CHARACTERIZATION OF SOIL HEALTH IN NEW YORK STATE

Summary

Cornell CALS
College of Agriculture and Life Sciences

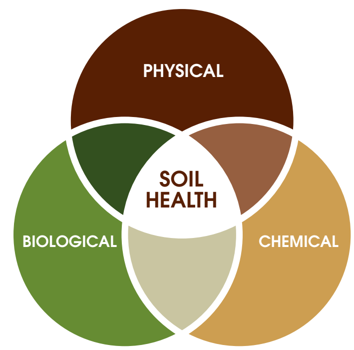
Cornell Soil Health Laboratory

NEW YORK SOIL HEALTH

These new metrics can be used by policy makers, agricultural professionals, and farmers to interpret soil health data and set goals for improved soil health and carbon farming.

Key Summary Points

- **1,456 samples** were analyzed to assess the state of soil health across New York State (NYS).
- **Soil health in New York** is affected by both soil type and cropping system differences that relate to carbon cycling and soil disturbance.
- **New metrics** were established to evaluate soil health in NYS.
- **Aspirational soil health goals** were established for different soil types and cropping systems.
- **Soil carbon storage potential** was assessed for different soil types and cropping systems: Annual Grain and Processing Vegetable systems have greater potential for carbon farming than Pasture, Dairy Crop, and Mixed Vegetable systems.



Introduction

The soil is a foundational resource for life on earth and its health is critical to the sustainability of agriculture, food systems, and green infrastructures. Soil also plays an important role in water and air quality, the integrity of the biosphere, and the climate. Soil health concepts, practices, and testing have generated a growing awareness of the soil's central role and highlights that sustainable soil management requires an understanding of biological, physical, and chemical processes and their interrelationships. Furthermore, it is recognized that human management can significantly degrade or improve the quality of the soil.

New York State (NYS), through Cornell University, has been a global leader in the development of soil health programs, including the development of testing methodologies. NYS land managers are becoming increasingly excited about improving the health of their soils. As progress is made in characterizing the health of soils nationwide, researchers will be able to develop regionally specific interpretive metrics that are shaped by the interplay of soil management with soil types and climate. As part of that effort, we have summarized soil health data from New York State to understand differences in soil health. And these new metrics can be used to interpret soil health data and set goals for improved soil health and carbon farming.

September 2020

This is an abridged version of the full report available at:
bit.ly/NYSoilHealthCharacterizationReport

Methods

The NYS Soil Health dataset was compiled from 1,456 NYS soil samples collected from 2014 to 2018 (Figure 1). All samples were run through the standard Comprehensive Assessment of Soil Health package at the Cornell Soil Health Laboratory. Composite soil samples were collected to a depth of 0-6 inches. Soil health results were characterized across four textural groups, including coarse, loam, silt loam, and fine textural groups and five cropping system categories including Annual Grain, Dairy Crop, Pasture, Processing Vegetable, and Mixed Vegetable.

