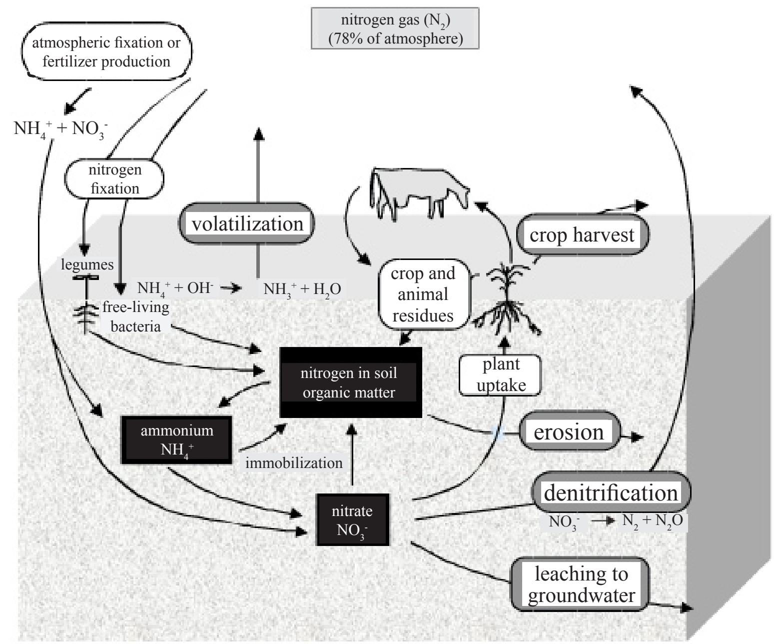
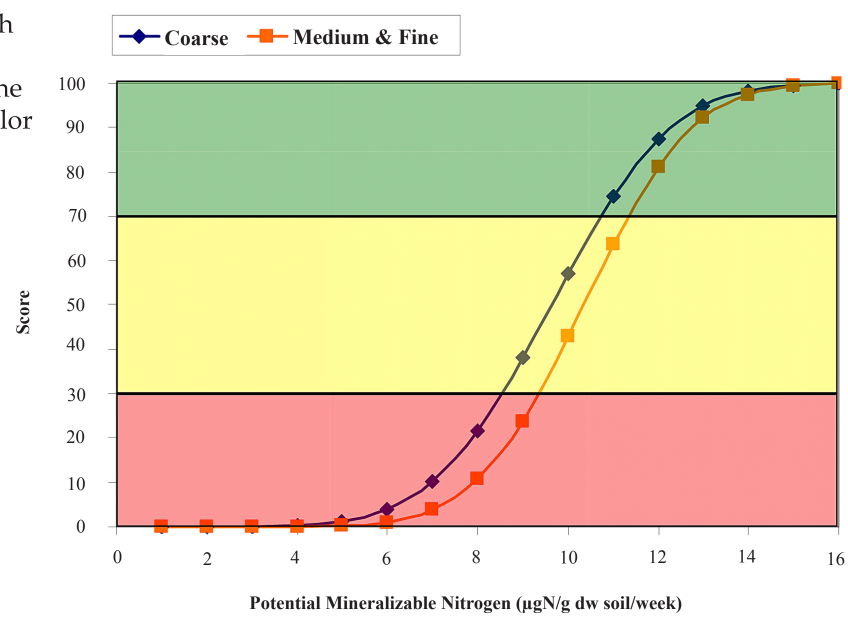


Figure 15. *The nitrogen cycle in an agricultural system. Source: Building Soil for Better Crops 2nd edition, Sustainable Agriculture Network - USDA.*

Scoring function:

To the right is the scoring function graph for potentially mineralizable nitrogen for sand, silt and clay textured soils. The red, yellow and green shading reflects the color coding used for the ratings on the soil health report (see page 40).



Root health assessment

Root health assessment is a measure of the quality and function of the roots as indicated by size, color, texture and the absence of symptoms and damage by root pathogens including the fungi Fusarium, Pythium, Rhizoctonia, Thielaviopsis, and plant-parasitic nematodes such as northern root-knot. For vegetable production systems, a soil bioassay with beans was shown to be highly effective in assessing root health as a component of overall soil health. Beans are susceptible to the major pathogens that impact vegetable, legume, and forage crops grown in New York and the Northeast region, thus their suitability as an indicator plant. The selection of other indicator plants might be needed for the proper assessment of root health of soils under different production systems.

Basic Protocol:

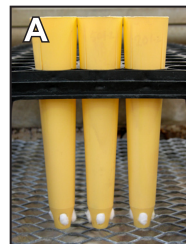
- A sub-sample from the composited bulk soil sample is thoroughly mixed.
- Approximately 200 cubic cm of soil is placed in each of 7 cone-tubes (A) which have a light cotton ball, paper towel, or small rock placed in the bottom to prevent soil loss through the drainage holes.
- Each tube is planted with one snap bean seed such as cv. 'Hystyle' or others. The seeds are treated with a combination of fungicides to prevent seed decay and seedling diseases (B). The helium (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 or in a screenhouse and watered regularly for 4 weeks (C).
- The plants are removed from their containers and the roots washed under running water and rated for root health on a scale of 1 to 9. For example:

  1 = white and coarse textured hypocotyl and roots; healthy (D);

  3 = light discoloration and lesions covering up tp a maximum of 10% of hypocotyl and root tissues (E);

  5 = approximately 25% of hypocotyl and root tissue have lesions, but the tissues remain firm. There is little decay or damage to the root system (F);

  7 to 9 = 50 to ≥ 75% of hypocotyl and roots severely symptomatic and at advanced stages of decay (G).



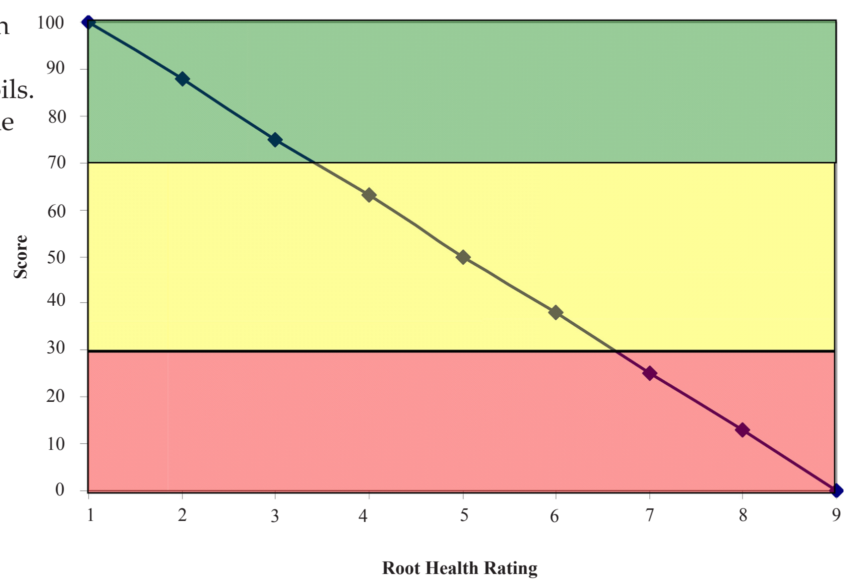
How root health relates to soil function:

Healthy roots are essential for vigorous plant growth and high yield by being efficient in mining the soil for nutrients and water, especially during stress-full conditions such as drought. Good soil tilth, and low populations and activities of root pathogens and other pests are critical for the development of healthy roots. Healthy roots also contribute to the active fraction of soil organic matter, promote rhizosphere microbial communities, contribute to increased aggregation, and reduced bulk density and soil compaction.

