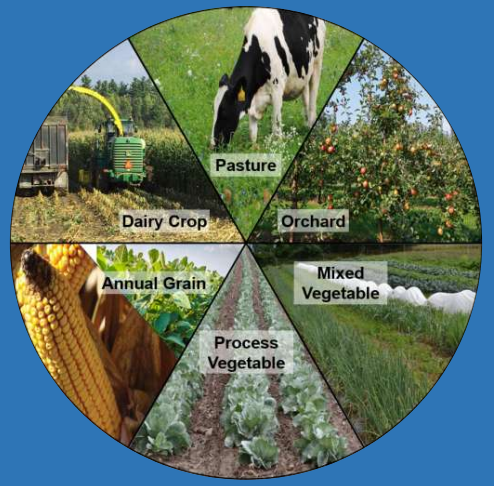
Monitoring Soil Health in the USA: Insights from the Cornell Soil Health Program



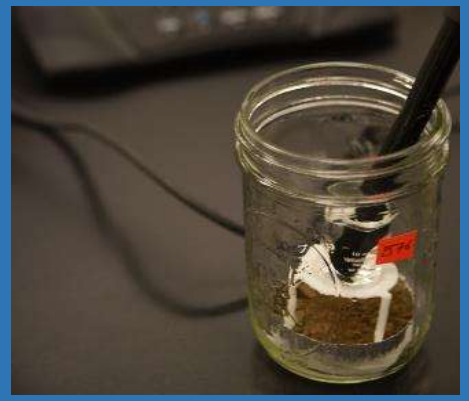
Joseph Amsili, PhD
Director of Cornell Soil Health Program

Cornell CALS College of Agriculture and Life Sciences

NEW YORK SOIL HEALTH

Measuring and Interpreting Soil Health

Comprehensive Assessment of Soil Health (CASH)



Comprehensive Assessment of Soil Health

- Cornell Soil Health Laboratory launched in 2006
- CASH test captures all important soil processes (physical, biological, chemical)
- **What is Measured, Gets Done!**

Integrated Report Includes:

- ❑ Measured values
- ❑ Rating (score) for each indicator for interpretation
- ❑ Overall Score – unweighted average of all scores
- ❑ Highlights constraints
- ❑ Offers management guidance

40,000+ samples processed in last 10 years

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
https://soilhealthlab.cals.cornell.edu

Page 1

Agricultural Service Provider:
Joseph Amsili
New York Soil Health / NYSH
jpa28@cornell.edu

Sample ID:
Field ID:
Date Sampled: 04/26/2022
Tillage: 1-7 inches

Measured Soil Textural Class: **loam**

Sand: **45%** - Silt: **37%** - Clay: **17%**

Group	Indicator	Value	Rating	Constraints
physical	Predicted Available Water Capacity	0.21	78	
physical	Surface Hardness	131	64	
physical	Subsurface Hardness	346	33	
physical	Aggregate Stability	4.1	6	Aeration, Infiltration, Rooting, Crusting, Sealing, Erosion, Runoff
biological	Organic Matter Soil Organic Carbon: 1.84 / Total Carbon: 1.96 / Total Nitrogen: 0.17	2.9	45	
biological	Predicted Soil Protein	5.30	36	
biological	Soil Respiration	0.5	33	
biological	Active Carbon	543	59	
chemical	Soil pH	8.0	21	
chemical	Extractable Phosphorus	1.6	47	
chemical	Extractable Potassium	30.2	39	
chemical	Additional Nutrients Ca: 1384.0 / Mg: 121.6 / S: 2.7 Al: 2.1 / Cu: 0.10 / Fe: 0.4 Mn: 2.9 / Zn: 0.2		88	

Overall Quality Score: **46** / Medium

CASH Test Ties Soil Health Indicators to Soil Processes

Physical Indicators	Soil Processes
Aggregate Stability	Resistance to dispersal: aeration, infiltration, crusting, germination, rooting, runoff & erosion
Available Water Capacity	Plant available water: water storage, drought resistance
Surface Hardness	0”- 6” compaction: aeration, surface rooting, infiltration, water transmission, germination, runoff & erosion
Subsurface Hardness	6” - 18” compaction: deep rooting, drought resistance, water movement and drainage, extreme precipitation resilience

Biological Indicators	Soil Processes
Soil Organic Matter & Total C	Water and nutrient storage/release, long-term energy storage, C sequestration
Active Carbon	C easily available as short-term microbial food source; biol. Activity
Soil Protein	Primary N-containing fraction of organic matter; N release
Soil Respiration	Integrates microbial abundance and metabolic activity; nutrient release

Chemical Indicators:	Processes as per standard soil test: nutrient availability, reaction, toxicity, pollution

Approaches for scoring measured values

1. Based on known threshold values
   - pH (e.g. pH ~ 6.3-7.2 is optimal for many crops)
   - Nutrients
   - EC, SAR

2. Based on peer group evaluation
   - When thresholds are unknown, undefined, or elusive
   - Analogous to standardized testing and medicine approaches that compare individual to the population
   - Calculate mean and standard deviation of all measurements within a population (group) →
   - Develop normal distribution function and from this a cumulative normal distribution function (used for scoring)

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
https://soilhealthlab.cals.cornell.edu

Page 1

Agricultural Service Provider:
Joseph Amsili
New York Soil Health / NYSH
jpa28@cornell.edu

Sample ID:
Field ID:
Date Sampled: 04/26/2022
Tillage: 1-7 inches

Measured Soil Textural Class: **loam**

Sand: **45%** - Silt: **37%** - Clay: **17%**

Group	Indicator	Value	Rating	Constraints
physical	Predicted Available Water Capacity	0.21	78	
physical	Surface Hardness	131	64	
physical	Subsurface Hardness	346	33	
physical	Aggregate Stability	4.1	6	Aeration, Infiltration, Rooting, Crusting, Sealing, Erosion, Runoff
biological	Organic Matter Soil Organic Carbon: 1.84 / Total Carbon: 1.96 / Total Nitrogen: 0.17	2.9	45	
biological	Predicted Soil Protein	5.30	36	
biological	Soil Respiration	0.5	33	
biological	Active Carbon	543	59	
chemical	Soil pH	8.0	21	
chemical	Extractable Phosphorus	1.6	47	
chemical	Extractable Potassium	30.2	39	
chemical	Additional Nutrients Ca: 1384.0 / Mg: 121.6 / S: 2.7 Al: 2.1 / Cu: 0.10 / Fe: 0.4 Mn: 2.9 / Zn: 0.2		88	

Overall Quality Score: **46** / Medium

Based on Threshold Values

Interpretation Ranges for Different P Soil Tests*

	Low and Medium	Optimum	High
Olsen	0–11	11–16**	>16
Morgan	0–4	4–10	>10
Bray 1 (Bray P-1)	0–25	25–45	>45
Mehlich 1	0–20	20–40	>40
Mehlich 3	0–30	30–50	>50
AB-DTPA (for irrigated crops)	0–8	8–11	>12

Table 1: General classification for sodium hazard of soil based on SAR values.

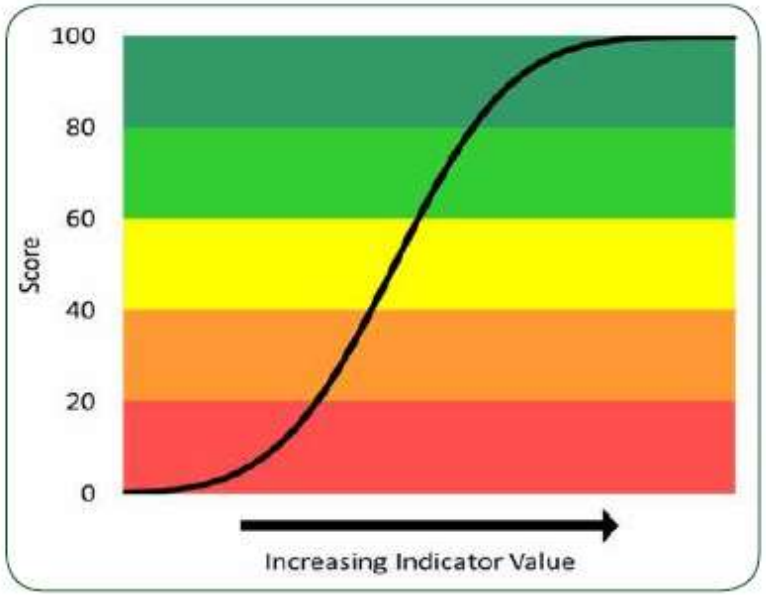
Classification	Sodium adsorption ratio (SAR)[2]	Electrical conductivity (EC) (dS/m)[1]	Soil pH	Soil physical condition
Sodic	≥13	<4.0	>8.5	poor
Saline-Sodic	≥13	>4.0	<8.5	varies
Slightly Saline	<13	2 - 4	<8.5	normal
Saline	<13	>4.0	<8.5	normal
High pH	<13	<4.0	>7.8	varies

[1]dS/m = mmho/cm
[2]If reported as exchangeable sodium percentage or ESP, use 15% as threshold value.

Based on peer group evaluation: Three Types of Scoring Functions

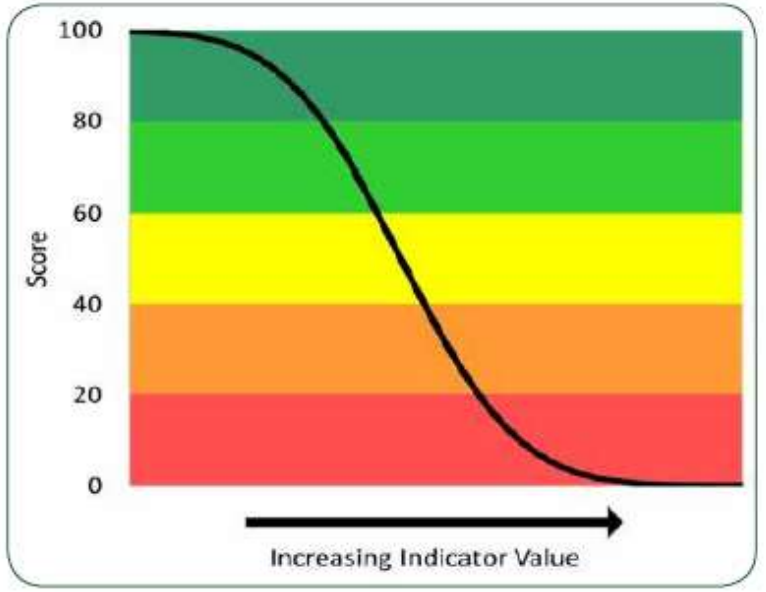
More is better
(e.g. SOM, SOC, POXC, Protein, Respiration, AggStab, AWC)

Score = 100 * CND

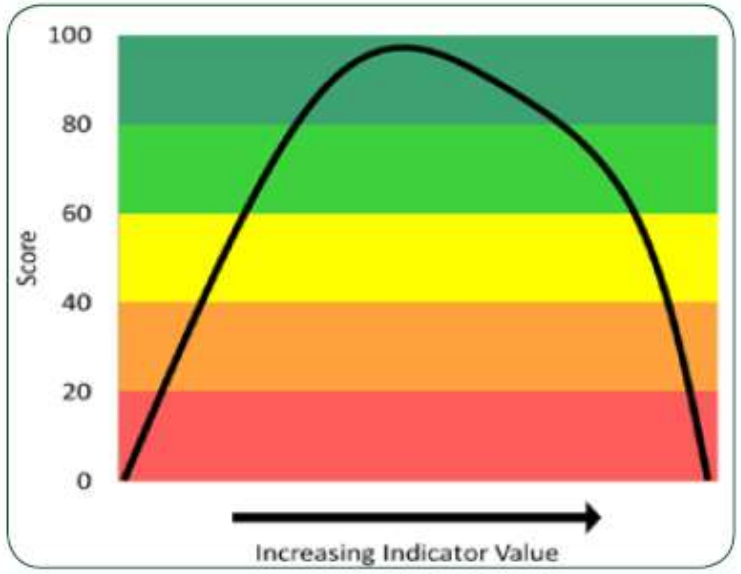


Less is better
(e.g. surface and subsurface hardness)

Score = 100 * (1-CND)



Optimum
(e.g. pH)

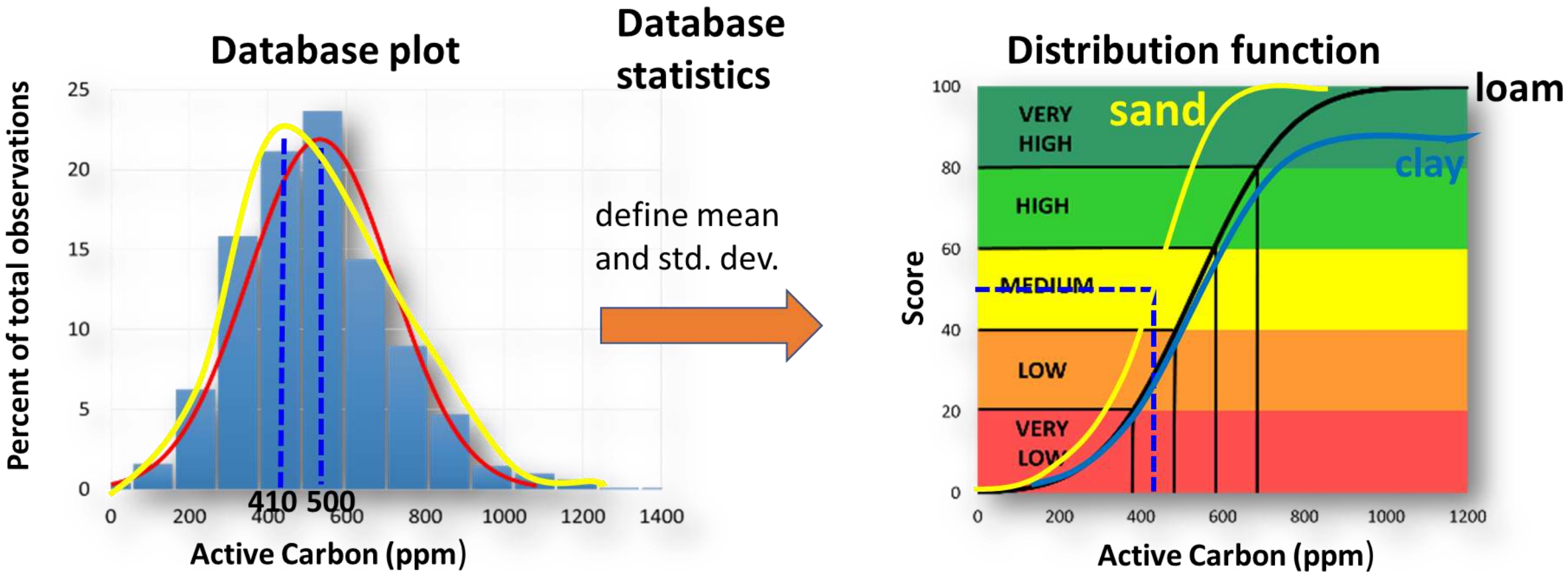


Based on: Andrews et al. (2004), Soil Management Assessment Framework (SMAF)