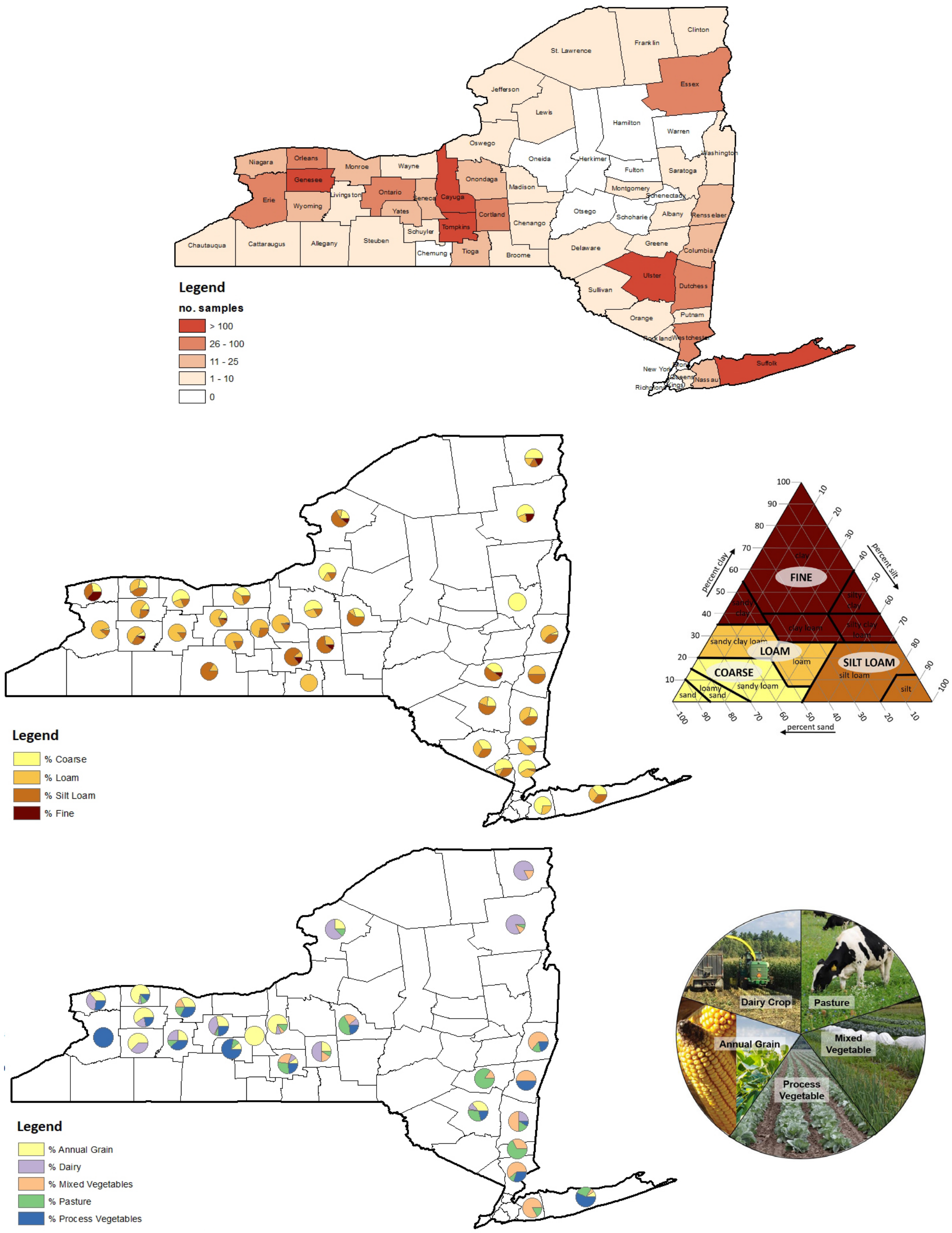


Figure 1. Distribution of soil health samples, their texture groups and cropping systems by county across New York State (n=1,456 for texture and n=542 for cropping system).

Analyses

The soil health analyses included the following indicators:

Biological Properties

Soil Organic Matter

is a measure of all carbon containing material that was derived from living organisms.

Soil Protein

is a measure of the fraction of soil organic matter which contains most of the nitrogen (N) available to plants and organisms.

Soil Respiration

is a measure of the metabolic activity of the soil microbial community.

Active Carbon

is a measure of the small portion of the organic matter that can serve as an easily available food source for soil microbes, thus helping fuel and maintain a healthy soil food web. It is also often a leading indicator of changes in soil organic matter.

Physical Properties

Available Water Capacity

reflects the quantity of water that a disturbed soil sample can store for plant use.

Aggregate Stability

is a measure of how well soil aggregates resist disintegration when hit by rain drops.

Surface Hardness

is a measure of the maximum penetration resistance (psi), or compaction, encountered in the soil surface (0-6 inch depth). determined using a field penetrometer (field measurement).

Subsurface Hardness

is a measure of the maximum penetration resistance (psi) encountered in the soil subsurface (6-18 inch depth).

Note: we do not report on soil chemical properties here, as they have been extensively measured previously, and are also discussed in the full technical report.

Results

Soils are affected by a combination of inherent and human management factors. A soil's inherent properties are shaped over time by the interaction among a location's unique soil forming factors: parent material, climate, topography, biology, and time. Inherent properties such as soil texture and mineralogy exert strong controls on the amount of storable carbon and nutrients, native pH, water holding capacity, drainage, and more. Information about these inherent soil properties across virtually all of the United States of America is available through Web Soil Survey or SoilWeb.