Poor root growth as a result of poor soil structure.

Scoring function:

To the right is the scoring function graph for root health assessment which is the same for sand, silt and clay textured soils. The red, yellow and green shading reflects the color coding used for the ratings on the soil health report (see page 40).



Chemical analysis

The chemical analysis as part of the Cornell Soil Health Test, is a traditional soil fertility test analysis package that measures levels of pH and plant macro- and micronutrients. Measured levels are interpreted in the framework of sufficiency and excess but are not crop specific. The analysis results for pH, extractable phosphorus and potassium have been integrated into the Cornell Soil Health Test Report (see pg 38-39). The secondary nutrients and micronutrient analyses are combined into one rating for the soil health report. The complete Cornell Nutrient Analysis report from CNAL, including crop-specific recommendations, is also provided with the Soil Health Test Report.

Basic Protocols:

Plant Available Nutrients:

Extractable phosphorus
Extractable potassium
Magnesium
Iron
Manganese
Zinc

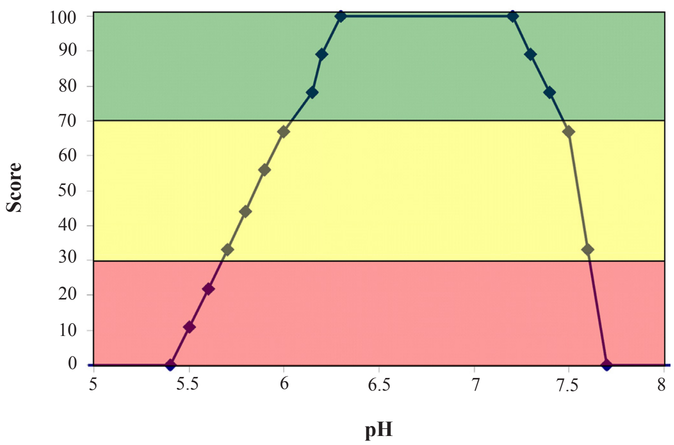
The available nutrients are extracted with Morgan's solution, a sodium acetate/acetic acid solution, well buffered at pH 4.8. Activated carbon is added to the extraction to aid in the removal of organic matter and to help decolorize the extraction solution. After shaking, the extraction slurry is filtered and analyzed for K, Ca, Mg, Fe, Al, Mn, and Zn on the ICP (Jyobin Yvon). The plant available PO_4-P is measured using an Alpkem Automated rapid flow analyzer.

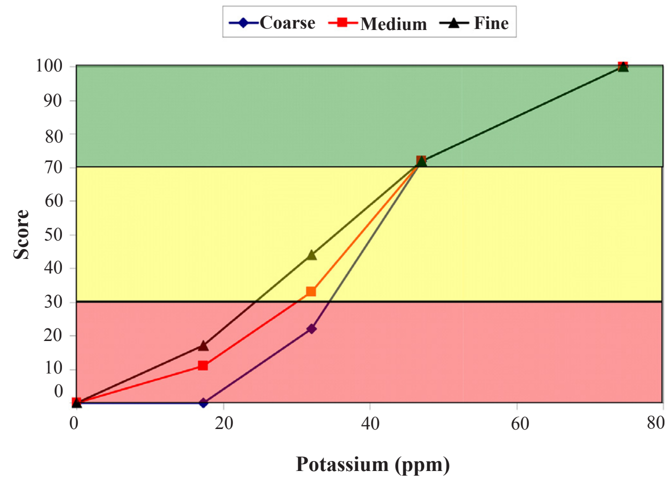
pH

The pH of a suspension of one part water to one part soil is determined either manually, using a standard pH meter and electrodes, or automatically, using a Fisher CAT™ titrimeter.

Scoring functions:

Shown are the scoring function graphs for pH, extractable phosphorus and potassium on sand, silt and clay textured soils. The red, yellow and green shading reflects the color coding used for the ratings on the soil health report (see page 40).





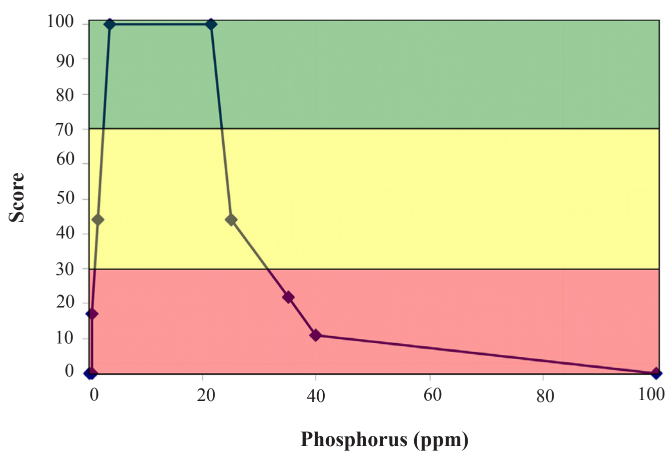


Table 3. *The optimal ranges for the secondary nutrients and micronutrients.*

NUTRIENT	PPM
Magnesium	> 33
Iron	< 25
Manganese	< 50
Zinc	> 0.25

If all nutrients are adequate then a score of 100 (good) is given on the report. If one nutrient is deficient or excessive a score of 56 (moderate) is given. If two or more nutrients are deficient or excessive a score of 11 (poor) is given.

Soil Health Report

The raw data from the individual indicators and background information about sample location and management history are synthesized into an auto-generated and grower-friendly report. The standard soil health test report presents soil health information for a field in a way that enables the identification of areas where soil management efforts may be targeted. From our research, we found that the textural differences in the surface soil have significant impact on the interpretation of soil health measurements. Therefore, a soil health test report template was developed based on the three major textural categories of the soil (sand, silt and clay).