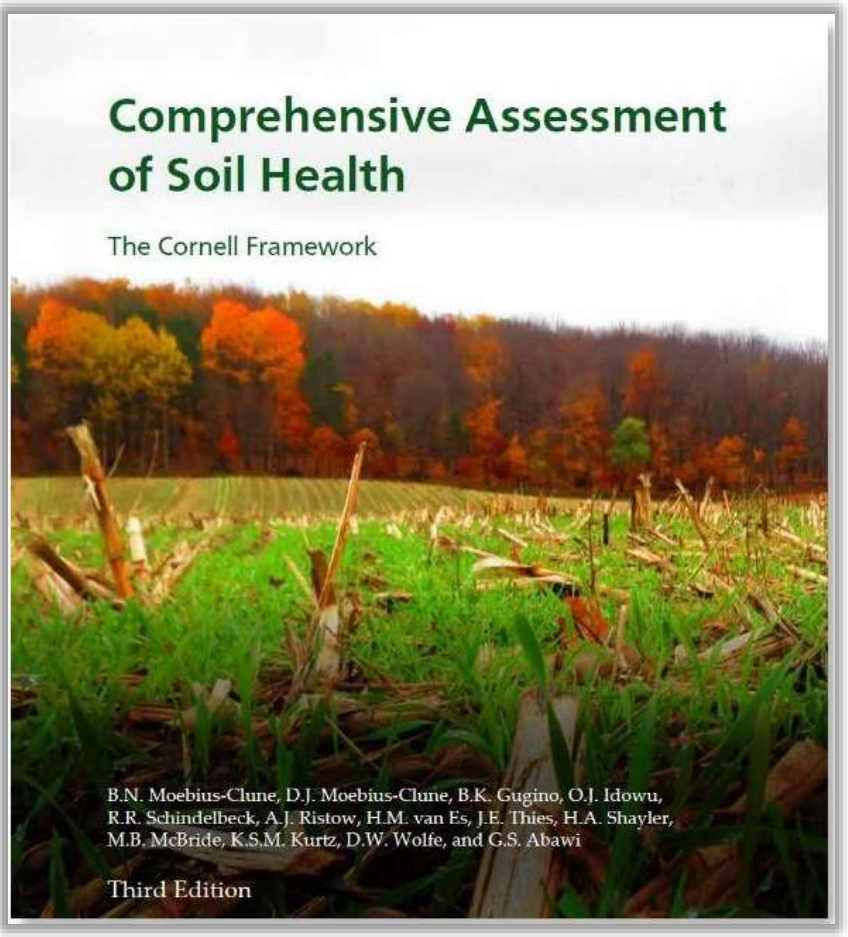
Generalized Scoring Function

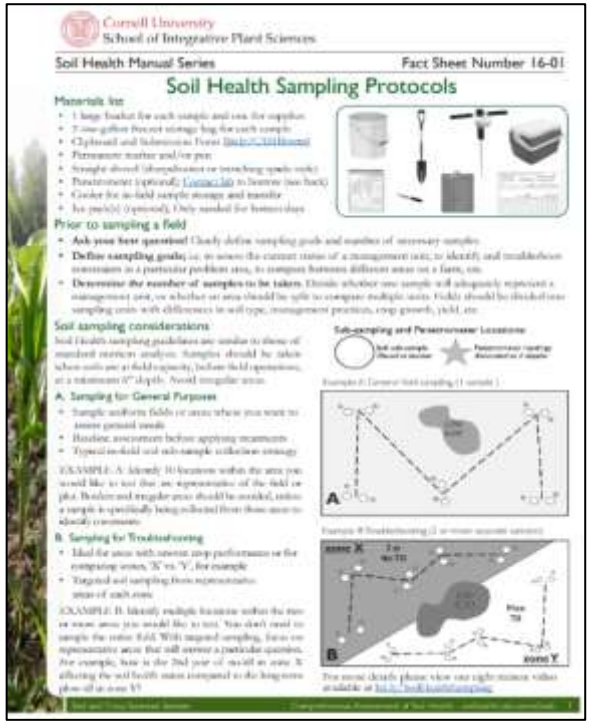
Cumulative Normal Distribution Function

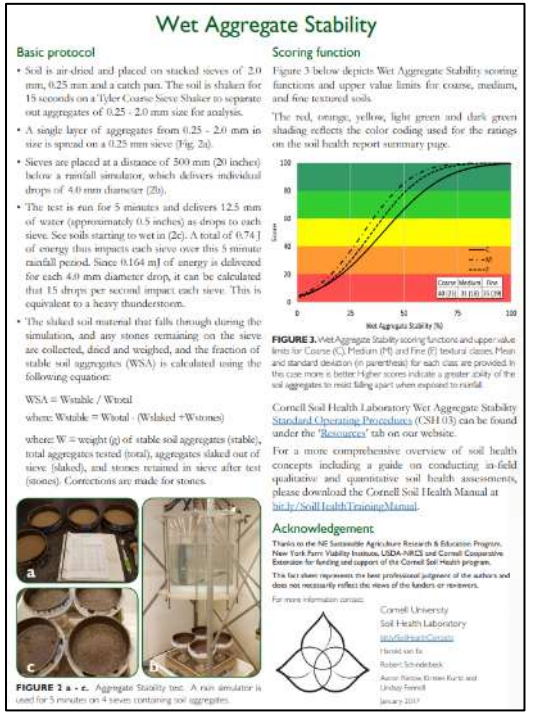
separate functions by textural group for most indicators



Cornell Soil Health Manual and Fact Sheet Series





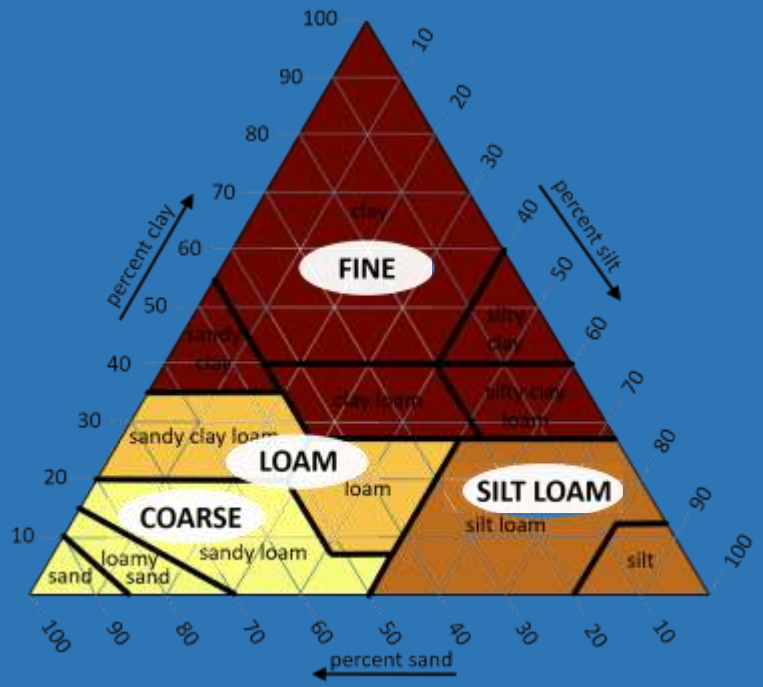


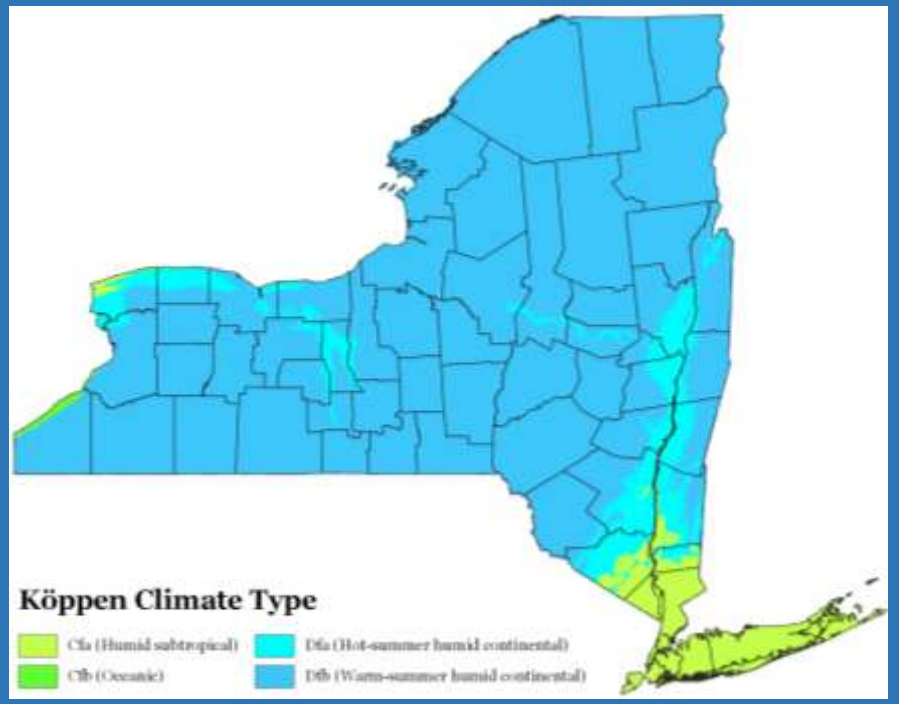
Cornell Soil Health Manual: https://soilhealth.cals.cornell.edu/manual/

Fact Sheets: https://soilhealth.cals.cornell.edu/resources/soil-health-manual-series-fact-sheets-2/