However, in agriculture and many other environments, human activities have increasingly become a force of change on the landscape. Tillage and crop rotations, as well as carbon and nutrient flows through erosion, organic amendments and residue harvesting choices have dramatically altered the chemical, physical and biological health of the soil which is superimposed onto the inherent soil characteristics. We examined the effects of soil texture, cropping system, and their interaction on various soil health properties.

Key Factors Controlling Soil Health Identified

Indeed, an analysis of the NYS soil health dataset demonstrated that certain properties were defined mostly by soil texture while others were mostly impacted by cropping system, and yet others were impacted equally by both. Soil texture explained most variation in available water capacity, which was not much impacted by cropping system. Whereas, cropping system explained nearly all variation in aggregate stability, protein, and respiration values, which were little impacted by soil texture. Cropping system and soil texture explained an equal amount of variance in soil organic matter and active carbon.

Effect of Soil Texture on Soil Health Indicators

Soil texture is a dominant inherent soil property that exerts strong controls on a soil's ability to function. In order to evaluate the impacts of human land management on the soil, the effects of this underlying inherent soil property on biological and physical soil health parameters needs to be understood.

Compost and manure inputs help replace carbon and nutrients that are lost in annual cropping systems.

Biological Soil Health

The quantity and quality of soil organic matter is controlled by a soil's textural class. Soils with higher concentrations of silt and clay (fine-textured) can store more organic matter than sandy (coarse-textured) soils due to the large amount of surface area that can bind with organic molecules. Accordingly, fine textured soils had higher soil organic matter, respiration, active carbon, and protein than coarse textured soils by 79%, 59%, 56%, and 13%, respectively, with medium-textured soils generally being intermediate (Figure 2). The two organic matter quality indices, protein/soil organic matter and active carbon/soil organic matter, were 60% and 19% higher in coarse textured soils than in fine textured soils, which indicates greater proportions of extractable high-quality "fresh" organic matter relative to "older" stable and mineral-bound organic matter.

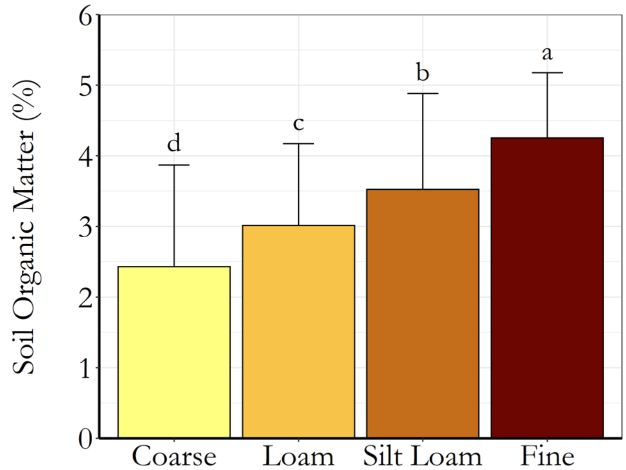


Figure 2. Mean soil organic matter across soil texture groups.

Physical Soil Health

Soil texture exerted a dominant control on available water capacity but showed weaker relationships with the other soil physical parameters, aggregate stability and soil hardness. The effect of soil texture on available water capacity has been well studied, and coarse-textured (sandy, gravelly) soils store less water because large pores between particles are unable to hold on to water against gravity. Specifically, as sand content increases, available water capacity goes down (r = -0.70). In contrast, fine-textured (clayey) soils can store the most water, but some of that is tightly held in micropores and unavailable to plants. Soils with intermediate textures (silty and loamy) are known to store the most plant available water. Silt loams and silty clay loam soils had the highest available water capacity. Silt loam soils had 273%, 139%, 47%, and 28%, higher available water capacity than sand, loamy sand, sandy loam, and loam soil textures (Figure 3). There was no clear effect of soil texture on aggregate stability in NYS soils, but silt loams had slightly higher subsurface hardness than loam soils, which has been reaffirmed by previous findings.

