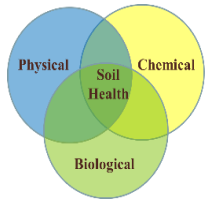
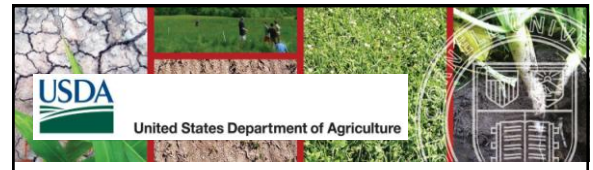
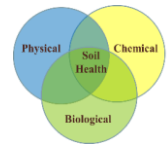
Managing for Soil Health begins with a Soil Health Assessment



Eric Boettger
Resource Conservationist
United States Department of Agriculture
Natural Resources Conservation Service



Cornell Soil Health Assessment: A Diagnostic Approach for Evaluating and Managing Soil Health



Bianca Moebius-Clune, Ph.D.
bianca.moebius-clune@wdc.usda.gov
Director, Soil Health Division
Science & Technology Deputy Area, NRCS

A Team Effort!

The Core Development Team at Cornell University:
George Abawi (Retired from Department of Plant Pathology, Geneva), Beth Gugino (now Penn State), John Idowu (now NMSU), Bianca Moebius-Clune (now NRCS), Daniel Moebius-Clune, Robert Schindelbeck, Janice Thies, Harold van Es (all in Department of Crop and Soil Sciences), David Wolfe (Horticulture), Many Growers and Extension Educators

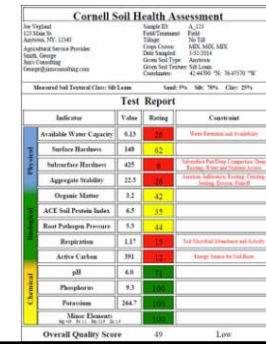
Collaborators: Dorn Cox (Greenstart NH), Brandon Smith (NH-NRCS), Heather Darby (UVM), Ray Weil (UMD), Thomas Bjorkman (Horticulture), NRCS, Conservation Districts, and a growing network of other people and organizations

Funders:

USDA · Northern New York Agricultural Development Program · Northeast Region SARE · NRCS Natural Resources Conservation Service · IPM · NY farm viability INSTITUTE · NH Dept of Ag Food & Markets · New Hampshire Charitable Foundation · Cornell University Cooperative Extension

Soil Health Assessment

- Why assess soil health?
- The Cornell Soil Health Assessment
  - The report at a glance
  - Indicators measured
  - What do they mean?
  - Managing identified constraints
- Framework for Soil Health Management Planning and Implementation



Cornell Soil Health Assessment

Test Report

	Indicator	Value	Rating	Constraint
Physical	Available Water Capacity	0.13	28	
	Surface Hardness	148	62	
	Subsurface Hardness	425	30	
	Aggregate Stability	22.5	26	
Biological	Organic Matter	3.2	42	
	ACE Soil Protein Index	6.5	35	
	Root Pathogen Pressure	5.5	44	
	Respiration	1.17	15	
	Active Carbon	391	12	
Chemical	pH	6.0	71	
	Phosphorus	9.3	100	
	Potassium	264.7	100	
	Minor Elements		100	
	Overall Quality Score		49	Low

Time for a Soil Fact

Time for a Soil Fact

TRUE or False

There are more soil microorganisms in a teaspoon of healthy soil than there are people on the earth?

Time for a Soil Fact

TRUE

Millions of species and billions of organisms—bacteria, algae, microscopic insects, earthworms, beetles, ants, mites, fungi and more—represent the greatest concentration of biomass anywhere on the planet! Microbes, which make up only one half of one percent of the total soil mass, are the yeasts, algae, protozoa, bacteria, nematodes, and fungi that process organic matter into rich, dark, stable humus in the soil.