Research Findings

Effects of Soil Type and Climate



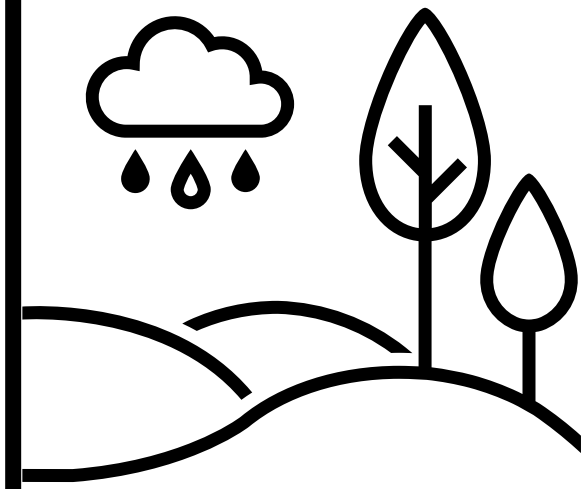


Credit: Richard Stehouwer

Major Factors of Soil Health

Production Environment

Inherent

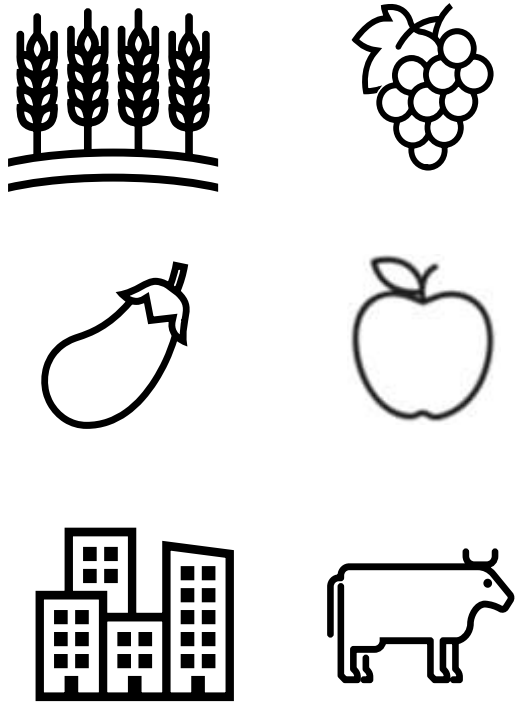


Parent material (minerals), climate, biology, slope, and time

No control

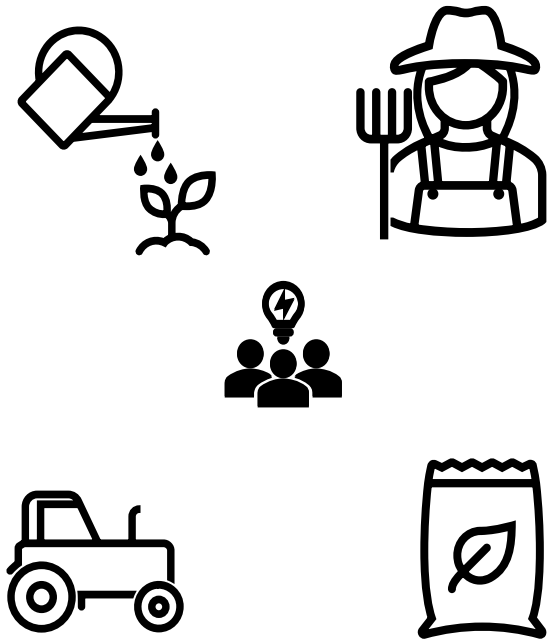
X

Cropping System



Limited control

Management



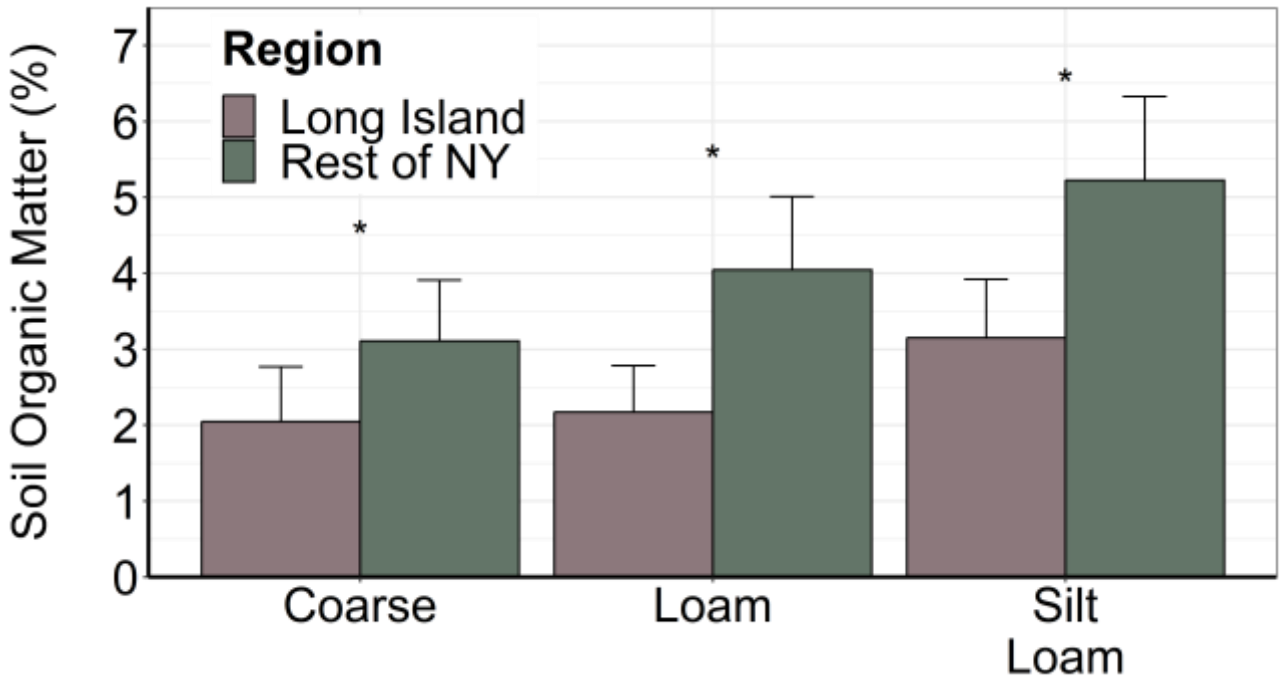
Much control

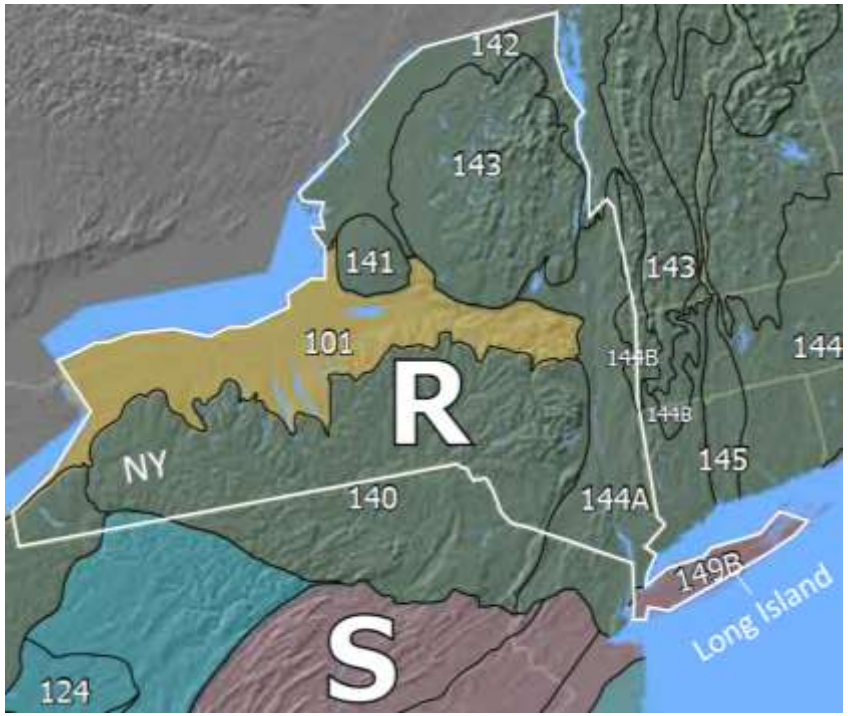
Graphics by Valentina Rubio

Regional Impacts on Soil Health – Think Climate

Long Island soils have lower soil organic matter on average than the rest of NY

Pastures from Long Island vs. the rest of NY





Explanation: LI's Coarser textured soils and 3.3 °C warmer climate are likely causes of these differences.

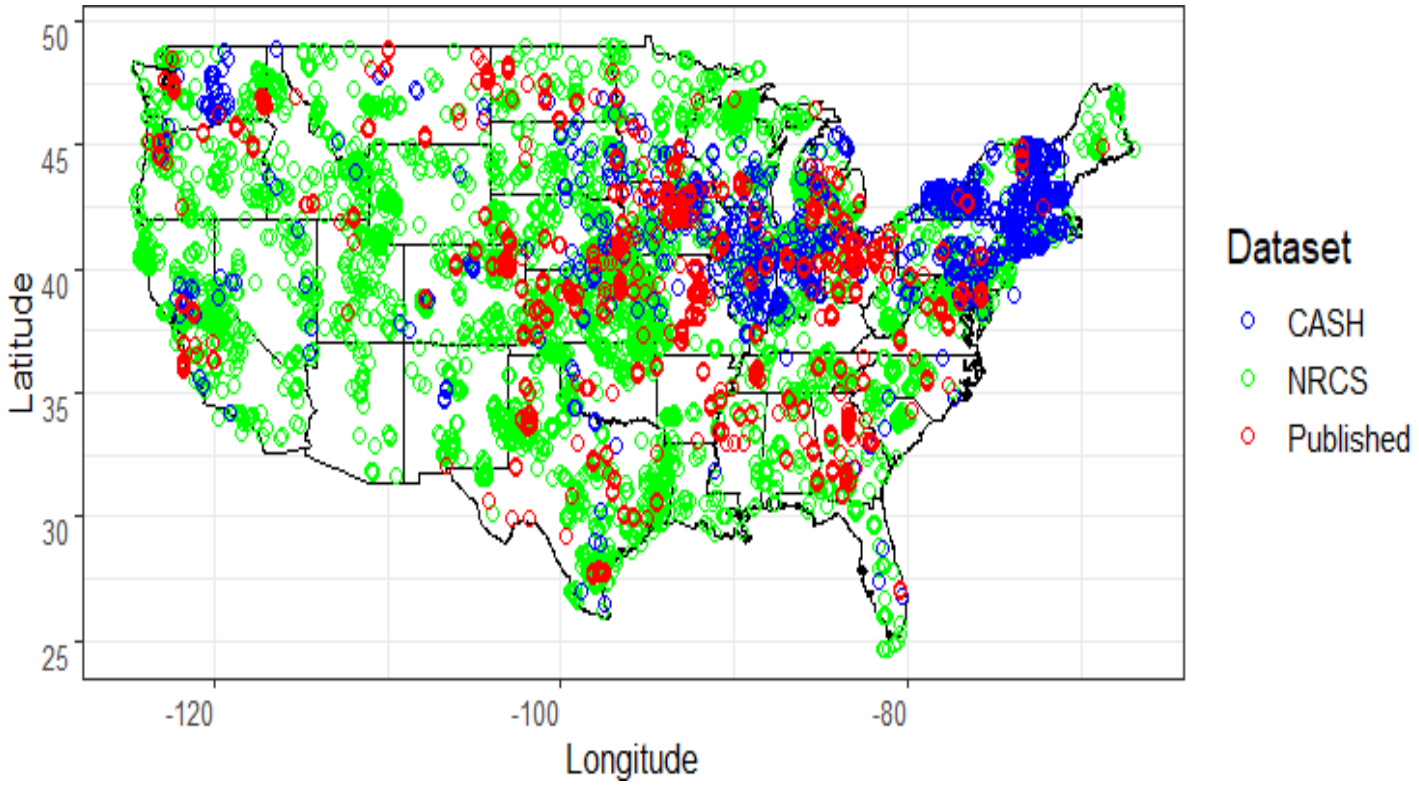
Amsili et al., 2023

SHAPE: New soil health interpretation tool

S – Soil
H – Health
A – Assessment
P – Protocol
for
E – Evaluation

- Peer-group population
- Fuzzy logic (CND)
- Bayesian Modeling

Large database – 14,680 Soil Organic Carbon Obs.



Nunes et al., 2021. The soil health assessment protocol and evaluation applied to SOC.

USDA Agricultural Research Service

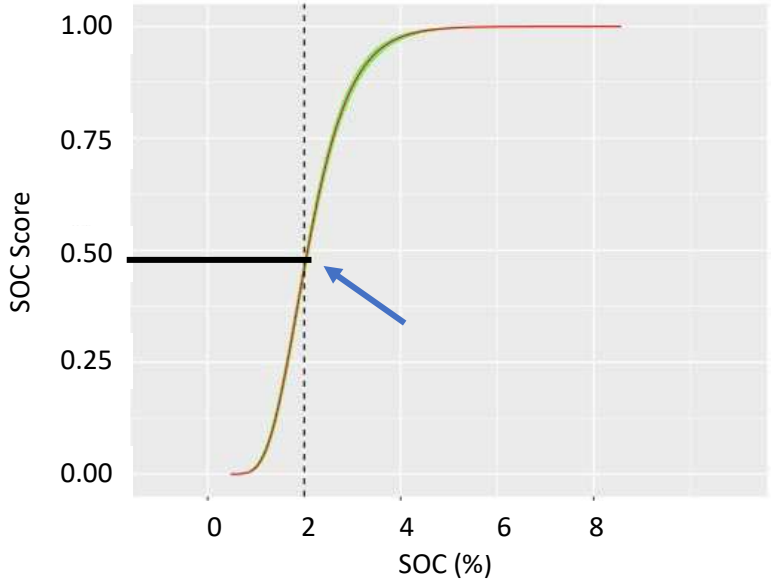
Data Interpretation: SHAPE for soil organic carbon

Mollisol - Iowa

Silty clay loam, Endoaquol

Peer group:

Texture:	**T3**
Suborder:	**S3**
Temp:	**10 °C**
Precip:	**900 mm**



SOC = **2%**

Score = **0.46**

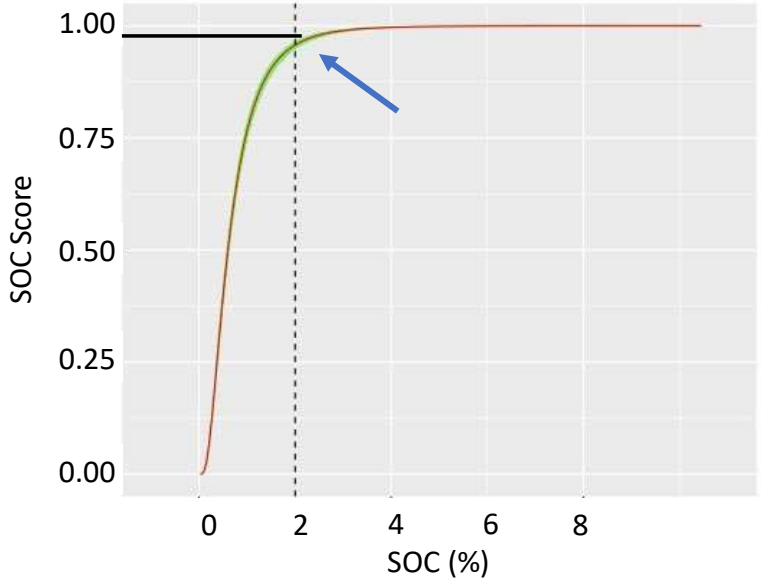
Medium

Aridisol - Texas

Loamy, Calcic Petrocalcids

Peer group:

Texture:	**T2**
Suborder:	**S5**
Temp:	**18 °C**
Precip:	**330 mm**



SOC = **2%**

Score = **0.96**

HIGH

Nunes et al., 2021

SHAPE is now available for SOC, **POXC, ACE Protein, Resp, and Ag stability**

SHAPEv1.2 Soil Health Dashboard

SOC | POXC | ACE-Protein | Respiration | CASH Aggregate Stability | KSSL Aggregate Stability | Batch Score Instructions