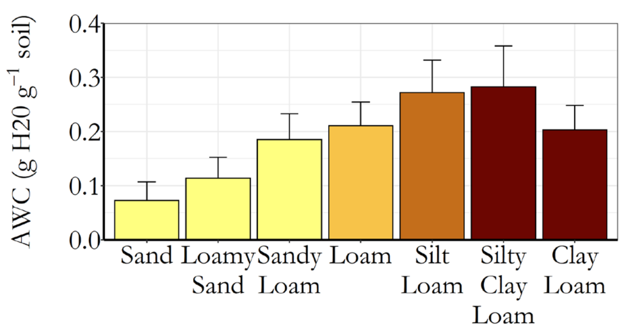


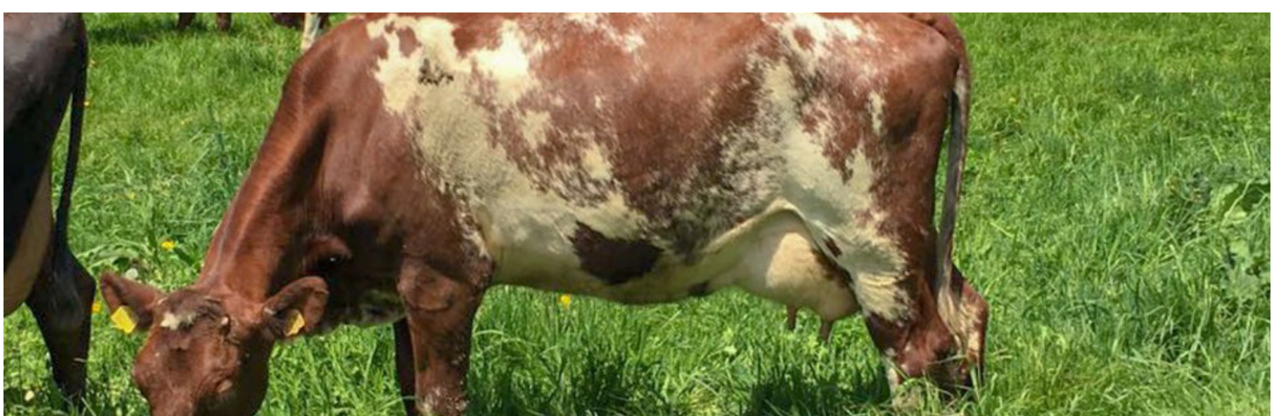
Figure 3. Mean values of available water capacity across seven soil texture classes.

Effect of Cropping System on Soil Health Indicators

Human activities impact soil health through cropping system categories highlighted in this analysis. Pastures maintain the best soil health because these fields are seldom disturbed by tillage and receive year-round root and shoot carbon and nutrient inputs, as well as manure droppings. Mixed Vegetables are often grown organically where compost, other organics, and legume rotations are used to maintain soil fertility. Dairy Cropping systems can maintain soil health due to cycling of carbon and nutrients through manure inputs and rotations with perennial hay. In contrast, Annual Grain and Processing Vegetable systems are intensively managed and typically don't have the ability to apply enough organic amendments to replace the carbon that is lost each year (typically 50-80% of the carbon and nutrients are harvested and exported off the farm). Highlighting the effects of different cropping systems on biological and physical soil health parameters can help farmers, agricultural professionals, and policy makers identify opportunities to improve soil health.

Biological Soil Health

Cropping systems strongly impact the quantity and quality of soil organic matter, which were assessed using the four biological soil health indicators (Figure 4, for *loam* soils only). Pasture soils best accrue and maintain soil organic matter and maintained 67%, 55%, and 32% higher soil organic matter, respectively, than Processing Vegetable, Annual Grain, and Dairy Cropping systems. As a generalization, the percentage of soil organic matter in long-term pasture soils represents a good upper limit for what may be stored for each texture group. Small-scale diversified Mixed Vegetable farms also showed high soil organic matter levels. When all samples were combined regardless of texture, Pasture had the highest soil organic matter followed by Mixed Vegetable, Dairy Crop, Annual Grain and Processing Vegetables. Intensive tillage and infrequent additions of organic amendments keep Annual Grain and Processing Vegetable systems with lower soil organic matter. Labile organic matter indicators, including active carbon, protein, and respiration, were similarly high in Pasture systems (Figure 4). Protein was consistently higher in Pasture and Mixed Vegetable farms across soil textures, indicating that organic nitrogen reserves were higher in these soils.