The soil health test report is presented on a single page and consists of different sections laid out in a visually enhanced format to present information to the growers and agricultural service providers. The sections of the report include:

1. **Background information:** The information collected during sampling is presented in this section. This includes the farm name and contact information, the sample number, the date of sampling, the local extension educator name, current crop and tillage and their history over the past 2 years, drainage and slope conditions, soil type and soil texture.

2. **Indicator list:** This section gives a list of indicators that were measured for soil health assessment. They are color coded to separate the physical, biological and chemical indicators.

3. **Indicator values:** This presents the values of the indicators that were measured either in the laboratory or field.

4. **Ratings:** This section presents the scores and color coded ratings of the soil quality indicators. The indicators are scored on a scale of 1-100 based on scoring functions developed for individual indicators. In addition, the indicators are rated with color codes depending on their scores. Generally, a score of less than 30 is regarded as low and receives a red color code. A score from 30 to 70 is considered medium and is color coded yellow. A score value higher than 70 is regarded as high and color coded green.

5. **Constraints:** If the rating of a particular indicator is poor/ low (red color code), the respective soil health constraints will be highlighted in this section. This is a very useful tool for identifying areas to target their management efforts. Suggested management practices to address the identified constraints can be found on pages 52-53.

6. **Overall quality score:** An overall quality score is computed from the individual indicator scores. This score is further rated as follows: less than 40% is regarded as very low, 40-55% is low, 55-70% is medium, 70-85% is high and greater than 85% is regarded as very high. The highest possible quality score is 100 and the least score is 0, thus it is a relative overall soil health status indicator.

CORNELL SOIL HEALTH TEST REPORT (COMPREHENSIVE)

(1)

Name of Farmer: GROWER A	**Sample ID:**
Location:	**Agent:**
Field/Treatment: VEGETABLES	**Agent's Email:**
Tillage: PLOW TILL	**Given Soil Texture:** SILTY
Crops Grown: PUMPKIN/PUMPKIN/PUMPKIN	**Date Sampled:** 5/18/2007

	Indicators (2)	Value (3)	Rating (4)	Constraint (5)
PHYSICAL	Aggregate Stability (%)	18	18	aeration, infiltration, rooting
PHYSICAL	Available Water Capacity (m/m)	0.18	64	
PHYSICAL	Surface Hardness (psi)	348	2	rooting, water transmission
PHYSICAL	Subsurface Hardness (psi)	472	3	Subsurface Pan/Deep Compaction
BIOLOGICAL	Organic Matter (%)	1.7	9	energy storage, C sequestration, water retention
BIOLOGICAL	Active Carbon (ppm) [Permanganate Oxidizable]	312	5	Soil Biological Activity
BIOLOGICAL	Potentially Mineralizable Nitrogen (µgN/ gdwsoil/week)	2.0	0	N Supply Capacity
BIOLOGICAL	Root Health Rating (1-9)	7.0	25	Soil-borne Pest Pressure
CHEMICAL	*pH	7.3	89	
CHEMICAL	*Extractable Phosphorus (ppm) [Value <3.5 or >21.5 are downscored]	17.0	100	
CHEMICAL	*Extractable Potassium (ppm)	73	100	
CHEMICAL	*Minor Elements		100	
(6)	OVERALL QUALITY SCORE (OUT OF 100):		43.0	Low

Measured Soil Textural Class:==> silt loam

SAND (%): 37.0 *SILT (%): 55.0* *CLAY (%): 8.0*

Location (GPS): Latitude=> Longitude=>

* See Cornell Nutrient Analysis Laboratory report for recommendations

CORNELL SOIL HEALTH TEST REPORT (COMPREHENSIVE)

Name of Farmer: GATES FARM RESEARCH TRIAL	**Sample ID:**
Location:	**Agent:**
Field/Treatment:	**Agent's Email:**
Tillage: PLOW TILL	**Given Soil Texture: SILTY**
Crops Grown: SWEET CORN/BEANS/CORN GRAIN	**Date Sampled: 06-May-08**

	Indicators	Value	Rating	Constraint
PHYSICAL	Aggregate Stability (%)	17	18	aeration, infiltration, rooting
PHYSICAL	Available Water Capacity (m/m)	0.21	85	
PHYSICAL	Surface Hardness (psi)	48	93	
PHYSICAL	Subsurface Hardness (psi)	214	79	
BIOLOGICAL	Organic Matter (%)	2.6	25	energy storage, C sequestration, water retention
BIOLOGICAL	Active Carbon (ppm) [Permanganate Oxidizable]	615	50	
BIOLOGICAL	Potentially Mineralizable Nitrogen (µgN/ gdwsoil/week)	7.8	9	N Supply Capacity
BIOLOGICAL	Root Health Rating (1-9)	6.6	38	
CHEMICAL	*pH	7.0	100	
CHEMICAL	*Extractable Phosphorus (ppm) [Value <3.5 or >21.5 are downscored]	10.0	100	
CHEMICAL	*Extractable Potassium (ppm)	58	72	
CHEMICAL	*Minor Elements		100	
	OVERALL QUALITY SCORE (OUT OF 100):		64.1	**Medium**

Measured Soil Textural Class:==> silt loam

SAND (%): 41.4 *SILT (%): 50.6* *CLAY (%): 8.0*

Location (GPS): Latitude=> *Longitude=>*

* See Cornell Nutrient Analysis Laboratory report for recommendations

CORNELL SOIL HEALTH TEST REPORT (COMPREHENSIVE)

Name of Farmer: GROWER B	**Sample ID:** _ _ _
Location:	**Agent:**
Field/Treatment: VEGETABLES	**Agent's Email:**
Tillage: NO TILL	**Given Soil Texture: LOAMY**
Crops Grown: SQUASH/HAIRY VETCH	**Date Sampled: 4/3/2007**

	Indicators	Value	Rating	Constraint
PHYSICAL	Aggregate Stability (%)	65	94	
	Available Water Capacity (m/m)	0.16	52	
	Surface Hardness (psi)	155	58	
	Subsurface Hardness (psi)	225	76	
BIOLOGICAL	Organic Matter (%)	4.6	80	
	Active Carbon (ppm) [Permanganate Oxidizable]	546	36	
	Potentially Mineralizable Nitrogen (µgN/ gdwsoil/week)	12.1	82	
	Root Health Rating (1-9)	2.0	88	
CHEMICAL	*pH	6.8	100	
	*Extractable Phosphorus (ppm) [Value <3.5 or >21.5 are downscored]	23.7	100	
	*Extractable Potassium (ppm)	102	100	
	*Minor Elements		100	
	OVERALL QUALITY SCORE (OUT OF 100):		80.6	**High**

Measured Soil Textural Class:==> silt loam

SAND (%): 21.0 *SILT (%): 73.0* *CLAY (%): 6.0*

Location (GPS): Latitude=> Longitude=>

* See Cornell Nutrient Analysis Laboratory report for recommendations

Soil Management

Soil chemical imbalances can be addressed through application of chemical amendments such as lime and fertilizer. Although there are only four main strategies for improving soil biological and physical health (tillage, cover crops, organic amendments and crop rotation), the options within each strategy are numerous and the combinations are endless. Not all soil management practices are practical or adaptable to all farm situations therefore trying out practices on a smaller scale and modifying them to suit the particular farm operation is recommended. On the following pages are descriptions of some of the management options. Information on additional resources can be found on page 58.