Soil Properties

Texture: T3

Suborder: S4

Temperature (degrees C): 9

Precipitation (mm): 1000

Example Batch Data

Choose a dataset: POXC

Download

POXC Batch Scoring

Upload POXC Batch CSV

Browse... No file selected

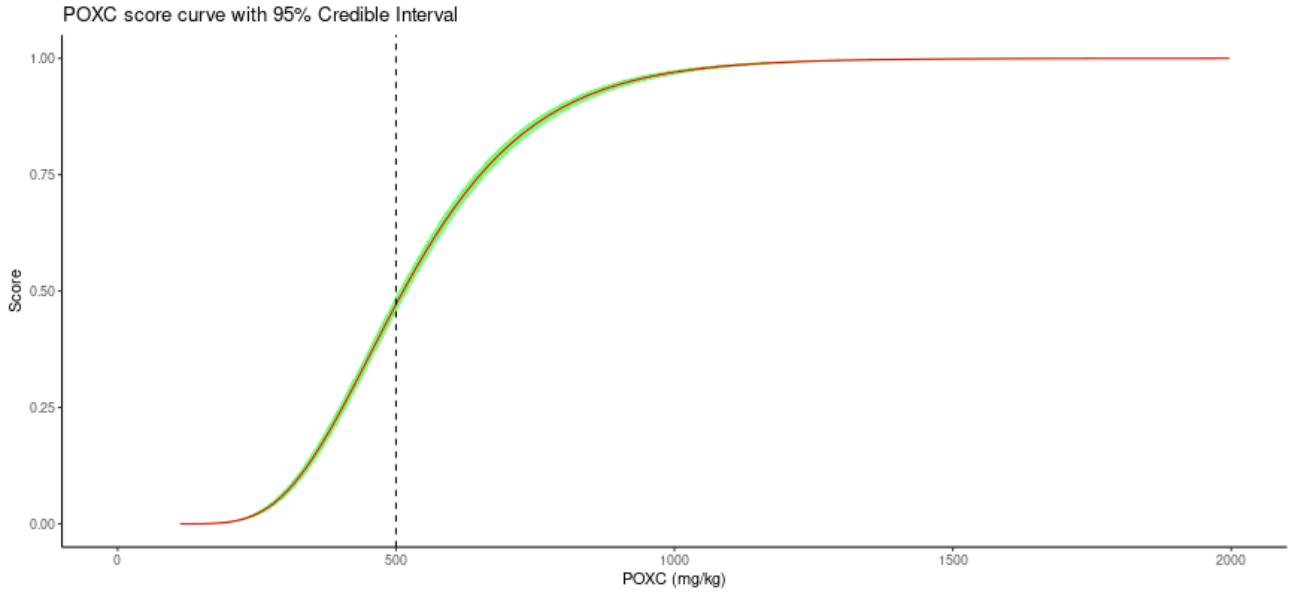
Download Scored Data

POXC Single Site Scoring

POXC (mg/kg): 500

POXC SHAPE score with credible interval

2.5%	Mean	97.5%
0.45	0.47	0.49



Peer Group Thresholds

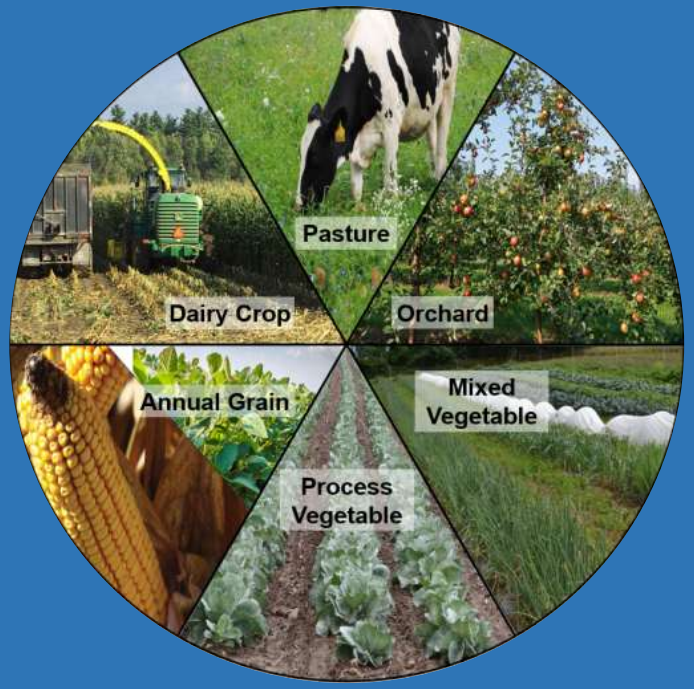
Score	90%	95%	99%
POXC (mg/kg)	807.43	918.30	1168.93

WEB APP: https://paparker.shinyapps.io/shape_app/

Nunes et al., In review. SHAPEv1.0 Scoring curves and peer group benchmarks for dynamic soil health indicators (will be published in 2024)

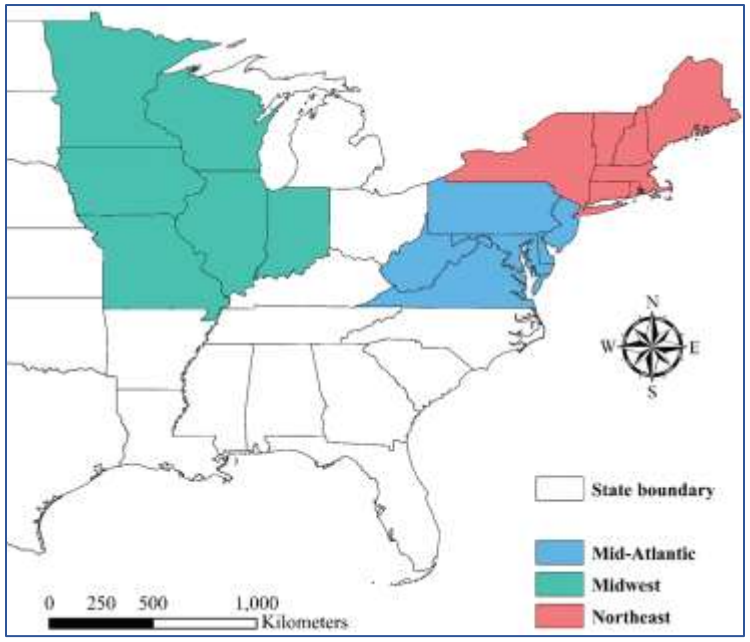
Research Findings

Effects of Cropping system



Regional Soil Health Differences

Fine et al., 2017; data for medium-textured soils



Why do inherently better soils show lower soil health outcomes?

	Northeast	Mid-Atlantic	Midwest
Ag Stability (%)	48.8 a	42.7 b	25.2 c
Avail Water Cap (g/g)	0.19 c	0.22 b	0.23 a
PenResist-15 (kPa)	1050 a	1346 b	1264 b
PenResist-45 (kPa)	2037	2005	2053
OrgMatter (%)	3.99 a	4.12 a	3.04 b
ActC (mg/kg)	549 a	564 a	475 c
Protein (mg/g)	8.8 b	10.0 a	4.9 c
Respiration (mg CO2/g)	0.70 b	0.86 a	0.47 c

Cropping Systems, Carbon and Nutrient Cycling and Balances

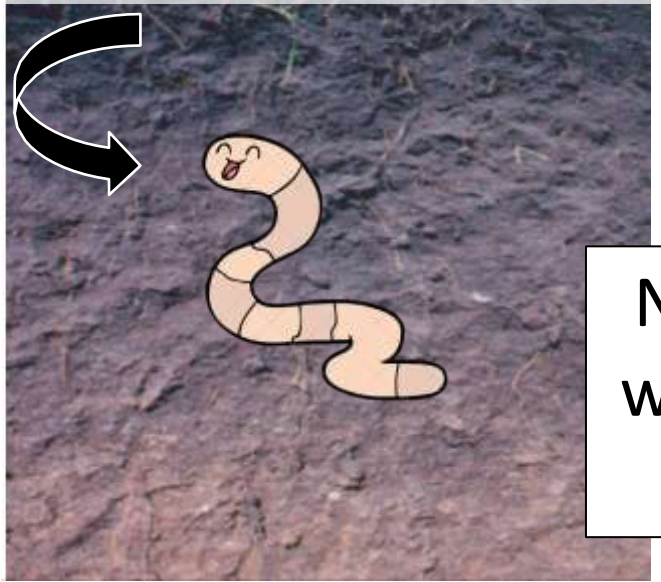
Two Extremes related to Agricultural Specialization