Pastures maintain healthy soils through continuous perennial plant inputs and manure droppings.

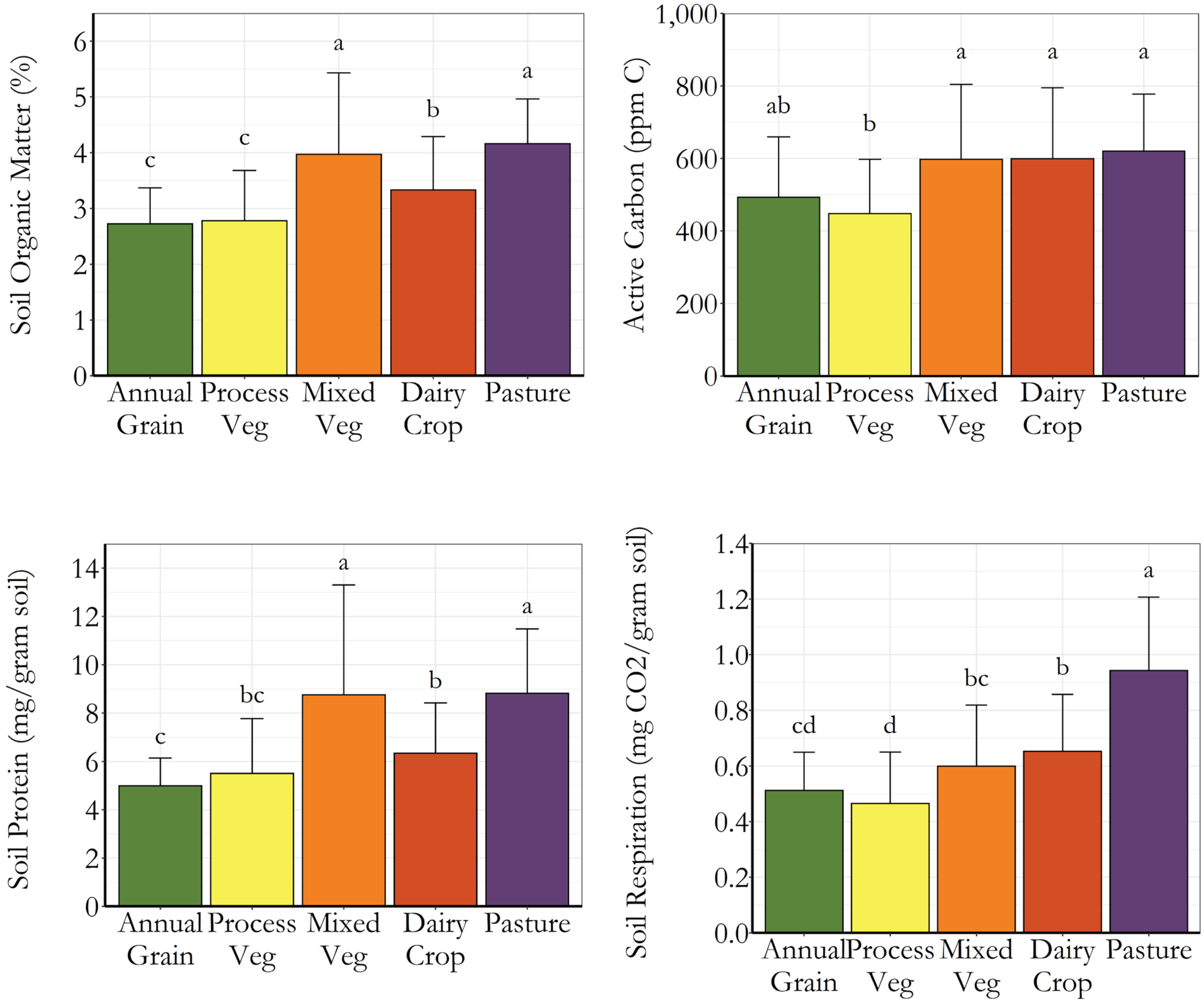


Figure 4. Mean soil organic matter, active carbon, soil protein, and soil respiration across cropping systems on *loam* textured soils.