Soil Health Assessment

- Why assess soil health?
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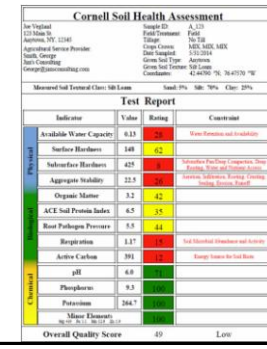
  - Indicators measured
  - What do they mean?
  - Comments on managing identified constraints
- Lessons from Research and Case Examples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	Active Carbon	391	12	Energy Source for Soil Biota
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	Phosphorus	9.5	100	
	Potassium	264.7	100	
	Minor Elements		100	
	Overall Quality Score		49	Low

Reasons for Soil Health Testing

- **Understand constraints** beyond nutrient limitations and excesses
- **Target management practices** to alleviate those constraints
- **Measure** soil improvement or degradation from management
- **Facilitate applied research**
- **Improve awareness** of Soil Health (not just plant nutrition)
- **Enable valuation** of farmland
- **Enable assessment** of farming system risk

Time for a Soil Fact

Time for a Soil Fact

TRUE or False

The best soil on most farms is found in the fence row?

Time for a Soil Fact

TRUE

These undisturbed remnants of what soil properties were once like is no surprise to farmers who have dug into that soil. It's crumbly, dark, and loose, and it's a model of soil structure and organic matter for farmers who are trying to make their soil healthier.

Soil Health Assessment

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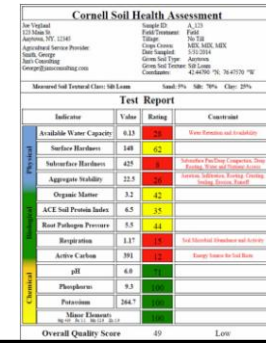
  - The report at a glance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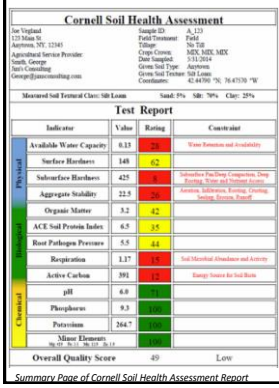
Cornell Soil Health Assessment Report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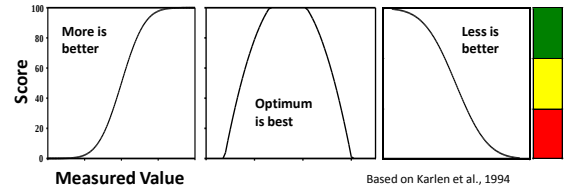
Summary Page of Cornell Soil Health Assessment Report

- Integrative
- Assesses Physical, Chemical, and Biological Functioning
- Process Oriented
- Indicators and Interpretation
- Scoring Functions
- Overall score
- Targeted Management Suggestions

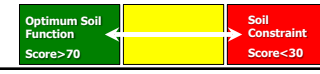
Indicator interpretation

3 types of Scoring Functions interpret how constrained soil processes are:



Based on Karlen et al., 1994

- Adjusted by texture
- Not yet adjusted for different US regions, nor for production systems



For each indicator, report provides interpretation and management prioritization

Aggregate Stability is a measure of how well soil aggregates or crumbs hold together under rainfall or other rapid wetting stresses. Measured by the fraction of dried aggregates that disintegrate under a controlled, simulated rainfall event similar in energy delivery to a hard spring rain, the value is presented as a percent, and scored against a distribution observed in regional soils with similar textural characteristics. A physical characteristic of soil, Aggregate Stability is a good indicator of soil biological and physical health. Good aggregate stability helps prevent crusting, runoff, and erosion, and facilitates aeration, infiltration, and water storage, along with improving seed germination and root and microbial health. Aggregate stability is influenced by microbial activity, as aggregates are largely held together by microbial colonies and exudates, and is impacted by management practices, particularly tillage, cover cropping, and fresh organic matter additions.

Your measured Aggregate Stability value is **22.5%**, corresponding with a score of **26**. This score is in the **Low** range, relative to regional soils with similar texture. **Aggregate Stability should be given a high priority in management decisions based on this assessment, as it is likely to be an important constraint to proper soil functioning and sustainability of management at this time.** Please refer to the management suggestions table at the end of this document.