Natural or Pasture

Returned:
90-100%

No disturbance through tillage

high root
turnover



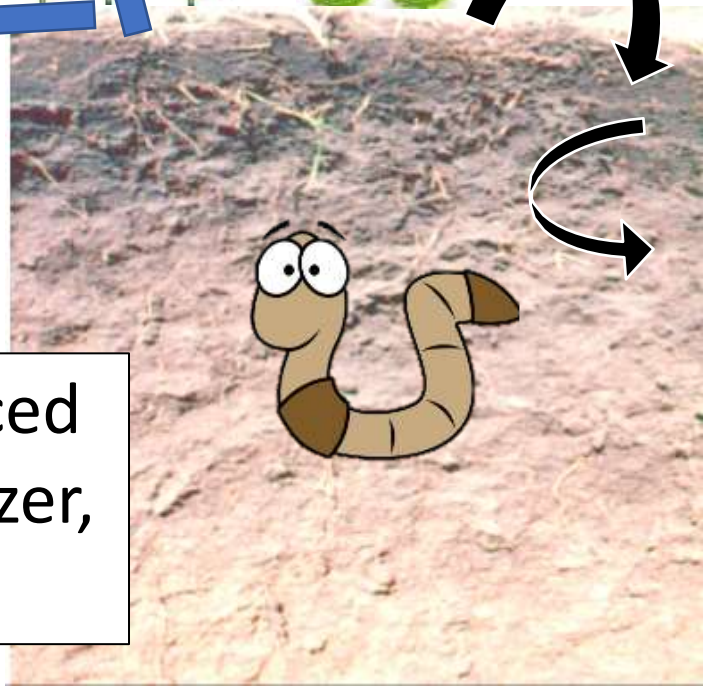
Cash Crops

CO_2 loss
from tillage

Harvest:
50-70%

Returned:
30-50%

Erosion

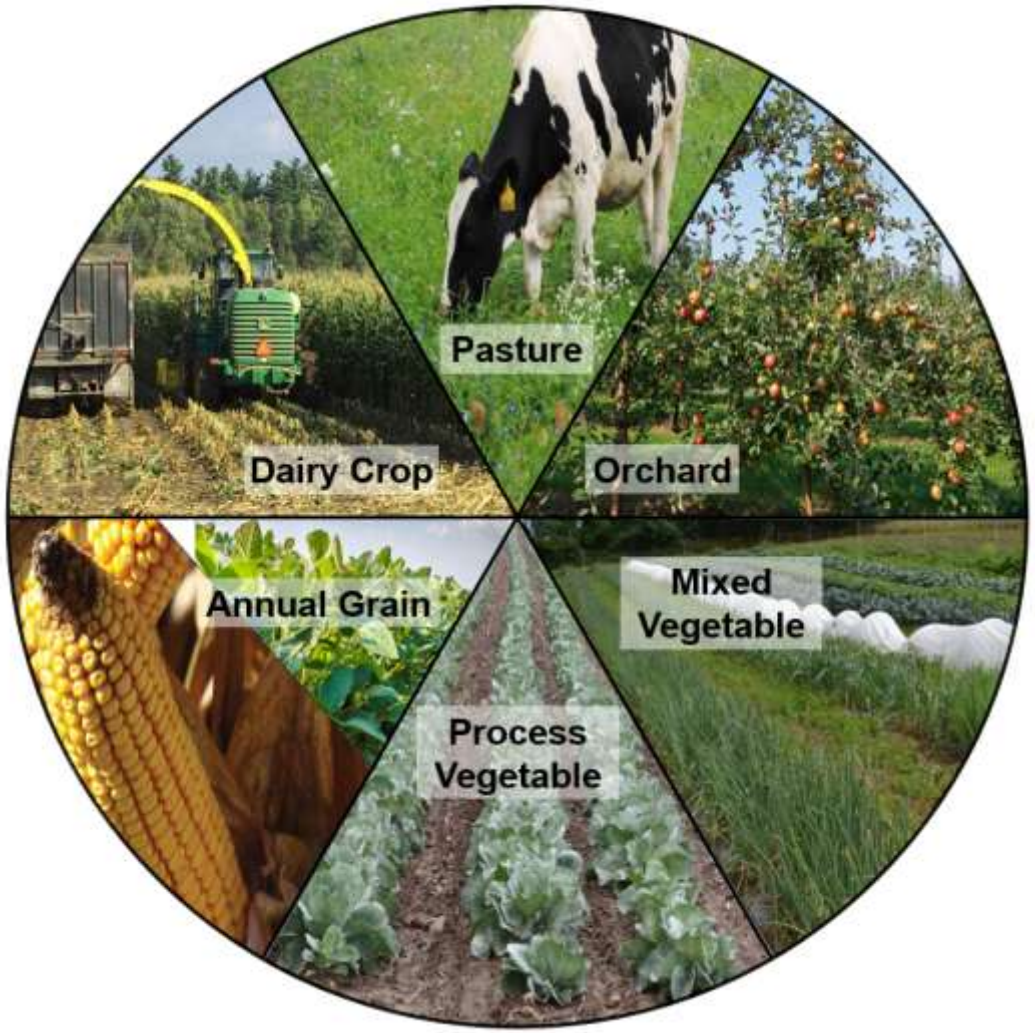


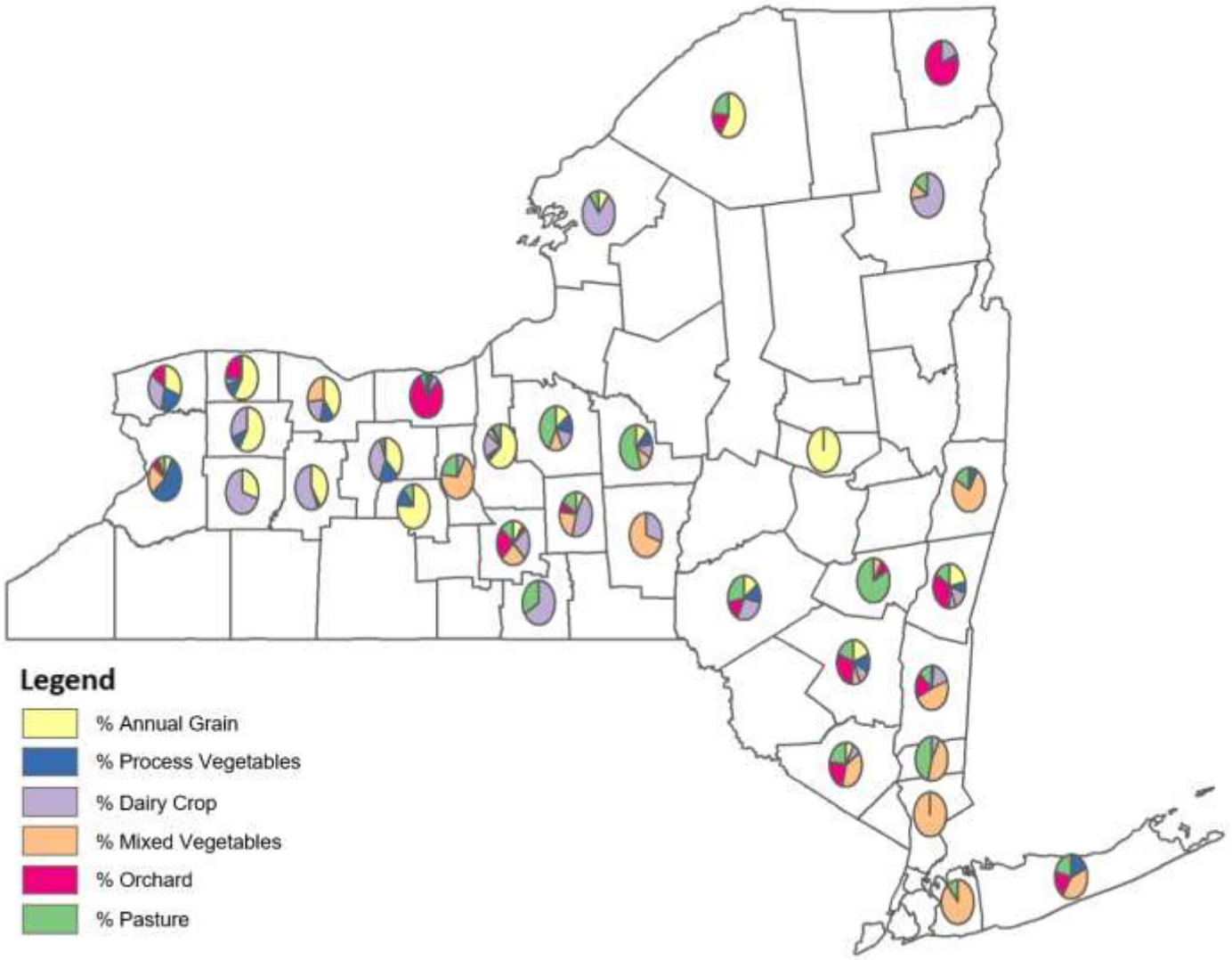
low root
turnover

Nutrients are replaced with synthetic fertilizer, but not carbon

Characterization of Soil Health in New York State

How do Cropping Systems (human land use) impact soil health?

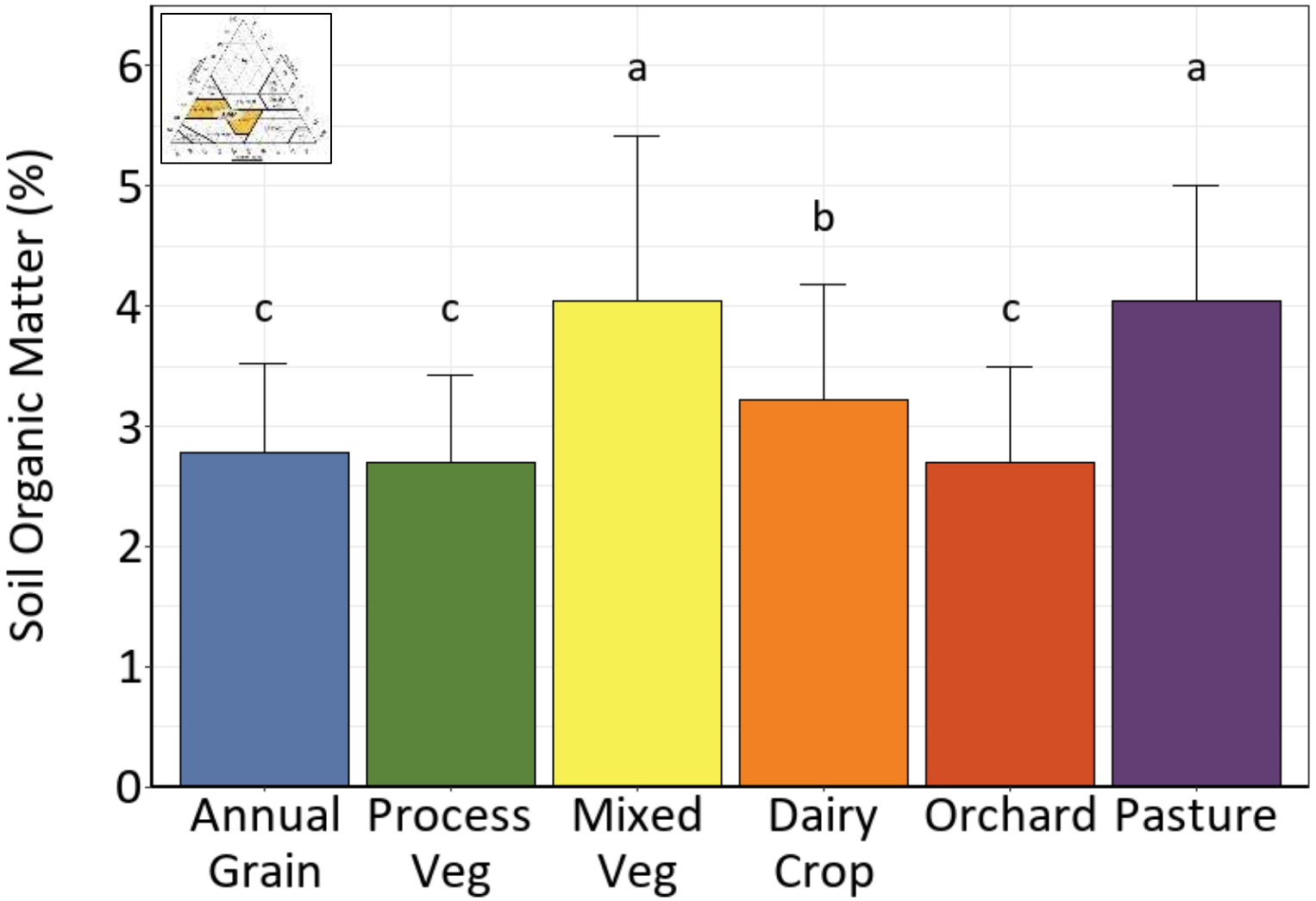




CornellCALS College of Agriculture and Life Sciences

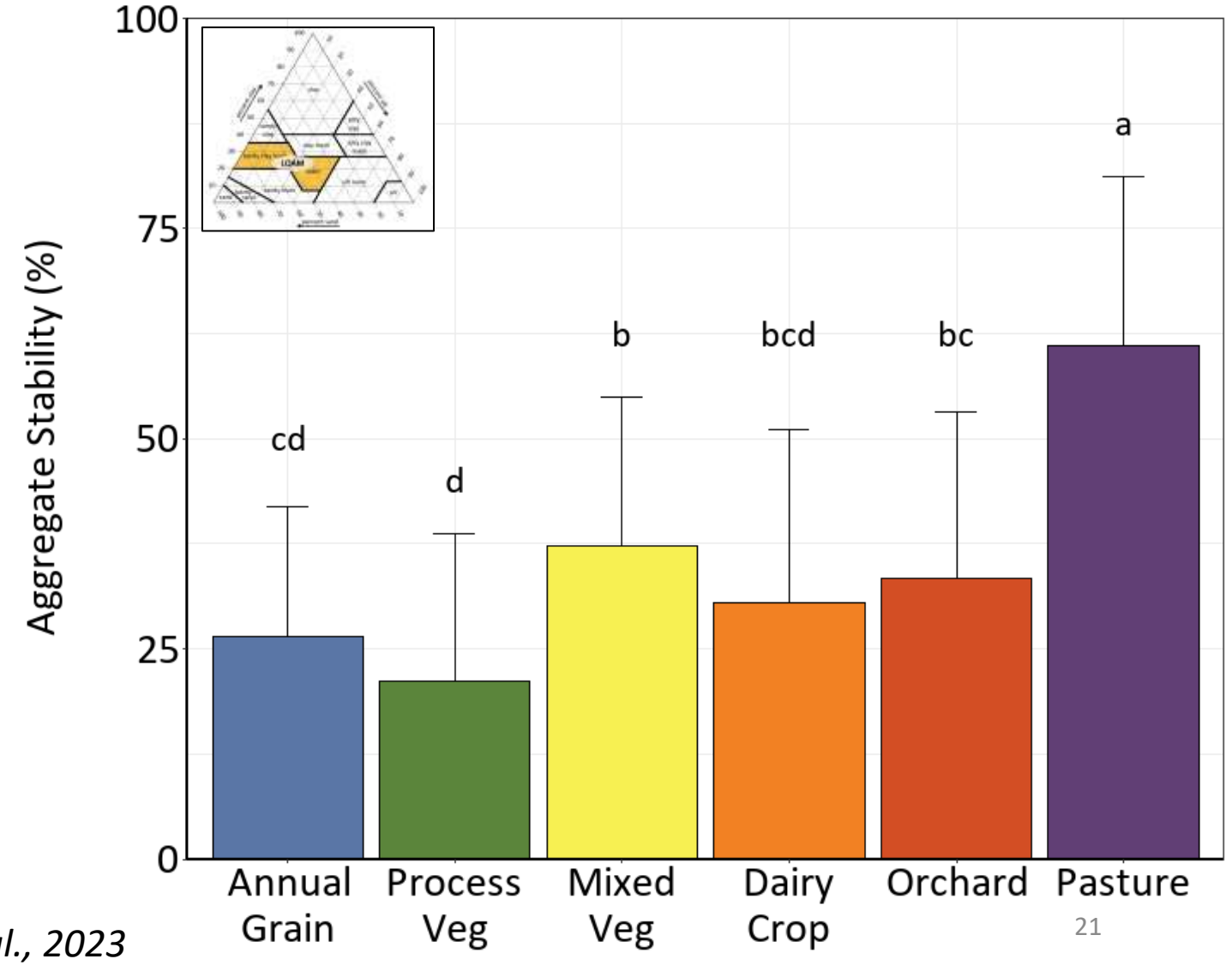
Amsili et al., 2023. Empirical approach for developing production environment soil health benchmarks

Pastures and Mixed Veg systems maintained the highest levels of soil organic matter



Amsili et al., 2023

- Undisturbed pastures had the highest aggregate stability
- Mixed Veg had greater aggregate stability than Processing Vegetables



Amsili et al., 2023

NYS Soil Health and Climate Resiliency Act

- Signed by Kathy Hochul on Dec. 23, 2021 (approved unanimously in assembly and senate)

“…

establish appropriate voluntary [benchmarks] for soil health reflective of different <u>regions</u>, <u>soil types</u>, and <u>[cropping system]</u>

….”

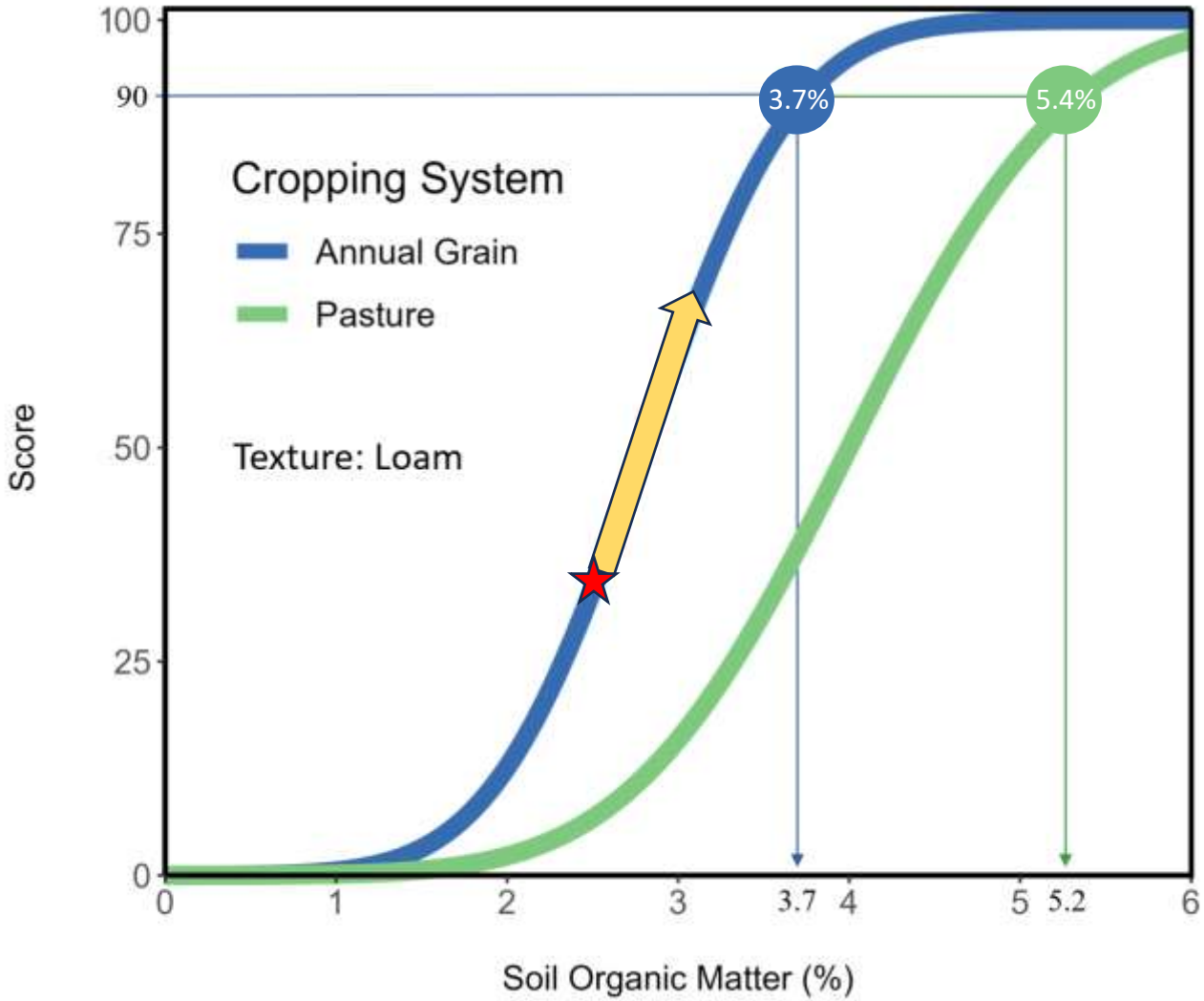
Setting Benchmarks for Soil Health

- Metrics for quality standards are common for air and water, but not for soil
- Soil health benchmarks can help farmers calibrate their management
- Soil health benchmarks can help target policy efforts
- Soil health benchmarks need to be
  - Adapted to regions
  - Adapted to soil types (soil texture, etc.)
  - Adapted to production system