Mixed Vegetable systems tend to be smaller in scale and therefore can build healthy soils through compost applications and intensive cover cropping.

Physical Soil Health

The different cropping systems exerted a stronger control on aggregate stability than available water capacity and soil compaction. Pasture soils had the highest aggregate stability in all texture groups. Specifically, aggregate stability was 2.6, 2.3, 2.0, and 1.6 times higher than Processing Vegetable, Annual Grain, Dairy Crop, and Mixed Vegetable systems, respectively (Figure 5). High soil organic matter in undisturbed pasture systems and intact root systems and arbuscular mycorrhizal fungi help build and maintain stable soil aggregates. (Note: conventional tillage has also been shown to decrease aggregate stability compared to no-till and perennial systems, but tillage effects could not be analyzed from this dataset). Mixed Vegetable systems maintained 59%, 46%, and 22% higher aggregate stability than Processing Vegetable, Annual Grain, and Dairy Crop systems (Figure 5), despite the use of intensive tillage to manage weeds and nutrients in this system (Mixed Vegetable systems were often organic operations that cannot rely on herbicides for weed management). This is presumably due to the more common use of composts and other organic amendments in Mixed Vegetable systems that help build and maintain soil organic matter and protein. Both soil organic matter and protein have a positive effect on aggregate stability (r = 0.61 and r = 0.56, respectively).

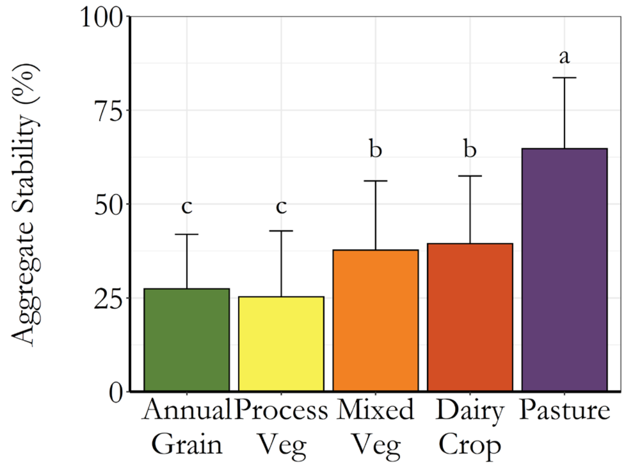
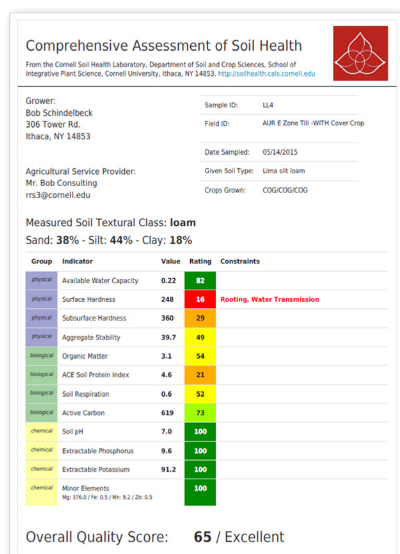


Figure 5. Mean aggregate stability across cropping systems on *loam* textured soils.

Cropping systems that maintain higher % soil organic matter levels can positively affect available water capacity, but this effect is stronger in coarser textured soils than other texture groups. Although the effects of cropping system on soil hardness weren't consistent across texture groups, we found some evidence of higher surface compaction on Dairy Crop fields and higher subsurface compaction on Processing Vegetable fields compared to Mixed Vegetable fields.

Soil Health Scoring Functions for New York State

The Comprehensive Assessment of Soil Health (CASH) framework interprets laboratory results through scoring functions that rate a soil sample within a larger population of measured values. There are inherent challenges with defining one-size-fits-all soil health scoring functions by combining data from different regions with different textures and cropping systems. This research provides the data necessary for better interpretive metrics for New York State's soils and allows farmers to evaluate fields relative to those with the same soil type and cropping system.