Management Suggestions for Physical and Biological Constraints

Constraint	Short Term Management Suggestions	Long Term Management Suggestions
Available Water Capacity Low	• Add stable organic materials, mulch • Add compost or biochar • Incorporate high biomass cover crop	• Reduce tillage • Rotate with sod crops • Incorporate high biomass cover crop
Surface Hardness High	• Perform some mechanical soil loosening (strip till, aerators, broadfork, spader) • Use shallow-rooted cover crops • Use a living mulch or interseed cover crop	• Shallow-rooted cover/rotation crops • Avoid traffic on wet soils, monitor • Avoid excessive traffic/tillage loads • Use controlled traffic patterns/lanes
Subsurface Hardness High	• Use targeted deep tillage (subsoiler, yeomans plow, chisel plow, spader.) • Plant deep rooted cover crops/radish	• Avoid plows/disks that create pans • Avoid heavy loads • Reduce traffic when subsoil is wet
Aggregate Stability Low	• Incorporate fresh organic materials • Use shallow-rooted cover/rotation crops • Add manure, green manure, mulch	• Reduce tillage • Use a surface mulch • Rotate with sod crops and mycorrhizal hosts
Organic Matter Low	• Add stable organic materials, mulch • Add compost and biochar • Incorporate high biomass cover crop	• Reduce tillage mechanical cultivation • Rotate with sod crop • Incorporate high biomass cover crop
Soil Protein Index Low	• Add N-rich organiic matter (low C:N source like manure, high N well-finished compost) • Incorporate young, green, cover crop biomass • Plant legumes and grass-legume mixtures • Inoculate legume seed with Rhizobia & check for nodulation	• Reduce tillage • Rotate with forage legume sod crop • Cover crop and add fresh manure • Keep pH at 6.2-6.5 (helps N fixation) • Monitor C:N ratio of inputs
Root Pathogen Pressure High	• Use disease suppressive cover crops • Plant on ridges/raised beds • Monitor irrigation • Biofumigate	• Use disease suppressive cover crops • Increase diversity of crop rotation • Sterilize seed and equipment • Improve drainage/monitor infiation
Respiration Low	• Maintain plant cover throughout season • Add fresh organic materials • Add manure, green manure • Consider reducing biocide usage	• Reduce tillage mechanical cultivation • Increase rotational diversity • Maintain plant cover throughout season • Cover crop with symbiodic host plants
Active Carbon Low	• Add fresh orgalac materials • Use shallow-rooted cover/rotation crops • Add manure, green manure, mulch	• Reduce tillage mechanical cultivation • Rotate with sod crop • Cover crop whenever possible

Constrained and Suboptimal indicators are flagged in report management table

Time for a Soil Fact

Time for a Soil Fact

One percent of organic matter in the top six inches of soil would hold approximately how many gallons of water per acre?

A - ~ 43560 gallons
B - ~ 43 gallons
C - ~ 27,000 gallons
D - ~ 270 gallons

Time for a Soil Fact

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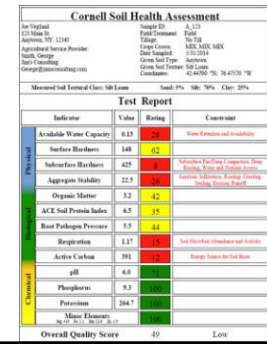
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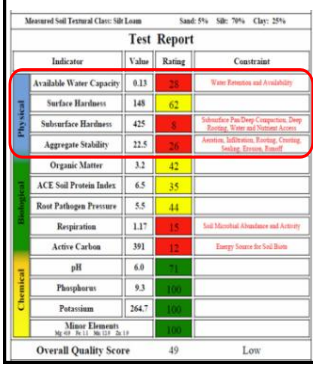
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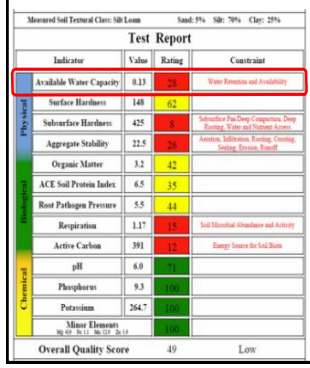
- Available Water Capacity
- Surface Hardness and Subsurface Hardness
- Aggregate Stability