Production Environment Soil Health (PESH) Benchmarks

Example - Annual Grain and Pasture systems on loam soils in upstate NY

- Development of soil health benchmarks by soil type, cropping system, and region (**production environment**)
- → define benchmarks as the 90th percentile
- Establishes clear pathways and realistic soil health targets



Amsili et al., 2023

PESH Benchmarks – *Pasture as a Universal Benchmark*

- Pastures represent the best possible soil health outcome for a given soil type/region, thus can act as a universal upper benchmark for all other cropping systems

Credit: Englebert Farms and Real Organic Project

Upstate NY
Pasture Cropping System

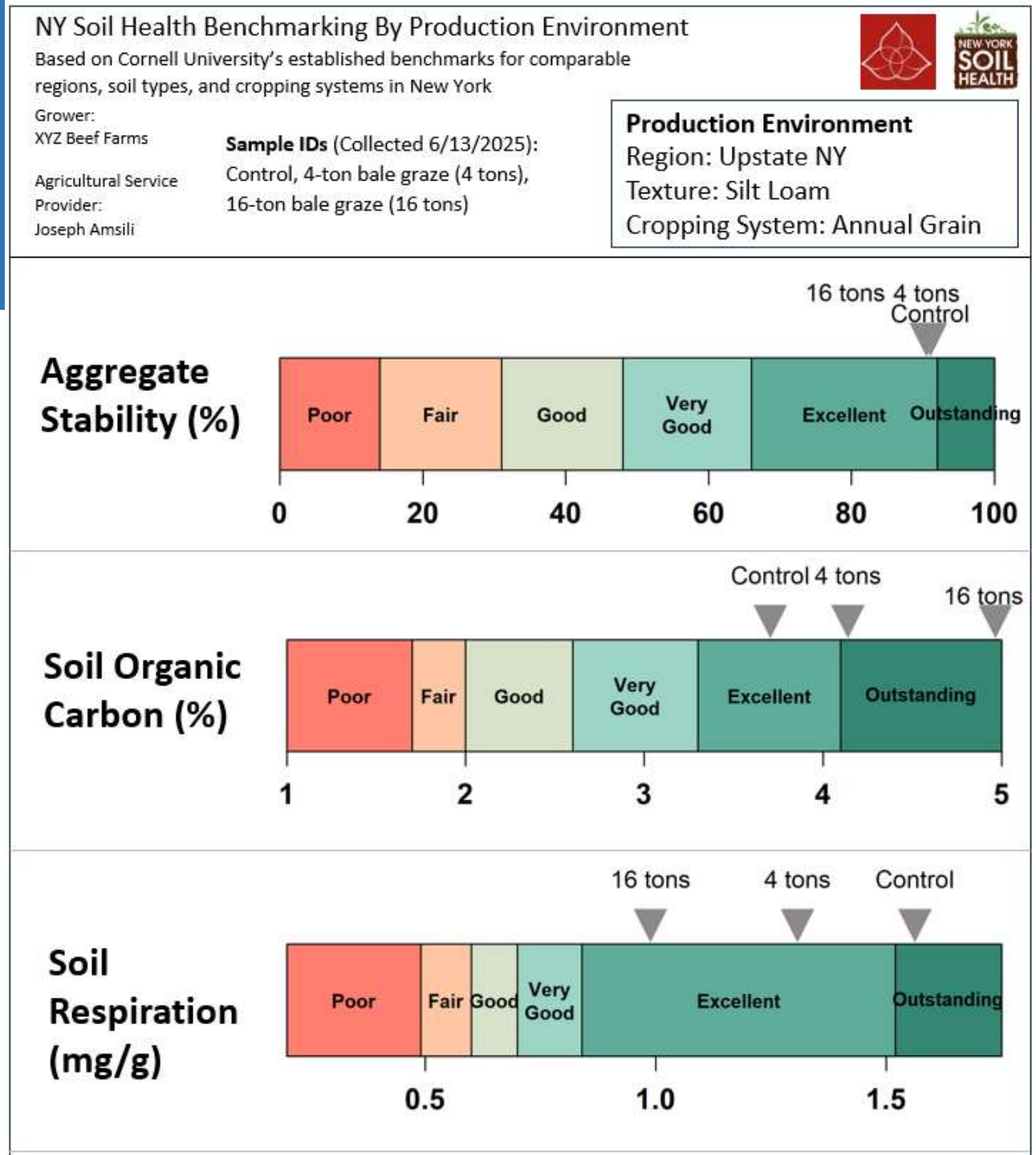
Texture Class	n	Q75 SOM %	Q90 SOM %
Coarse	21	3.3	3.9
Loam	59	4.9	5.4
Silt Loam	69	5.8	6.1
Fine	7*	5.8	6.1

Amsili et al., 2023 + New Data

Soil Health Benchmarking Reports for the Farmer and Service Provider

Breaks between 6 categories refer to specific benchmark values:

- Between Poor and Fair is Q25
- Between Fair and Good is Q50
- Between Good and Very Good is Q75
- Between Very Good and Excellent is Q90
- Between Excellent and Outstanding is Q90 for Pasture Systems



Soil Health Benchmarking infographics for the consumer:

Marketing soil health and carbon farming to the consumer:

- Website
- Farmers Market
- Buyers

OECHSNER FARMS

GROWING HEALTHY SOIL: 2024 HIGHLIGHTS

By closely monitoring our soil's health, we're continuously improving our farming methods to leave the land better than before.

Check out our latest farm results!

SOIL HEALTH CHAMPION '24 NY

WE DIG HEALTHY SOIL

NEW YORK SOIL HEALTH

HOW WE GOT THERE

Oechsner Farms builds soil health and carbon levels through their committment to diverse crop rotations that include perennial red clover sods, cover crops, and reducing tillage where possible.

SOIL HEALTH SCORE

Cornell University's composite soil health score is based on a suite of physical, biological, and chemical measurements. Healthy soil provides a favorable growing environment for crops and soil organisms, and defends them from pests and diseases.

SOIL ORGANIC CARBON

Soil organic carbon, the concentration of carbon in a soil, is essential for healthy soil and is derived from plant and organismal remains. It supports moisture retention, stable crop growth, healthy biological communities, and climate change mitigation.

Average farm values are Cornell University established benchmarks for comparable soil types and cropping systems. Oechsner Farms data based on soil samples collected across eight fields in 2024.

NEW YORK SOIL HEALTH

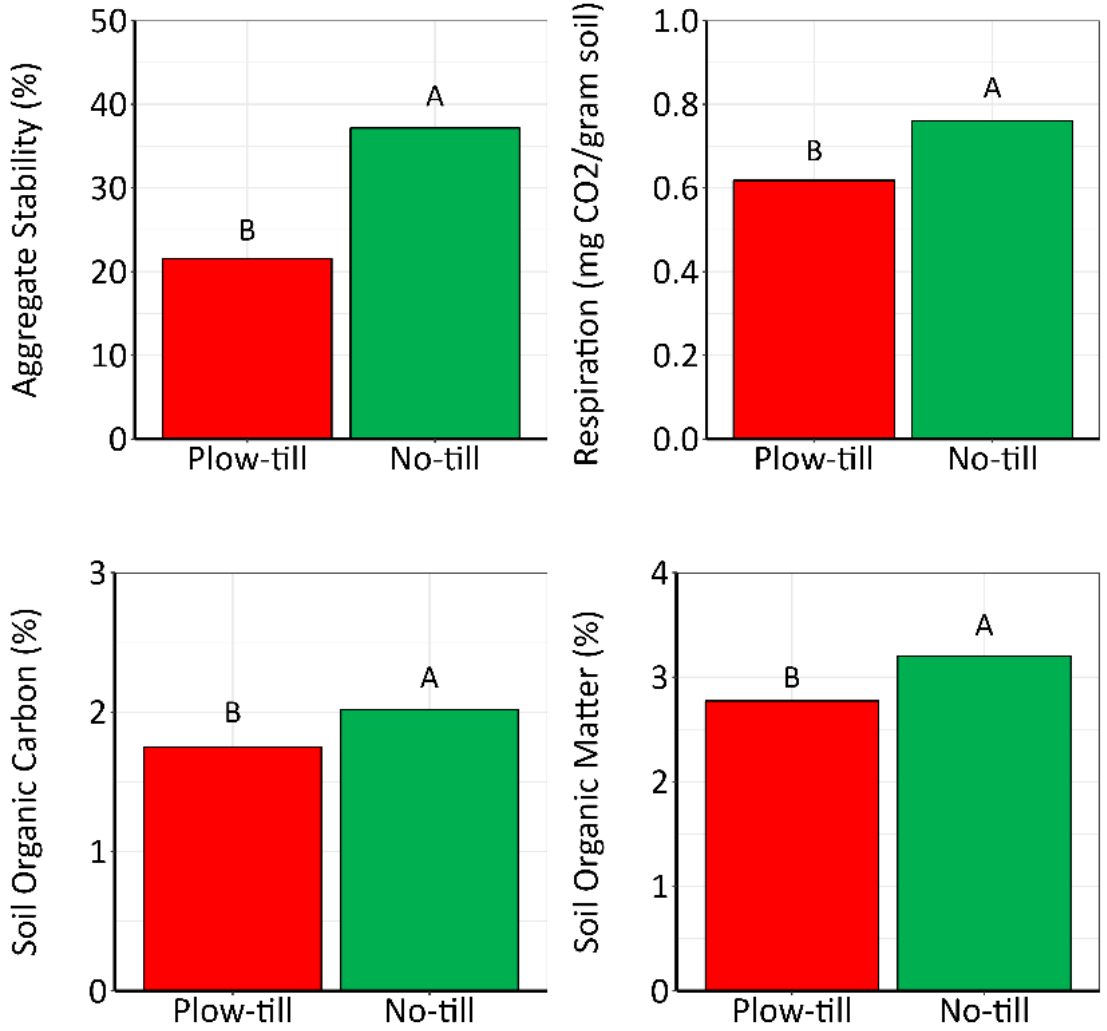
LEARN MORE:
OechsnerFarms.com & NewYorkSoilHealth.org/Champions

Cornell CALS

Effects of Agronomic Management

Effects of tillage on soil health (0-6 in)

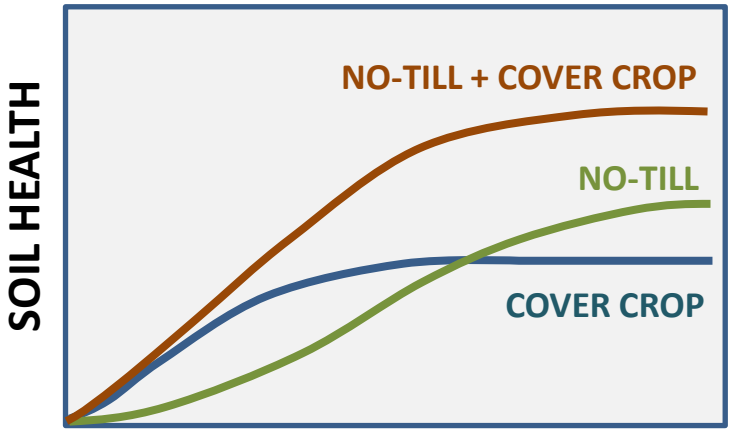
26 Years Tillage – Honeoye Silt Loam - Aurora, New York (1992-2019)