Cover Crops

Cover crops provide a canopy for seasonal soil protection and improvement between the production of the main crops. Cover crops usually are grown for less than one year. When plowed under and incorporated into the soil for improved fertility, cover crops are also referred to as green manure. Cover crops have the potential for recycling nutrients which otherwise would be lost through leaching during off-season periods. Cover crops with shallow fibrous root systems, such as many grasses, rapidly build soil aggregation in the surface layer. Cover crops with deep roots can help break-up compacted layers, and bring nutrients from deeper soil layers to make them available for the following cash crop. Leguminous cover crops can also fix atmospheric nitrogen for the benefit of the crop that follows. Other benefits from cover crops include protection of the soil from water and wind erosion, improved soil tilth and suppressing soil-borne pathogens. Dead cover crop material may be left on the soil surface, and are then referred to as mulch, which can reduce evaporation of soil moisture, increase infiltration of rainfall, increase soil organic matter and aid in the control of annual weeds. Leguminous cover crops suitable for the Northeastern US include clovers, hairy vetch, field peas, alfalfa, and soybean while popular non-leguminous cover crops include rye, oats, wheat, oilseed radish, sudangrass, and buckwheat.

When selecting cover crops it is important to consider:

- What are your goals for using a cover crop(s)? Is it to increase organic matter, break-up surface or subsurface compaction, weed and disease suppression, nutrient management, or prevent erosion?
- Where can cover crops fit into the rotation? Summer, winter, or season-long?
- When and how should the cover crop be killed or incorporated? Winter-kill vs. chemical applications vs. rolled and chopped?
- What cover crops are suitable for the climate?
- What cover crops fit with the current production practices including any equipment constraints?
- Susceptibility or host status of the cover crop to major pathogen(s) of concern

Winter cover crops:

Winter cover crops are planted in late summer into fall, typically following harvest of a cash crop. Both hardy grasses and leguminous crops can be planted. Some crops like buckwheat and oats will be damaged by frost or winter-killed while others will require tillage, rolling or chemical management in spring prior to planting. Although in Northern climates the choices are limited by the short growing season, planting a winter cover crop can provide protection from soil erosion, suppression of weeds and root pathogens and can increase soil organic matter and aggregation. For late harvested crops, winter cover crops might be better interseeded. Winter cover crops commonly planted in the Northeast include winter rye, hairy vetch, oats, wheat, red clover and various mixtures of the above.

Summer fallow cover crops:

Summer fallow cover crops are more common in vegetable than field crop rotations. A fast growing cover crop could be planted between summer vegetable crops. However, this option is severely limited in the north by the short growing season and severe cold. For example, buckwheat can be grown after early spring lettuce and prior to planting a crop of fall broccoli. In shorter season climates, a more successful option may be to interseed a cover crop into the main crop once the latter becomes established, but it is important to avoid competition by the cover crop for water and nutrients.

Season-long cover crops:

Full season-long cover crops, serve as rotational crops and are an excellent way of accumulating a lot of plant biomass. However, often this means taking the field out of cash crop production for a season. This will especially benefit fields with low fertility and farms with limited access to manures and other sources of organic amendments. Relay cover cropping is also another option. This is when a crop such as red clover is spring seeded into wheat, which then continues to grow after the wheat crop is harvested. It is important to keep in mind that some cover crops such as buckwheat, ryegrass, crown vetch and hairy vetch have the potential to become a weed problem if they set seed.

Four common cover crops in the Northeast:

Winter rye (*Secale cereale*)**:**

is very winter hardy and can be seeded late into the fall after many late harvest crops. It can serve as a nutrient catch crop, reduce erosion, increase organic matter, suppress weeds, reduce soil-borne pathogen populations and it can be sown with legumes if desired. Rye will grow aggressively in spring and therefore needs to be killed before it matures to reduce potential weed problems, depleted soil moisture and nitrogen immobilization. Rye can be incorporated as a green manure, mowed or killed with a herbicide in reduced tillage systems, preferably several weeks prior to planting the main crop.

Oat (*Avena sativa*)**:**

is not winter hardy in the Northeast. However in early spring the oat biomass can serve as mulch for weed suppression. It can be mixed with a legume and also be used to prevent erosion, scavenge excess nutrients, add biomass and act as a nurse crop.

Photo by Lynn Betts USDA-NRCS

Sudangrass and sorghum-sudangrass hybrids (*Sorghum bicolor* x *S. bicolor* var. *sudanese*)**:**

are fast growing during warm weather, although they are not winter hardy in the Northeast. However, in early spring the killed biomass can serve as mulch for weed suppression. It can be used as a soil builder, subsoil loosener and weed suppressor when sown at high rates. When used for their allelopathic (biofumigant) properties, incorporating young tissue (1 to 3 months old) when the soil is warm (microbially active) is recommended, especially for control of plant-parasitic nematodes.

Hairy vetch (*Vicia villosa*)**:**

is an excellent spring biomass producer and nitrogen contributor therefore making it good for weed suppression and as a nitrogen source. It improves topsoil tilth by reducing surface crusting, ponding and runoff. It needs to be planted in early September for good establishment and overwintering.

Soil Management

Organic Amendments

Organic matter is critical for maintaining soil structure, and increasing water infiltration as well as water holding capacity. It can also increase cation exchange capacity (CEC), nutrient retention, and microbial diversity and activities. Organic matter can be added through incorporation of cover crops as green manures as well as additions of composts, animal manures, and crop residues. The addition of organic amendments is particularly important in vegetable production where minimal crop residue is returned to the soil and more intensive tillage is required that promotes the rapid depletion of soil organic matter. The impact of various organic amendments on soil physical, chemical and biological properties can be different and thus is important to consider when making soil management decisions.