Physical Indicators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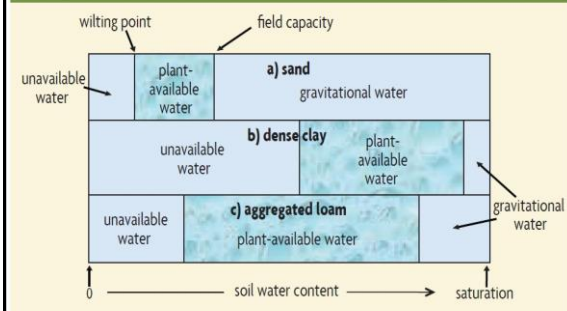
Available Water Capacity

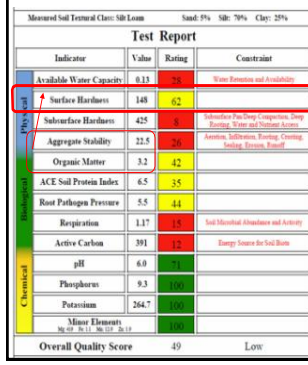
- Measures plant available water per amount of soil
- Between field capacity and wilting point
- Critical to improve in droughty soils
- Influenced by aggregation, texture, organic matter

Water storage depends on texture, organic matter, and aggregation



Magdoff & van Es, 2009

Physical Indicators



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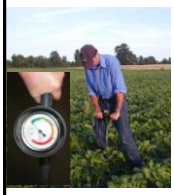
Surface Hardness

- Measures compaction 0-6”
- Affects infiltration, erosion
- Influences plant available water (infiltration, volume)
- Influences nutrient access, plant stress, disease
- Critical to improve, esp in hill side soils
- Influenced by aggregation and organic matter

Compaction = Loss of Large Pores

Need to know WHERE and WHY



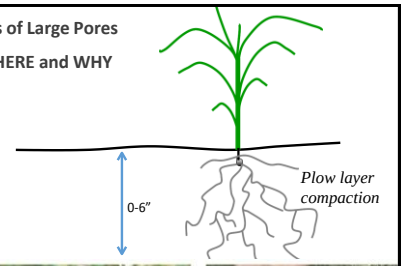
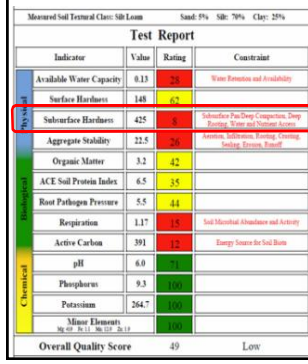



Photo by D. Degolyer


Photos from *Building Soils for Better Crops*

Physical Indicators



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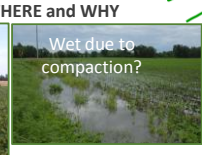
Subsurface Hardness

- Measures compaction 6-18”
- Affects drainage, erosion
- Influences plant available water (deep soil volume)
- Influences nutrient access, plant stress, disease
- Critical to maintain plant-accessible subsoils for deep rooted plants, for *drought resilience*
- Influenced by soil type, texture, aggregation, and organic matter, traffic, disturbance

Compaction = Loss of Large Pores

Need to know WHERE and WHY




Photos: Bianca Moebius-Clune

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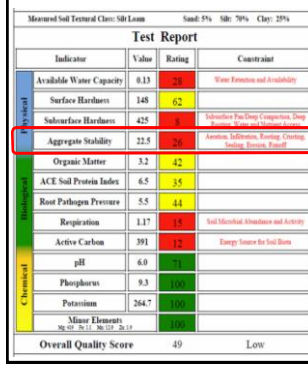

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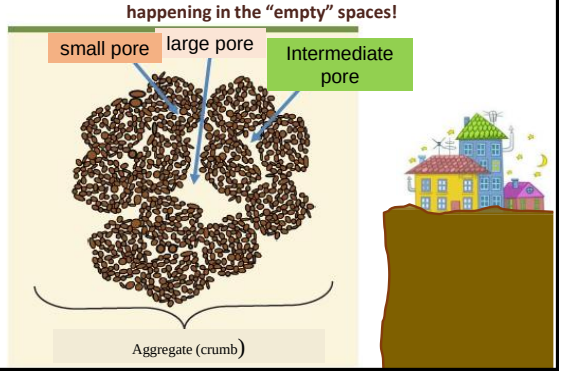
Aggregate Stability

- Measures strength of aggregates against precipitation impact
- Affects
  - Water infiltration, movement and storage
  - Erosion, crusting
  - Aeration
  - Organic matter protection and biotic activity
- Influenced by OM, biota (bacteria, fungi, etc), management (residue, tillage)
- Biological activity is critical
  - mycorrhizal fungi, decomposers (bacteria, fungi, other fauna), cyanobacteria, algae

An Aggregate is like a House

The interesting stuff (soil biota and their activities, water, air…) is happening in the "empty" spaces!