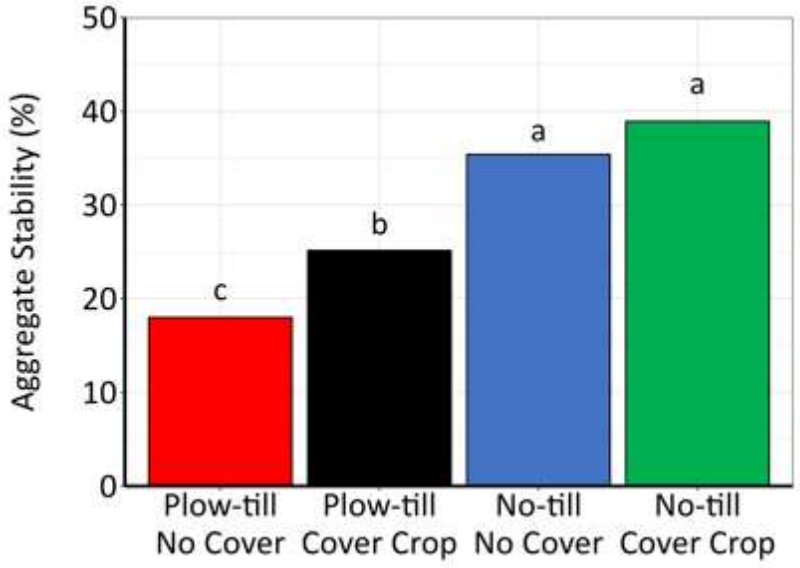


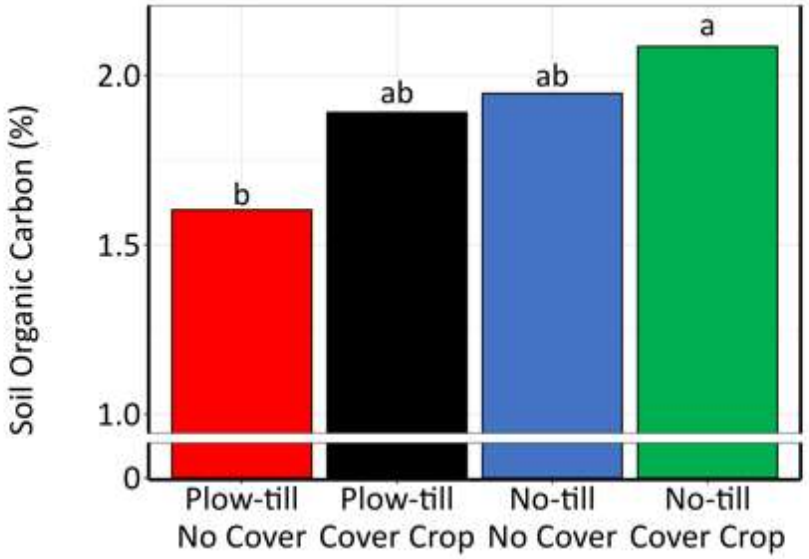
2019 Sampling: Unpublished data; same experiment as in Nunes et al. 2018

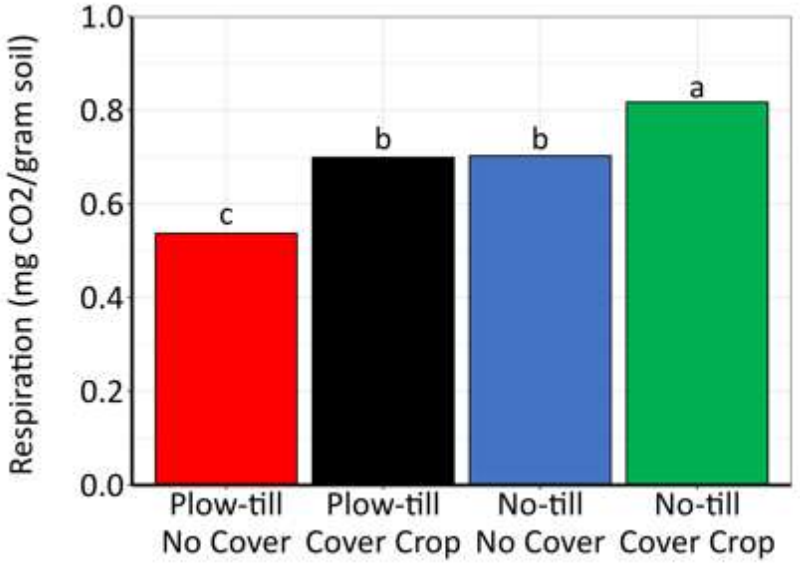
Stacking No-till and Cover Crops led to additive benefits

26 Year Tillage and 6 Year Cover Crops - Aurora, New York (1992-2019)





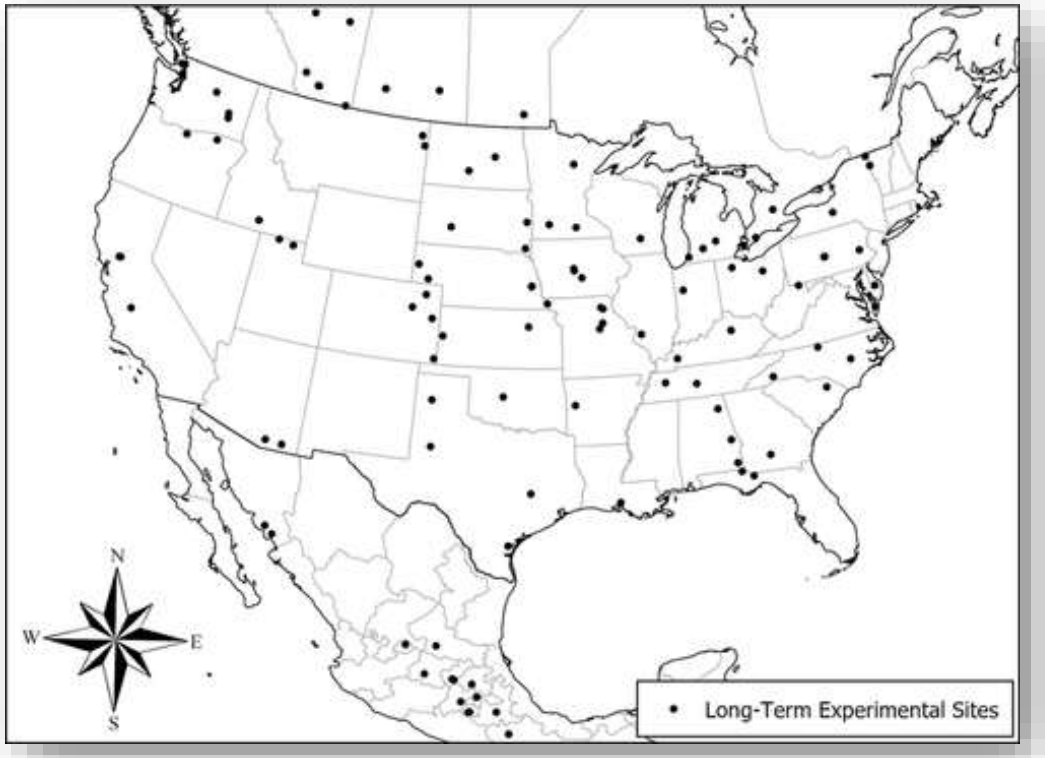


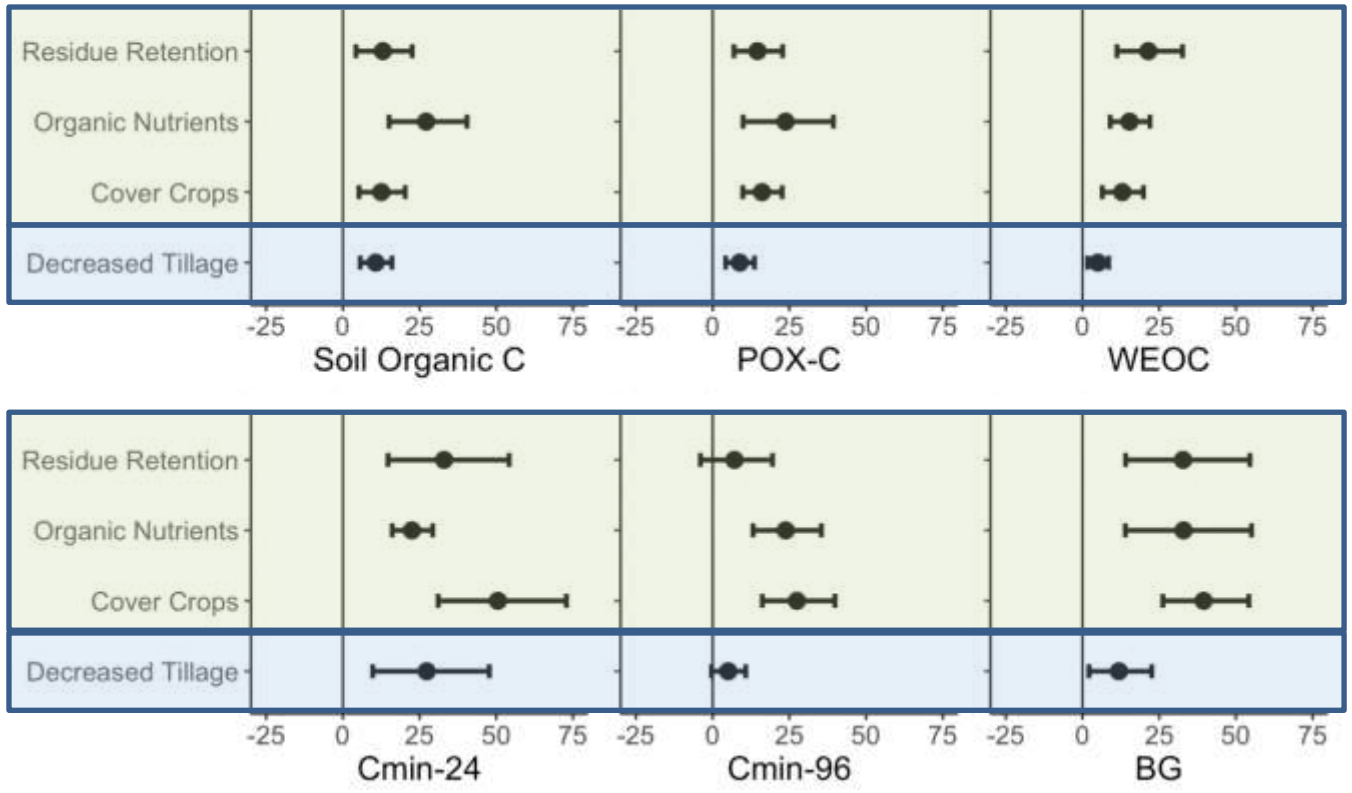


2019 Sampling: Unpublished data; same experiment as in Nunes et al. 2018

Management that increases organic matter inputs leads to slightly larger increase on biological indicators than decreased tillage

North America Soil Health Assessment Project (Soil Health Institute)



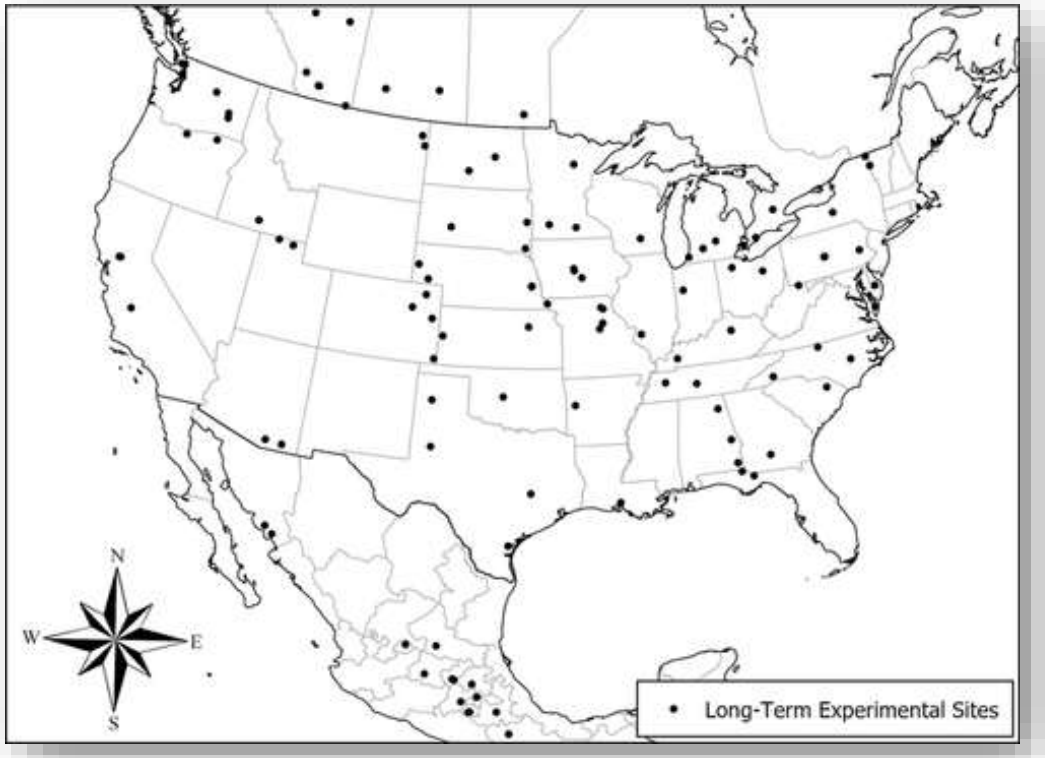


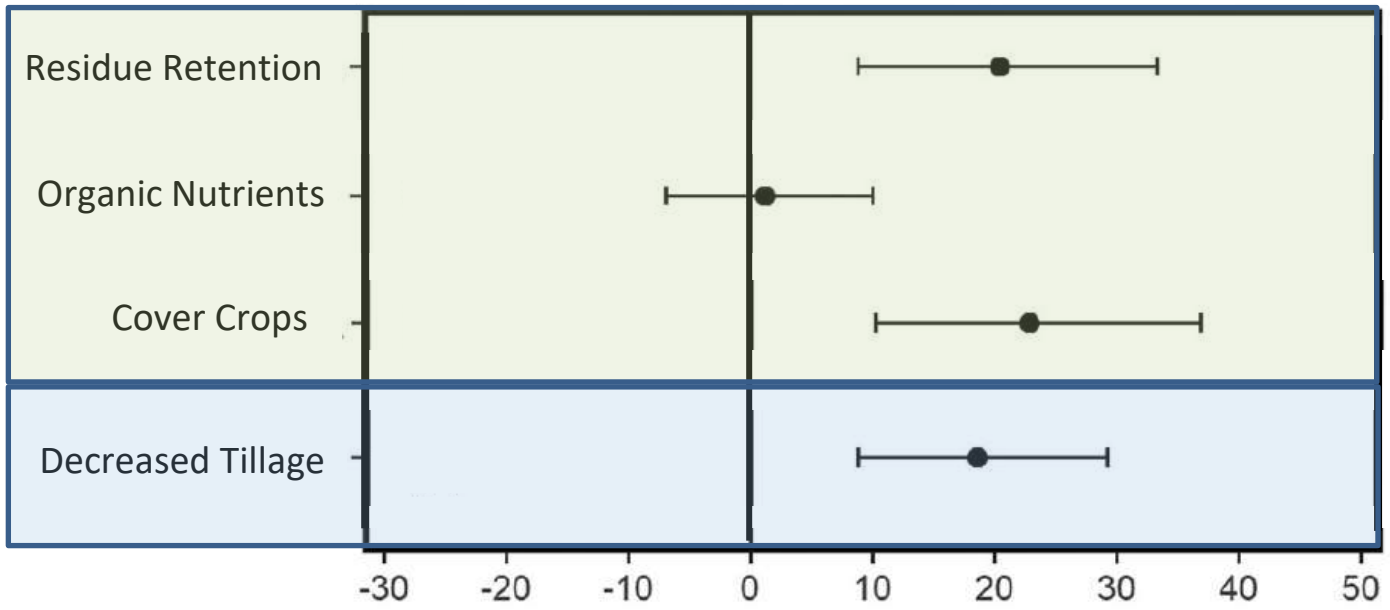
% increase

Liptzin et al., 2022. An evaluation of carbon indicators of soil health in long-term agricultural experiments