Comprehensive Assessment of Soil Health

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

Grower:
Bob Schindelbeck
306 Tower Rd.
Ithaca, NY 14853

Agricultural Service Provider:
Mr. Bob Consulting
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Sample ID: LL4
Field ID: AUR E Zone Till -WITH Cover Crop
Date Sampled: 05/14/2015
Given Soil Type: Lima silt loam
Crops Grown: COG/COG/COG

Measured Soil Textural Class: **loam**
Sand: **38%** - Silt: **44%** - Clay: **18%**

Group	Indicator	Value	Rating	Constraints
physical	Available Water Capacity	0.22	82	
physical	Surface Hardness	248	16	Rooting, Water Transmission
physical	Subsurface Hardness	360	29	
physical	Aggregate Stability	39.7	49	
biological	Organic Matter	3.1	54	
biological	ACE Soil Protein Index	4.6	21	
biological	Soil Respiration	0.6	52	
biological	Active Carbon	619	73	
chemical	Soil pH	7.0	100	
chemical	Extractable Phosphorus	9.6	100	
chemical	Extractable Potassium	91.2	100	
chemical	Minor Elements Mg: 376.0 / Fe: 0.5 / Mn: 9.2 / Zn: 0.5		100	

Overall Quality Score: **65** / Excellent

Aspirational Soil Health Goals

This report includes a first attempt at developing aspirational soil health goals for NYS by soil texture and cropping system. It is based on the 75th percentile of the distribution for each biological and physical soil health indicator (Table 1) in each grouping. These aspirational soil health goals provide realistic targets for NYS farmers within the context of their own production environment.

Table 1. Aspirational soil health goals (Q75 basis) by cropping system and soil texture for biological and physical soil health indicators. Aspirational goals for surface and subsurface hardness are 100 psi and 250 psi. Acronyms: Soil Organic Matter (SOM), Active Carbon (ActC), Protein (Prot), Respiration (Resp), Aggregate Stability (AgStab), Available Water Capacity (AWC).

Coarse-Textured							
Cropping System	**n**	**SOM**	**ActC**	**Prot**	**Resp**	**AgStab**	**AWC**
		%	ppm C	mg/g	mg CO_2/g	%	g H_2O /g soil
Annual Grain	26	2.7	440	6.8	0.54	45	0.18
Processing Veg	22	2.2	510	5.7	0.43	30	0.20
Mixed Veg	24	4.5	790	14.1	0.70	59	0.21
Dairy Crop	19	2.5	530	6.0	0.54	38	0.16
Pasture	11	3.8	674	9.5	0.78	84	0.24
Loam							
Cropping System	**n**	**SOM**	**ActC**	**Prot**	**Resp**	**AgStab**	**AWC**
		%	ppm C	mg/g	mg CO_2/g	%	g H_2O /g soil
Annual Grain	110	3.2	600	5.4	0.58	36	0.22
Processing Veg	45	3.1	500	5.4	0.54	38	0.22
Mixed Veg	26	4.9	740	10.9	0.75	50	0.23
Dairy Crop	53	3.7	680	7.3	0.71	50	0.23
Pasture	11	4.8	720	10.1	1.15	76	0.26
Silt Loam							
Cropping System	**n**	**SOM**	**ActC**	**Prot**	**Resp**	**AgStab**	**AWC**
		%	ppm C	mg/g	mg CO_2/g	%	g H_2O /g soil
Annual Grain	52	4.2	710	7.2	0.68	46	0.25
Processing Veg	38	3.7	610	7.1	0.62	39	0.29
Mixed Veg	35	4.4	760	9.6	0.75	62	0.30
Dairy Crop	28	4.4	740	7.9	0.72	49	0.29
Pasture	21	6.3	810	12.3	1.47	88	0.32
Fine-Textured							
Cropping System	**n**	**SOM**	**ActC**	**Prot**	**Resp**	**AgStab**	**AWC**
		%	ppm C	mg/g	mg CO_2/g	%	g H_2O /g soil
Annual Grain	7	4.6	740	7.2	0.68	46	0.24
Processing Veg	*	4.0	650	7.1	0.62	39	0.27
Mixed Veg	*	4.8	800	9.6	0.75	62	0.27
Dairy Crop	16	4.7	780	7.9	0.72	49	0.24
Pasture	*	6.3	850	12.3	1.47	88	0.27

*Not enough fine-textured samples with crop codes. Interpolated based on silt loam values.