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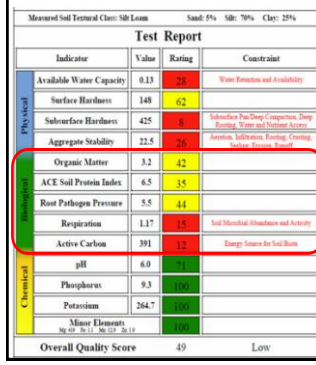

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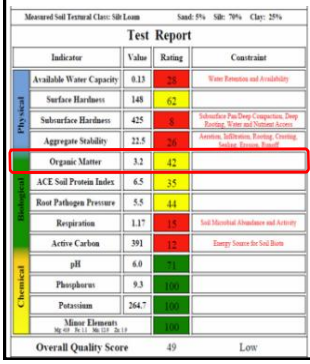
- Organic Matter Content
- Protein Content
- Root Pathogen Pressure
- Respiration
- Active Carbon

Biological Indicators



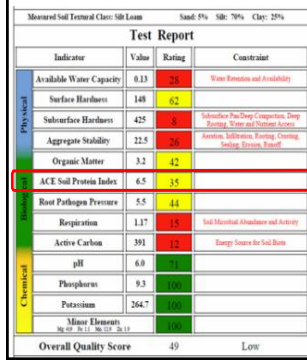
Test Report

	Indicator	Value	Rating	Constraint
Physical	Available Water Capacity	0.13	28	Water Retention and Availability
	Surface Hardness	148	62	
	Subsurface Hardness	425	8	Subsurface Pan/Deep Compaction, Deep Rooting, Water and Nutrient Access
	Aggregate Stability	22.5	26	Aeration, Infiltration, Rooting, Crusting, Sealing, Erosion, Runoff
Biological	Organic Matter	3.2	42	
	ACE Soil Protein Index	6.5	35	
	Root Pathogen Pressure	5.5	44	
	Respiration	1.17	15	Soil Microbial Abundance and Activity
	Active Carbon	391	12	Energy Source for Soil Biota
Chemical	pH	6.0	71	
	Phosphorus	9.3	100	
	Potassium	264.7	100	
	Minor Elements		100	
Overall Quality Score		49	Low	

Organic Matter Content

- Measures organic material lost on ignition
- Affects exchange capacity and nutrient storage (exchangeable and bonded)
- Affects aggregation, water holding capacity, hardness

Biological Indicators



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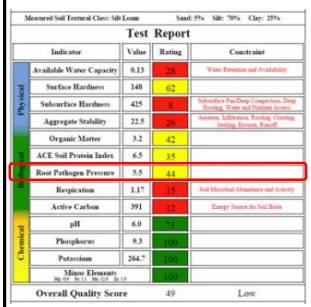
Protein Content

- Measures organic N pool
  - Influences N cycling and availability to plants
- Proteins come from: plant residues, root turnover, microbial biomass N, organic matter amendments

Biological Indicators



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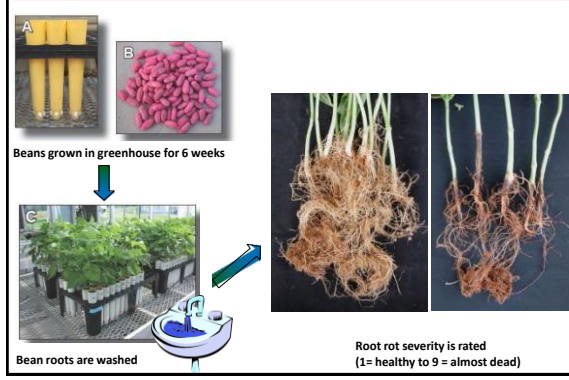
Root Pathogen Pressure

- Measure of the quality and function of roots as indicated by size, color, texture and absence of root damage.
- Affects organic matter, aggregation and compaction.