Animal manure:

The application of manure can have many soil and crop health benefits such as increasing nutrient levels (nitrogen, phosphorus, and potassium in particular) that benefit not only the crop but also the soil microbial community. However not all manures are created equal and will vary depending on the animal, feed, bedding, and manure-storage practices employed. Manure containing a lot of bedding is typically applied as a solid while manure with minimal bedding is applied as a liquid. Manure solids and liquids may be separated, or can also be composted prior to application to help stabilize the nutrients. Due to the variability in nutrient content, manure analysis may be beneficial and take the guesswork out of estimating the nutrient content and characteristics of the manure.

Manuring of the soil can also influence soil organic matter and fresh uncomposted manure is very effective at increasing soil aggregation. However, the impact is dependent on the amount of solids delivered. It also can increase the CEC, soil pH, and total pore space. Careful attention should be paid to the timing of application and optimizing application to meet the needs of the crop or cropping sequence. Excessive or untimely application can cause plant or soil damage and pose an environmental danger to water resources.

Compost:

Unlike manure, compost is very stable and not a readily available source of nutrients. The composting process uses heat and microbial activity to quickly decompose simple compounds like sugars and proteins, leaving behind more stable complex compounds such as lignins and humic acids.

The stable products of composting are an important source of organic matter. The addition of compost increases available water capacity by improving water retention and pore space on which water and nutrients can bind. Compost is less effective at building soil aggregation than fresh manure, because the readily-degradable organic compounds have already been decomposed. Composts differ in their efficiency to suppress various crop pests, although they can sometimes be quite effective.

Green manure crops:

Green manure crops are those grown for the purpose of improving the soil fertility with microbial diversity and organic matter content in general as opposed to cover crops which are grown more for the purpose of erosion protection and cycling of nutrients. When incorporated, green manures add a lot of fresh, readily degradable material to the soil, which fuels the soil's microbial community. The increased production of microbial exudates helps hold the individual soil particles together as aggregates. A soil with better aggregation (aggregate stability) is more resilient in heavy rain storms and is capable of greater water infiltration.

In reduced tillage systems, one way to get the added benefits of green manure crops is to only incorporate them in the planting row and use the killed crop between the rows as a mulch.

Crop residue:

Crop residue is another important source of organic matter. As it decomposes, the organic matter is going back into the soil and improving soil tilth. Crop residue left on the surface will protect against erosion and improve surface aggregation, thereby reducing crusting and surface compaction. However, diseased crop debris can harbor inoculum that can become a problem during the next season if a susceptible crop is planted. Crop rotation with non-host crops belonging to different plant families will reduce pathogen inoculum. Removal and composting of crop debris may be an option in some situations. Incorporation or plowing down of crop debris to encourage the decomposition process may be an option depending on the tillage system and crop rotation sequence being employed.

Photo by Jeff Vanuga USDA-NRCS

OTHER SOURCES OF ORGANIC AMENDMENTS:

- Municipal wastes (yard debris, biosolids)
- Organic wastes from food processing industries
- Organic wastes from paper mills, timber industry and brewing facilities
- Post-consumer food wastes (home, restaurant, and institutional)

Soil Management

Tillage

As new technologies have been developed, the reliance on tillage to kill weeds, incorporate crop debris, and prepare seedbeds has been diminished. Extensive tillage reduces soil aggregation, resulting in crusting and soil compaction as well as often stimulating the microbial community that burns off organic matter quickly. There is consensus that reducing tillage intensity will improve soil health and over time reduce production costs.

There are many different strategies for reducing tillage intensity aside from going to no-till (Table 4). Strip tillage uses a shank set at the depth of the compacted layer (if present) to rip the compacted layer and then a series of coulters to form a narrow, shallow ridge into which the seeds are planted. Zone tillage is similar to strip tillage without the rip shank (Figure 17). Instead of preparing the entire field as a seedbed, only a narrow band is loosened, enabling crop or cover crop residue to remain on the soil surface as a mulch. Implementing the use of permanent drive rows often better facilitates reduced tillage systems.

Reduced tillage can also be thought of in the long-term and modified based on the cropping sequence. Different tillage practices can be rotated depending on the soil management goals and concerns. For some crops such as potato, more intensive tillage and soil disturbance may be required in order to establish and harvest the crop, but the subsequent sweet corn (or other) crop(s) could be strip- or no-tilled into a killed winter rye cover crop.

Frost tillage can be a means of alleviating soil compaction in the winter. It is done when the soil is frozen between 1 and 3 inches deep; conditions that typically occur on average 4 to 6 days per winter in New York State and other similar production regions. The soil below the frost layer is non-plastic or dry, ideal conditions for tillage. Frost-tilled soil leaves a rough surface but subsequent freeze-thaw action loosens the soil and allows the clods to fall apart in the spring.

However, the type and timing of tillage are often site specific and dependent on the cropping system and equipment availability. Reducing both tillage frequency and intensity will reduce the burning of organic matter and lead to improved soil tilth and microbial activity, resulting in soils that are less susceptible to compaction and more resilient.

Figure 17. *Examples of different tillage systems. Strip tillage with a vertical shank followed by two wavy coulters (A). Two-row strip tillage unit with an opening coulter, followed by a vertical shank, two closing coulters to form a small ridge then a rolling basket to firm the ridge (B). No-till planted sweet corn planted into a killed sweet clover fall cover crop (C). Soil following frost tillage. The large clods will mellow and break down as a result of subsequent freeze-thaw action (D).*

Table 4. Tillage System Benefits and Limitations

Tillage System	Benefits	Limitations
	FULL-FIELD TILLAGE	
Moldboard plow	Easy incorporation of fertilizers and amendments.	Leaves soil bare.
	Buries surface weed seeds and also diseased debris/pathogen surviving structures.	Destroys natural aggregation and enhances organic matter loss.
	Dries soil out fast.	Surface crusting and accelerated erosion common.
	Temporarily reduces compaction.	Causes plow pans.
		High energy requirements.
Chisel plow	Same as above, but with more surface residues.	Same as above, but less aggressive destruction of soil structure, less erosion, less crusting, no plow pans, and less energy use.
Disc harrow	Same as above.	Same as above, but additional develop-ment of disk pans.
	RESTRICTED TILLAGE	
No-till	Little soil disturbance and low organic matter losses.	Hard to incorporate fertilizers and amendments.
	Few trips over field.	Wet soils slow to dry and warm up in spring.
	Low energy use.	Can't alleviate compaction without using tillage.
	Most surface residue cover and erosion protection.	
Zone-till/ Strip-till	Same as above.	Same as above, but fewer problems with compaction.
Ridge-till	Easy incorporation of fertilizers and amendments.	Hard to use together with sod-type or narrow-row crop in rotation.
	Some weed control as ridges are built.	Equipment needs to be adjusted to travel without disturbing ridges.
	Seed zone on ridge dries and warms more quickly.	