Soil Organic Carbon Sequestration Potential

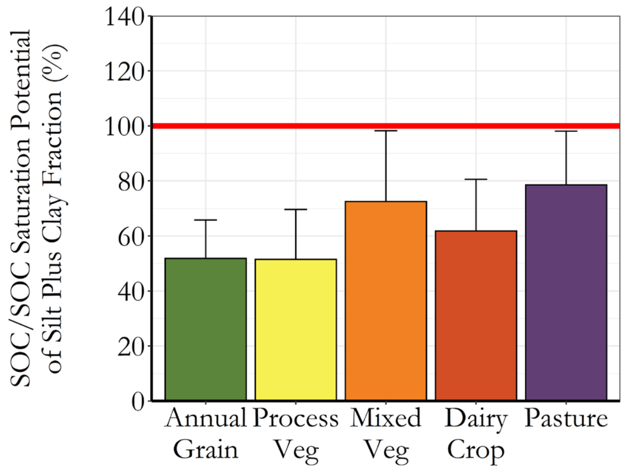

Figure 6. Soil organic carbon as a fraction of the saturation potential of the silt and clay fraction across different agricultural systems (based on grassland systems). Carbon sequestration potential is greater at lower saturation levels.

Soil health practices, including reduced tillage, cover crops, organic amendments, and perennial crops, have the potential to build and maintain soil organic carbon levels, which can help reduce carbon dioxide (CO_2) levels in the atmosphere. A recent estimate for the United States suggests that it is possible to sequester 68 Tg C yr-1 (250 Tg CO_2e) in croplands and grasslands with substantial investments in this area, equivalent to 36% of total US agricultural emissions or 3.7% of total US emissions in 2018. One challenge to those efforts is that carbon sequestration is dependent on keeping those management practices in place (permanence). An important consideration is that soils have a limited capacity to store soil organic carbon, mostly based on texture and mineralogy. As a soil approaches its saturation point, carbon inputs in the form of plant residues or organic amendments have decreased efficiency at further increasing soil organic carbon. Chemical adsorption of soil organic carbon to silt and clay particles is the dominant mechanism that stabilizes soil organic carbon in the soil. Once this is saturated, soil organic carbon can only build up in more labile fractions that are less protected, more readily decomposed and returned to the atmosphere as carbon dioxide.

Our results show that most fields under Annual Grain and Processing Vegetable cropping systems have less soil organic carbon than their capacities based on silt plus clay fractions in a grassland system (Figure 6). Therefore, these cropping systems have the greatest potential to stabilize additional soil organic carbon. Conversely, many fields in Pasture and Mixed Vegetable systems are closer to their saturation levels and therefore have less potential to sequester more carbon. Dairy Crop fields are intermediate. Annual Grain and Processing Vegetable systems can build soil organic carbon by incorporating the types of management practices that make Dairy Crop, Mixed Vegetable, and Pasture systems more successful. This includes applications of composts and manure, integration of livestock, better rotations, cover cropping and reduced tillage. Additionally, while it may be more difficult to further increase soil organic carbon in Mixed Vegetable and Pasture systems, it will be important for NYS climate mitigation strategy to maintain their carbon levels. Relative carbon saturation metrics can be used to optimize carbon allocations for soil sequestration and thereby also improve soil health.

Grain & Process Veg.
GREATEST POTENTIAL

Dairy Crop Fields
MEDIUM POTENTIAL

Pasture and Mixed Veg.
LESS POTENTIAL

Conclusions

This report summarizes the characterization of the soil health status of New York State soils by texture and cropping system. The full technical report is available at: bit.ly/NYSoilHealthCharacterizationReport. These efforts enable NYS policy makers, agricultural professionals, and farmers to interpret soil health data and set soil health goals within the context of their specific soil and management environments. Increased knowledge of the effects of soil texture, the most defining inherent soil property, and cropping system on biological and physical properties are vital to understanding how agricultural management affects healthy soil functioning.

Farmer chops alfalfa for hay. Dairy cropping systems that include alfalfa, a perennial legume, in the rotation helps improve the soil in between corn silage production.

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To obtain a copy:
Download a PDF at: bit.ly/NYSoilHealthCharacterizationSummary
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