Root Pathogen Pressure Bioassay

Beans (*Phaseolus vulgaris*) planted in fresh soil, grown in greenhouse, rated for disease



Beans grown in greenhouse for 6 weeks

Bean roots are washed

Root rot severity is rated (1= healthy to 9 = almost dead)

Biological Indicators

Measured Soil Textural Class: Silt Loam Sand: 5% Silt: 70% Clay: 25%

Test Report

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Respiration

Measures biological activity, which controls

- Decomposition
- Biological nutrient mineralization and immobilization
- Aggregation
- Plant-microbe interactions

Biological Indicators

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Active Carbon

- Measures labile carbon pool (breaks down for food)
- Energy source for microbial community
- Likely an early indicator of total organic matter gain or loss

Chemical Indicators

Measured Soil Textural Class: Silt Loam Sand: 5% Silt: 70% Clay: 25%

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Overall Quality Score		49	Low	

- Standard soil fertility test
- pH
- P - phosphorus
- K - potassium
- Minor elements
  - Deficiency or toxicity

In a nutshell: Soil Health Assessment Identifies Constraints & links each Indicator to Function of Soil Processes, which can be explicitly managed

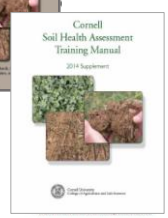
Physical Indicators	Soil Processes
Available Water Capacity	Water that plant can use; drought resistance, prevent leaching
Surface Hardness	Penetration resistance 0"- 6"; aeration, surface rooting, infiltration, germination, prevent runoff & erosion
Subsurface Hardness	Penetration resistance 6" - 18"; deep rooting, drought resistance, water movement and drainage, extreme precipitation resilience
Aggregate Stability	Resistance to falling apart during rainfall; aeration, infiltration, germination, prevent runoff & erosion
Biological Indicators	**Soil Processes**
Organic Matter	Water and nutrient storage/release, long-term energy storage, C sequestration
ACE Soil Protein Index	N containing fraction of organic matter, N release
Root Pathogen Pressure	Disease suppressiveness of microbial community for vegetables
Respiration	Microbial activity, nutrient release
Active Carbon	Carbon easily available as short-term microbial food source

Chemical Indicators: Standard Soil Test Analysis included, add-ons for heavy metals and salinity available

Cornell Soil Health Testing Services

More information and up-to-date soil health testing at:

http://soilhealth.cals.cornell.edu/



- Sample submission
- Manual
- Blog
- New manual in progress

Other resources:

Cornell Soil Health Team soilhealth.cals.cornell.edu

Time for a Soil Fact

Time for a Soil Fact

TRUE or False

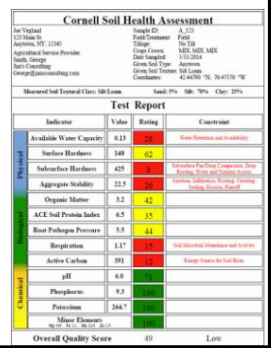
Organic matter holds 18-20 times its weight in water and recycles nutrients for plants to use?

Time for a Soil Fact

TRUE

Soil Health Assessment

- Why assess soil health?
- The Cornell Soil Health Assessment
  - The report at a glance
  - Indicators measured
  - What do they mean?
  - Managing identified constraints
- Framework for Soil Health Management Planning and Implementation



Cornell Soil Health Assessment

Test Report

	Indicator	Value	Rating	Constraint
Physical	Available Water Capacity	0.13	28	
	Surface Hardness	148	62	
	Subsurface Hardness	425	30	
	Aggregate Stability	22.5	56	
Biological	Organic Matter	3.2	42	
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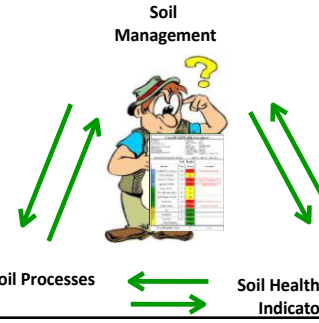
How do I use soil test information?