Source: Building Soils for Better Crops, 2nd edition, Sustainable Agriculture Network - USDA

Soil Management

Crop Rotation

Initially, crop rotation was practiced as a way to avoid depleting the soil of various nutrients. Today, crop rotation is also an important component of soil and pest management in many agricultural production systems. Crop rotations can be as simple as rotating between two crops and planting sequences in alternate years or they can be more complex and involve numerous crops over several years. Proper crop rotation can reduce insects and disease-causing pathogens as well as weed pressure by breaking their lifecycles through removal of a suitable host. Crop rotation can also aid in nutrient management through incorporation of crop residues and improve soil resiliency after a root crop such a carrot or potato. Many growers find yield increases when crops in different families are grown in rotation versus in monoculture and this is often referred to as the “rotation effect”.

Wheat is a good rotation crop in an intensive vegetable production rotation especially if Northern root-knot nematode is a problem. All grain crops are non-hosts for Meloidogyne hapla.

One basic rule of crop rotation is that a crop should not follow itself. Continuous cropping will result in the build-up of disease causing pathogens, nematodes, insects and weeds that can lead to yield reductions and the need for increased inputs such as herbicides, insecticides and other pesticides. The development of a cropping sequence should take into consideration the use of cover crops and season-long soil building crops for improving soil tilth and increasing soil organic matter. Rotating with a diversity of root structures from taproots to fibrous-rooted crops will also improve the soil’s physical, chemical and biological qualities. A list of general principles for crop rotation can be found on page 51. However, developing successful crop rotation sequences is farm specific and dependent on the unique combination of location and climatic factors, as well as economic and resource limitations.

General Principles for Crop Rotation

1. Follow a legume forage crop, such as clover or alfalfa, with a high nitrogen-demanding crop, such as corn, to take advantage of the nitrogen supply.

2. Grow less nitrogen-demanding crops, such as oats, barley, or wheat, in the second or third year after a legume sod.

3. Grow the same annual crop for only one year, if possible, to decrease the likelihood of insects, diseases, and nematodes becoming a problem.

4. Don't follow one crop with another closely related species, since insect, disease, and nematode problems are frequently shared by members of closely related crops.

5. Use crop sequences that promote healthier crops. Some crops seem to do well following a particular crop (for example, cabbage family crops following onions, or potatoes following corn). Other crop sequences may have adverse effects, as when potatoes have more scab following peas or oats.

6. Use crop sequences that aid in controlling weeds. Small grains compete strongly against weeds and may inhibit germination of weed seeds, row crops permit mid-season cultivation, and sod crops that are mowed regularly or intensively grazed help control annual weeds.

7. Use longer periods of perennial crops, such as a forage legume, on sloping land and on highly erosive soils. Using sound conservation practices, such as no-till planting, extensive cover cropping, or strip-cropping (a practice that combines the benefits of rotations and erosion control), may lessen the need to follow this guideline.

8. Try to grow a deep-rooted crop, such as alfalfa, safflower, or sunflower, as part of the rotation. These crops scavenge the subsoil for nutrients and water, and channels left from decayed roots can promote water infiltration.

9. Grow some crops that will leave a significant amount of residue, like sorghum or corn harvested for grain, to help maintain organic matter levels.

10. When growing a wide mix of crops - as is done on many direct marketing vegetable farms - try grouping into blocks according to plant family, timing of crops (all early season crops together, for example), type of crop (root vs. fruit vs. leaf), or crops with similar cultural practices (irrigated, using plastic mulch).

Source: Building Soils for Better Crops, 2nd edition, Sustainable Agriculture Network - USDA

Managing soil constraints

Interpreting the Soil Health Test Report:

The Cornell Soil Health Test (CSHT) report focuses on identifying opportunities for improved soil management and the color coded results help interpret measured indicators. Those that are considered as constraints are highlighted in red color and the associated soil processes affected by the limiting indicators are listed. An overall soil quality score at the bottom of the report page integrates the suite of indicators. It is important to recognize that the information presented in the report is not intended as a measure of a grower's management skills, but as a tool to target management practices towards addressing specific soil constraints. Complex soil interactions with management typically prohibit specific judgments on the results except in the case of controlled studies where randomization and high sampling intensities allow for hypothesis testing of established practices.

As an entry point in our understanding of soil health, any measured soil constraint can be taken as a management target. When multiple constraints are considered together, a management plan can be developed to restore functionality to the soil. Effective users of the soil health information will realize that implementation of a single practice can affect more than one indicator and benefit multiple soil functional processes.

Table 5. *Suggested management strategies for addressing soil health constraints*

	Suggested Management Practices	
	Short term or intermittent	**Long term**
Physical Concerns		
Low aggregate stability	Fresh organic materials (shallow-rooted cover/rotation crops, manure, green clippings)	Reduced tillage, surface mulch, rotation with sod crops
Low available water capacity	Stable organic materials (compost, crop residues high in lignin, biochar)	Reduced tillage, rotation with sod crops
High surface density	Limited mechanical soil loosening (e.g. strip tillage, aerators); shallow-rooted cover crops, bio-drilling, fresh organic matter	shallow-rooted cover/rotation crops; avoid traffic on wet soils; controlled traffic
High subsurface density	Targeted deep tillage (zone building, etc.); deep rooted cover crops	Avoid plows/disks that create pans; reduced equipment loads/traffic on wet soils
Biological Concerns		
Low organic matter content	Stable organic matter (compost, crop residues high in lignin, biochar); cover and rotation crops	Reduced tillage, rotation with sod crops
Low active carbon	Fresh organic matter (shallow-rooted cover/rotation crops, manure, green clippings)	Reduced tillage, rotation
Low mineralizable N (Low PMN)	N-rich organic matter (leguminous cover crops, manure, green clippings)	Cover crops, manure, rotations with forage legume sod crop, reduced tillage
High root rot rating	Disease-suppressive cover crops, disease breaking rotations	Disease-suppressive cover crops, disease breaking rotations, IPM practices
Chemical concerns	See also soil fertility recommendations	
Unfavorable pH	Liming materials or acidifier (such as sulfur)	Repeated applications based on soil tests
Low P, K and Minor elements	Fertilizer, manure, compost, P-mining cover crops, mycorrhizae promotion	Application of P, K materials based on soil tests; increased application of sources of organic matter; reduced tillage
High salinity	Subsurface drainage and leaching	Reduced irrigation rates, low-salinity water source, water table management
High sodium content	Gypsum, subsurface drainage, and leaching	Reduced irrigation rates, water table management

Table 5 shows recommended management approaches targeted at addressing specific measured soil constraints for both the short- and long-term. Combining these with growers' needs and abilities will allow for an active evaluation-scenario and the development of management solutions. In addition, 'success stories' of specific management practices that effectively address targeted soil constraints can enhance the knowledge base of soil management consequences.