SH Management Planning Process Overview

1. Determine farm background and management history

Compile background info: history by management unit, farm operation type, equipment, access to resources, situational opportunities or limitations.

2. Set goals and sample for soil health

Determine number and distribution of soil health samples needed according to operation background and goals.

3. For each management unit: identify and explain constraints, prioritize

Soil Health Report identifies constraints, guides prioritization. Explain results based on background, and adjust priorities.

4. Identify feasible management options

Management suggestions table available as part of Soil Health Report, or online with NRCS practice linkages

5. Create short and long term Soil Health Management Plan

Integrate agronomic science of 2-4 with grower realities of 1 to create a specific short-term schedule of management practices for each management unit and an overall long-term strategy

6. Implement, monitor, and adapt

Implement and document management practices. Monitor progress, repeat testing, and evaluate outcomes. Adapt plan based on experience and data over time.

Available Resources

Cornell Soil Health Test
http://soilhealth.cals.cornell.edu/extension/test.htm

Interpret results and work with farmers to implement practices
http://soilhealth.cals.cornell.edu/extension/manual.htm

Managing Cover Crops Profitably - SARE
http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition/Text-Version

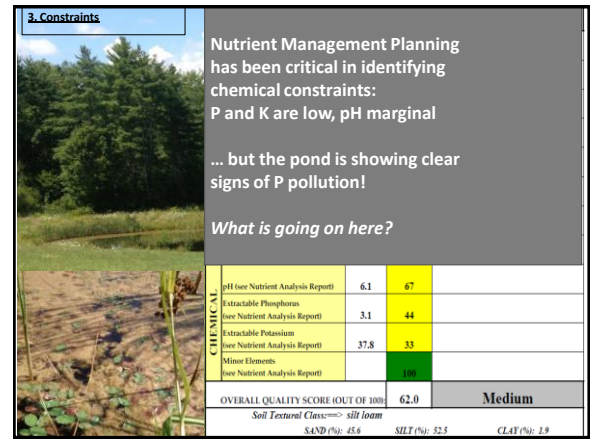
Crop Rotations - SARE
http://www.sare.org/content/download/60067/808447/Crop_Rotations.pdf

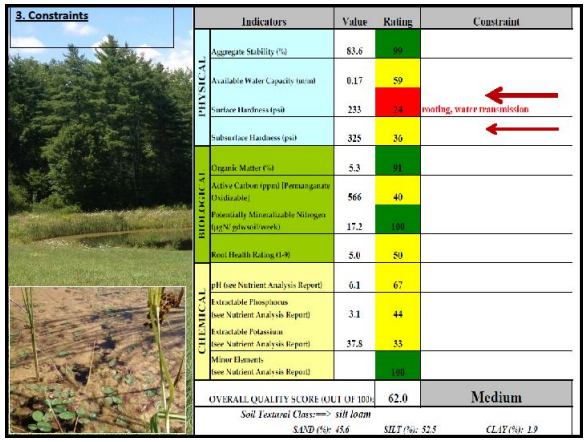

An Example:
Organic mixed operation
Lee, NH
Looks like ideal management – perpetual perennial cover, roots, biodiversity, and no tillage … BUT….


Questions and Discussion

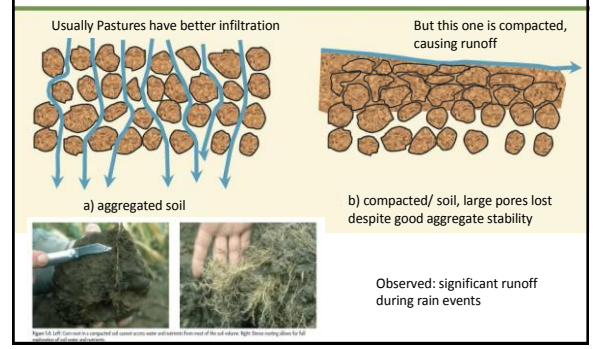

An Example:
Organic mixed operation
Lee, NH
Looks like ideal management – perpetual perennial cover, roots, biodiversity, and no tillage … BUT….