There are no specific 'prescriptions' for what management regimen should be pursued to address the highlighted soil health constraints, yet we can recommend a number of effective practices to consider when addressing specific constraints (Table 5).

The Soil Health Management Toolbox (Figure 17) lists the main categories of action for soil management.

THE SOIL HEALTH MANAGEMENT TOOLBOX

- Reducing or modifying tillage
- Crop rotation
- Growing cover crops
- Adding organic amendments
- Adding chemical amendments

Figure 17. *Strategies for soil health management.*

These management approaches can be used singularly or in combination as the same constraint might be overcome through a variety of management approaches. The ones that a grower chooses may depend on farm-specific conditions such as soil type, cropping, equipment, labor availability, etc. Each grower is generally faced with a unique situation in the choice of management options to address soil health constraints and each system affords its own set of opportunities or limitations to soil management.

CORNELL SOIL HEALTH TEST REPORT (COMPREHENSIVE)				
Name of Farmer: Willsboro Farm				Sample ID: E128
Location: Sayward Rd. Willsboro NY 12296				Agent: Bob Schindelbeck, Cornell University
Field/Treatment: TILL 3A				Agent's Email: 0
Tillage: 7-9 INCHES				Given Soil Texture: CLAY
Crops Grown: COG/COG/COG				Date Sampled: 4/25/2007
	Indicators	Value	Rating	Constraint
PHYSICAL	Aggregate Stability (%)	12	3	aeration, infiltration, rooting
PHYSICAL	Available Water Capacity (m/m)	0.17	43	
PHYSICAL	Surface Hardness (psi)	57	91	
PHYSICAL	Subsurface Hardness (psi)	200	82	
BIOLOGICAL	Organic Matter (%)	3.3	25	energy storage, C sequestration, water retention
BIOLOGICAL	Active Carbon (ppm) [Permanganate Oxidizable]	559	20	Soil Biological Activity
BIOLOGICAL	Potentially Mineralizable Nitrogen (µgN/ gdwsoil/week)	4.8	0	N Supply Capacity
BIOLOGICAL	Root Health Rating (1-9)	2.5	88	
CHEMICAL	*pH	6.1	67	
CHEMICAL	*Extractable Phosphorus (ppm) [Value <3.5 or >21.5 are downscored]	2.5	44	
CHEMICAL	*Extractable Potassium (ppm)	83	100	
CHEMICAL	*Minor Elements		100	
OVERALL QUALITY SCORE (OUT OF 100):		55.3		Medium
Measured Soil Textural Class:==> silty clay loam SAND (%): 16.0 SILT (%): 47.0 CLAY (%): 37.0				
Location (GPS): Latitude=> 44.366667 Longitude=> -73.433333				

* See Cornell Nutrient Analysis Laboratory report for recommendations

Figure 18. *Example of CSHT report to be interpreted.*

To enable a more direct interpretation of the CSHT report, a four step procedure was developed:

1. Identify and prioritize soil health constraints
2. List soil health management options that can address the constraints
3. Compile information on site history and farm background to help decide on management strategies
4. Select appropriate management strategies

An example of this process is presented in Figures 18 to 22.

Managing soil constraints

Step 1: Identify and prioritize constraints

Step 1. Identify and prioritize constraints

Flagged as constraints in the Soil Health Report

Low aggregate stability (poor soil structure) (High priority)

Low organic matter (carbon storage) (High priority)

Low Active C (hungry soil food web) (High priority)

Low PMN (low biological activity) (High priority)

CORNELL SOIL HEALTH TEST REPORT (COMPREHENSIVE)

Name of Farmer: Willsboro Farm	Sample ID: E128
Location: Sayward Rd. Willsboro NY 12296	Agent: Bob Schindelbeck, Cornell University
Field/Treatment: TILL 3A	Agent's Email: 0
Tillage: 7-9 INCHES	Given Soil Texture: CLAY
Crops Grown: COG/COG/COG	Date Sampled: 4/25/2007

	Indicators	Value	Rating	Constraint
PHYSICAL	Aggregate Stability (%)	12	3	aeration, infiltration, rooting
	Available Water Capacity (m/m)	0.17	43	
	Surface Hardness (psi)	57	91	
	Subsurface Hardness (psi)	200	82	
BIOLOGICAL	Organic Matter (%)	3.3	25	energy storage, C sequestration, water retention
	Active Carbon (ppm) [Permanganate Oxidizable]	559	20	Soil Biological Activity
	Potentially Mineralizable Nitrogen (µgN/ gdwsoil/week)	4.8	0	N Supply Capacity
	Root Health Rating (1-9)	2.5	88	
CHEMICAL	*pH	6.1	67	
	*Extractable Phosphorus (ppm) [Value <3.5 or >21.5 are downscored]	2.5	44	
	*Extractable Potassium (ppm)	83	100	
	*Minor Elements		100	
	OVERALL QUALITY SCORE (OUT OF 100):		55.3	Medium

Measured Soil Textural Class:==> silty clay loam

SAND (%): 16.0 SILT (%): 47.0 CLAY (%): 37.0

Location (GPS): Latitude=> 44.366667 Longitude=> -73.433333

* See Cornell Nutrient Analysis Laboratory report for recommendations

Figure 18. *Identify soil health constraints from the report sheet.*

Step 2: List management options

Step 1. Identify constraints, prioritize Flagged as constraints in the Soil Health Report	**Low aggregate stability (poor soil structure)** **Low organic matter (carbon storage)** **Low Active C (hungry soil food web)** **Low PMN (low biological activity)**
Step 2. List management options Several of these suggestions are listed in the Suggested Management Practices (Table 5)	**Add/ grow fresh organic matter** **Add stable organics (composts, biochar)** **Reduce tillage intensity** **Rotate with shorter season crop** **Find window for shallow-rooted cover crop**

Figure 19. *List potential management options that can address soil health constraints based on Table 4.*

Step 3: Determine site history/farm background	
Step 1. Identify constraints, prioritize Flagged as constraints in the Soil Health Report	Low aggregate stability (poor soil structure) Low available water (droughty, HARD) Low Active C (hungry soil food web) Low PMN (low biological activity)
Step 2. List management options Several of these suggestions are listed in the Suggested Management Practices (Table 5)	Add/ grow fresh organic matter Add stable organics (composts, bio-char) Reduce tillage intensity Rotate with shorter season crop Find window for shallow-rooted cover crop
Step 3. Determine site history/ farm background Note here any situational opportunities or limitations	Far from dairy farm Short growing season Soil "addicted to tillage" Diverse inventory of field equipment Grower willing to "try anything"

Figure 20. Compile farm background information relevant to addressing the constraints.

Step 4: Make a list of feasible management strategy	
Step 1. Identify constraints, prioritize Flagged as constraints in the Soil Health Report	Low aggregate stability (poor soil structure) Low available water (droughty, HARD) Low Active C (hungry soil food web) Low PMN (low biological activity)
Step 2. List management options Several of these suggestions are listed in the Suggested Management Practices (Table 5)	Add/ grow fresh organic matter Add stable organics (composts, bio-char) Reduce tillage intensity Rotate with shorter season crop Find window for shallow-rooted cover crop
Step 3. Determine site history/ farm background Note here any situational opportunities or limitations	Far from dairy farm Short growing season Soil "addicted to tillage" Diverse inventory of field equipment Grower willing to "try anything"
Step 4. Management Strategy	Drill barley/ timothy/ clover mix in spring Harvest barley Mow timothy/ clover as green manure Fall mow, rent ripper for strip till for corn (next year) Learn about strip tillage (Build soil for transition to strip till)

Figure 21. Decide on management solutions to address the constraints.

Managing soil constraints

Some additional considerations may assist in interpreting a Cornell Soil Health Test Report and help decide on management solutions.

i. The report is a management guide, not a prescription: The report shows the aspects of the soil needing attention in order to enhance productivity and sustainability. Users should see this report as a tool in planning the best soil management strategies for their fields. The information provided by the test on the physical and biological aspects of the soil together with the nutrient analysis results gives a better picture on the state of soil health.

ii. Different management approaches can be used to mitigate the same problem: The choice and details of management efforts to be used in overcoming soil health constraints are dependent on resources available to the farmer. For example, growers seeking to increase soil organic matter on their fields might approach this by using reduced tillage practices, adding organic matter or a combination of both methods, the latter generally yielding the best results.

iii. In addressing some soil constraints, management practices can affect multiple indicators:
Many of the soil health indicator measurements can benefit from a single management practice. For example, adding manure to the soil improves soil aggregation, increases organic matter and active carbon contents and improves soil nutrient status. However, the magnitudes of these effects are dependent on the specific management practices and soil types.

iv. Certain indicators are related, but over-interpretation of these relationships may be misleading: While the soil health indicators are often inter-related, the degree of interrelationship varies with soil type and previous management history. For example, a general relationship exists between organic matter and active carbon contents. However, active carbon deals with relatively fresh organic carbon that is readily available for microbial decomposition. A soil may be high in organic matter but be lacking the fresh decomposable component, which leads to a relatively low active carbon content.

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

vi. Soil health changes slowly over time: Generally, management practices to address soil health constraints take variable amounts of time for desired effects to be observed and measured; some changes in the indicators can be seen in the short term while others may take a much longer period to be realized. For example, fertilizer application for nutrient deficiencies and deep tillage to address subsurface compaction can produce immediate effects within a season. But conversion to no-tillage may take up to 3-5 years before beneficial changes in soil quality and productivity become noticeable. Remember, soil health management is a long-term strategy!

A template following the four step procedure for interpreting the CSHT report is provided on the next page and can be copied for use in management planning.

Compaction and smearing

Cornell Soil Health Test Report
Field Management Sheet

Step 1. Identify constraints, prioritize
Step 2. List management options
Step 3. Determine site history/ farm background
Step 4. Management Strategy

Additional Resources

Selected Book and Journal Resources:

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

Brady, N.C., and Weil, R.R. 2002. The Nature and Properties of Soils. 13th Edition. Prentice Hall. Upper Saddle River, NJ.

Clark, A. (ed.). 2007. Managing Cover Crops Profitably. 3rd Edition. Sustainable Agriculture Network, Handbook Series #9, Beltsville, MD. (order from: www.sare.org).

Doran, J.W., Coleman, D.C., Bezdicek, D.F., and Stewart, B.A. 1994. Defining Soil Quality for a Sustainable Environment. SSSA Special Publication No. 35. Soil Science Society of America, Madison, WI.

Doran, J.W., and Jones, A.J. 1996. Methods for Assessing Soil Quality. SSSA Special Publication No. 49. Soil Science Society of America, Madison, WI.
(order from: www.soils.org).

Magdoff, F., and Weil, R.R. (eds.). 2004. Soil Organic Matter in Sustainable Agriculture. CRC Press, Taylor and Francis Group, Boca Raton, FL.

Magdoff, F., and van Es, H. 2000. Building Soils for Better Crops. 2nd Edition. Sustainable Agriculture Network, Handbook Series, #4, Beltsville, MD.
(order from: www.sare.org).

Sarrantonio, M. 1994. Northeast Cover Crop Handbook. Soil Health Series, Rodale Institute, Kutztown, PA.
(order from: http://www.rodaleinstitutestore.org/store/customer/home.php)

Uphoff, N. et al. (eds.). 2006. Biological Approaches to Sustainable Soil Systems. CRC Press, Taylor and Francis Group, Boca Raton, FL.

Wolfe, D.W. 2001. Tales From the Underground: A Natural History of Subterranean Life. Perseus Publishing Group. Cambridge, MA.

Grubinger, V. Farmers and Innovative Cover Cropping Techniques. A 70-minute educational video featuring 10 farms from 5 northeastern states (PA, NH, NY, MA, NJ). University of Vermont Extension in conjunction with NE-SARE. (ordering information available at: http://www.uvm.edu/vtvegandberry/Videos/covercropvideo.html)

Grubinger, V. Vegetable Farmers and their Sustainable Tillage Practices. A 45-minute educational video featuring 9 farms from 4 northeastern states (PA, NH, NY, NJ). University of Vermont Extension in conjunction with NE-SARE. (ordering information available at: http://www.uvm.edu/vtvegandberry/Videos/covercropvideo.html)

Selected Web Resources:

Cornell Soil Health
(http://soilhealth.cals.cornell.edu):
is a resource on soil health in New York and the Northeast. It contains a more extensive list of available web-based resources.

National Sustainable Agriculture Information Service (http://attra.ncat.org/):
contains information pertaining to sustainable agriculture and organic farming including in-depth publications on production practices, alternative crop and livestock enterprises, innovative marketing, organic certification, and highlights of local, regional, USDA and other federal sustainable ag activities.

Northeastern Sustainable Agriculture Research and Education
(http://www.uvm.edu/~nesare/):
search the project report database for the latest in sustainable research and education projects that are ongoing in the northeast including information on soil management.

Soil Science Society of America
(http://www.soils.org):
is the website for the soil science professionals.

USDA-National Resources Conservation Service (NRCS) Soils (http:// soils.usda.gov):
is a website with a wealth of information of soil taxonomy, soil surveys, soil biology, and soil function, etc. for educators, researchers and land managers.