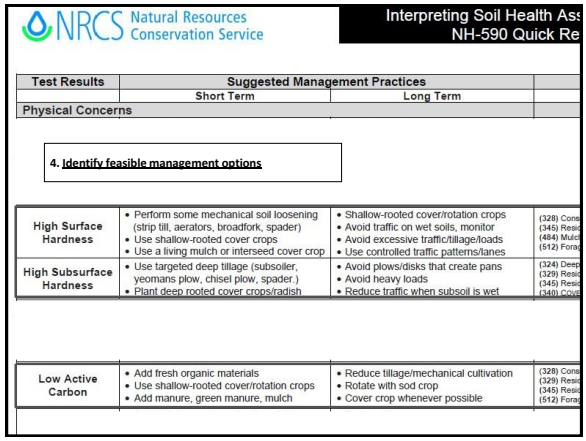

SH Management Planning Process Overview
1. Determine farm background and management history
Sloped hay field, sometimes grazed – especially recently, pond below field is full of algae (P excess); growth mediocre. Visible erosion, runoff during rain. Diverse inventory of field equipment, grower inclined to experiment with anything. Organic mixed operation.
2. Set goals and sample for soil health
Improve soil health, productivity, on-farm nutrient and carbon cycling, and long-term sustainability, and regain use of the pond for recreational purpose


3. Constraints
Nutrient Management Planning has been critical in identifying chemical constraints:
P and K are low, pH marginal
… but the pond is showing clear signs of P pollution!
What is going on here?
CHEMICAL
pH (see Nutrient Analysis Report) 6.1 67
Extractable Phosphorus (see Nutrient Analysis Report) 3.1 44
Extractable Potassium (see Nutrient Analysis Report) 37.8 33
Minor Elements (see Nutrient Analysis Report) 100
OVERALL QUALITY SCORE (OUT OF 100): 62.0 Medium
Soil Textural Class==> silt loam
SAND (%): 45.6 SILT (%): 52.5 CLAY (%): 1.9



Management must address explicit physical and then biological & chemical processes





SH Management Planning Process Overview

1. Determine farm background and management history

Sloped hay field, sometimes grazed – especially recently, pond below field is full of algae (P excess); growth mediocre. Visible erosion, runoff during rain. Diverse inventory of field equipment, grower inclined to experiment with anything. Organic mixed operation.

2. Set goals and sample for soil health

Improve soil health, productivity, on-farm nutrient and carbon cycling, and long-term sustainability, and regaining use of the pond for recreational purpose

3. For each management unit: identify and explain constraints, prioritize

Biggest constraint: Surface compaction causing loss of P inputs to pond, while soil P is low. Also: Subsurface compaction, low active carbon; K, P, and pH below optimal

4. Identify feasible management options

Need mechanical disturbance first: Surface mechanical disturbance, deep ripping/subsoiling along contours. Then fresh organic inputs, wood ash and/or manure additions, interseed additional crops for vigorous and diverse rooting.

5. Create short and long term Soil Health Management Plan

6. Implement, monitor, and adapt

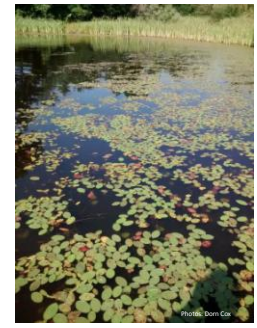
October 2013:
Spread wood ash
(addresses K, some P, pH)

Oct 2013:
Seed cover crop mix/forage of hairy vetch, winter rye, wheat, barley. Single pass 3" rotovator & no-till drill.

increased active C, decreased surface compaction, increased infiltration

Results: Vigorous growth

Results: Pond eutrophication cleared



Recreational use resumed in 2013, improved in 2014

Lessons demonstrated

- Nutrient constraints interact with physical and biological constraints to create water quality issues
- Prescribed BMPs have limitations
- Use systems indicators as feedback for adaptive management
- Need comprehensive Soil Health Management Planning, and adaptive implementation for progress in soil and water conservation

Moebius-Clune, B, Dorn Cox, 2014. Implementation of a Soil Health Management Plan resolves pond eutrophication at Tuckaway Farm, NH. What's Cropping Up? Vol. 24. No. 5, pp 49-53