Residue retention, cover crops, and decreased tillage were all similarly important for improving aggregate stability

North America Soil Health Assessment Project (Soil Health Institute)

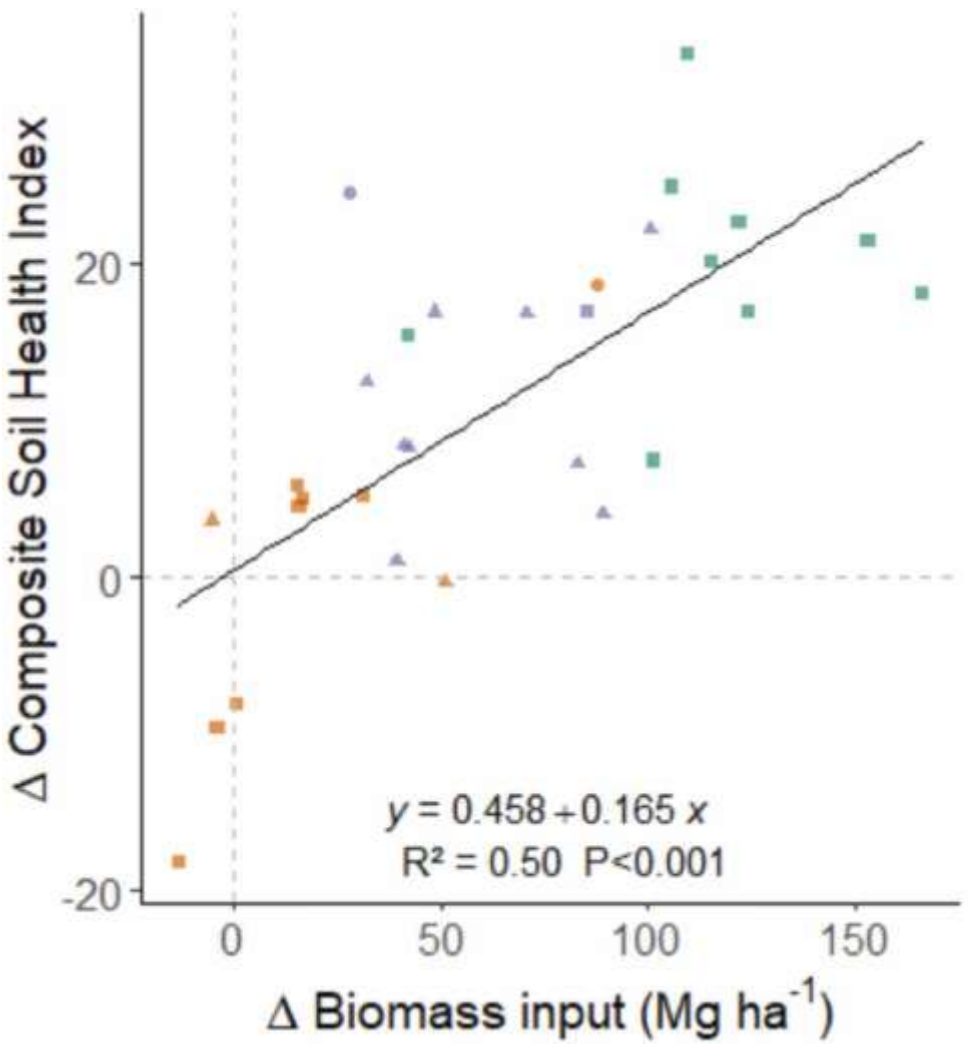




% increase in Aggregate Stability

Bagnall et al., 2022. Selecting soil hydraulic properties as indicators of soil health…

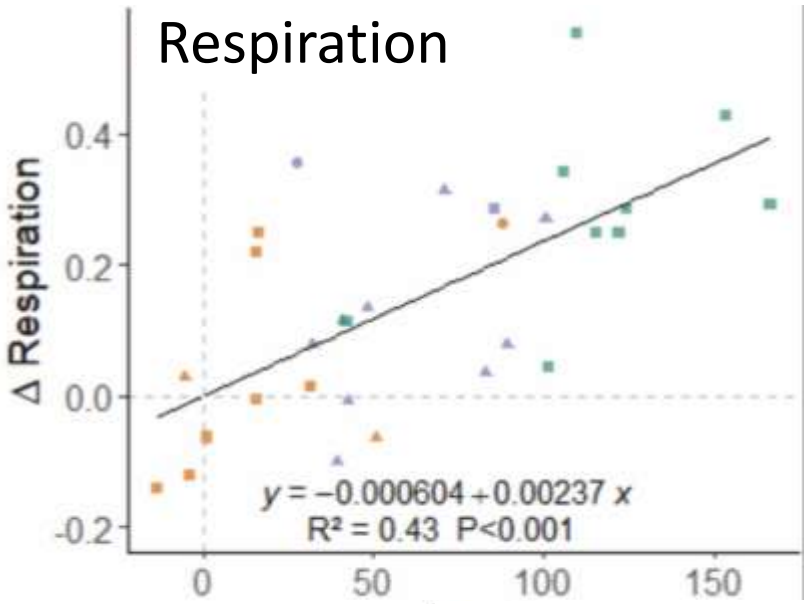
Biomass inputs drive management impacts on soil health



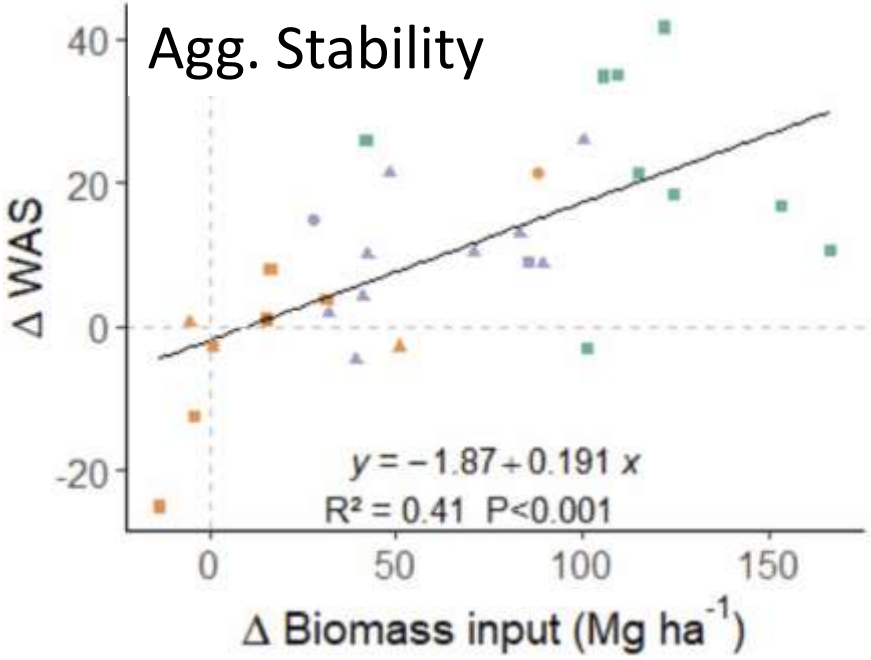
Experiment
- Exp 1
- Exp 2
- Exp 3

Tillage_Pasture
- CT_Y
- NT_N
- NT_Y

Respiration

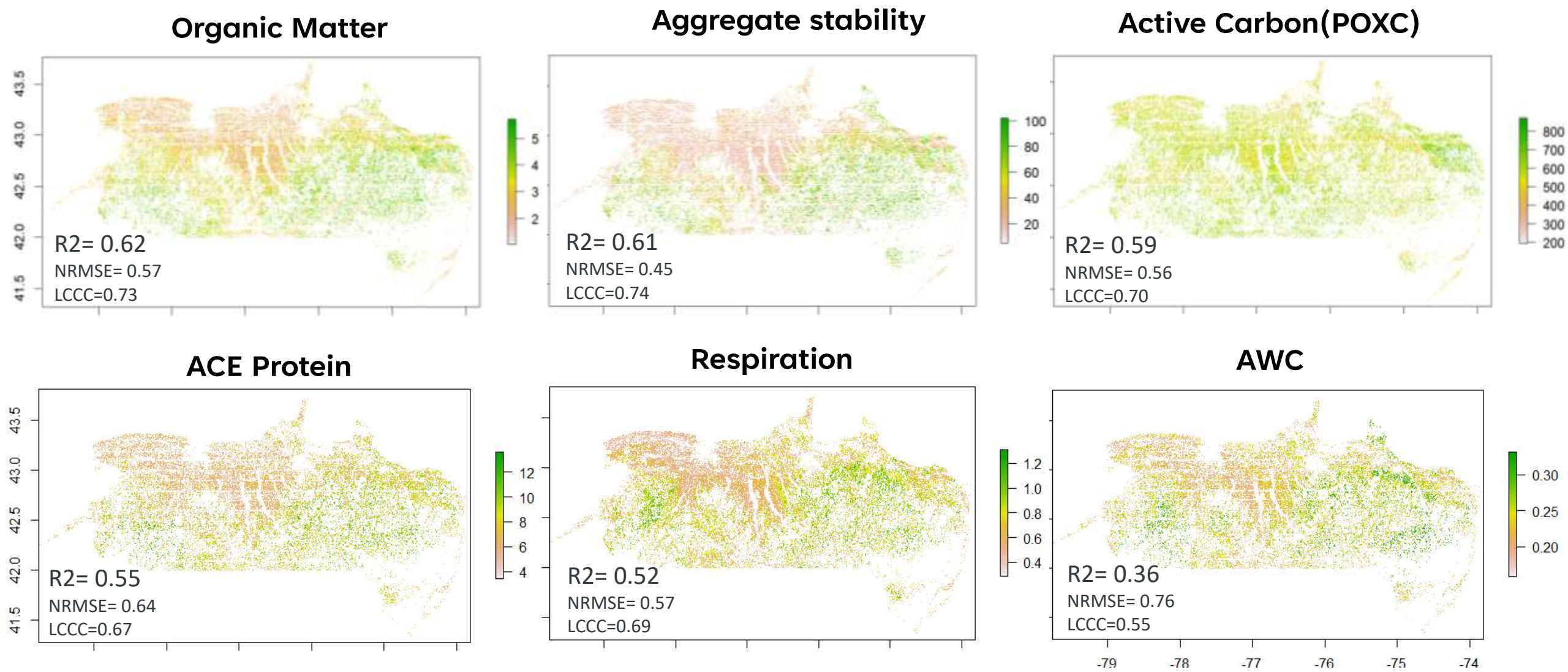


Agg. Stability



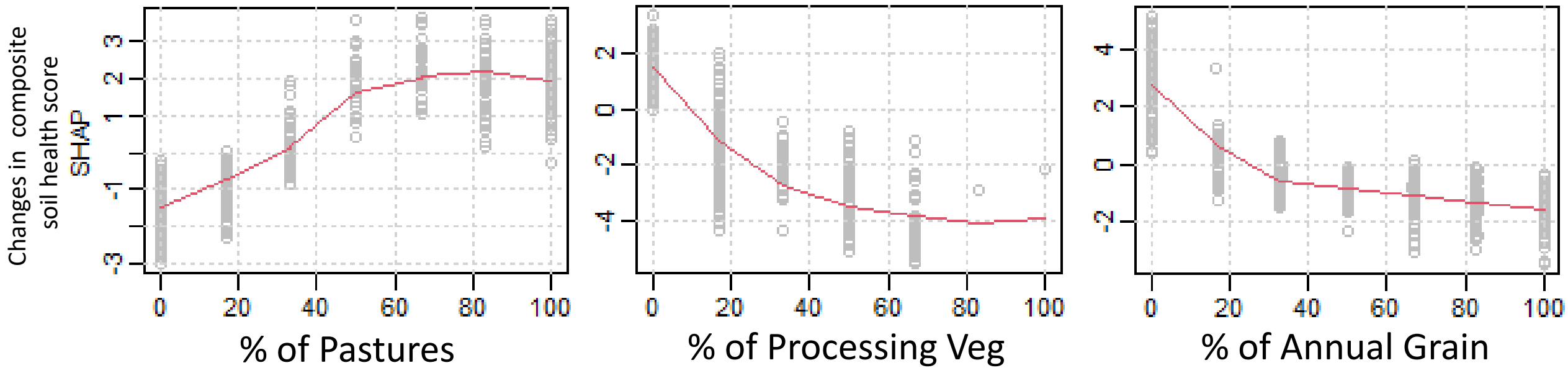
Rubio et al., 2025. Biomass inputs drive agronomic management impacts on soil health

Digital Soil Mapping – in New York



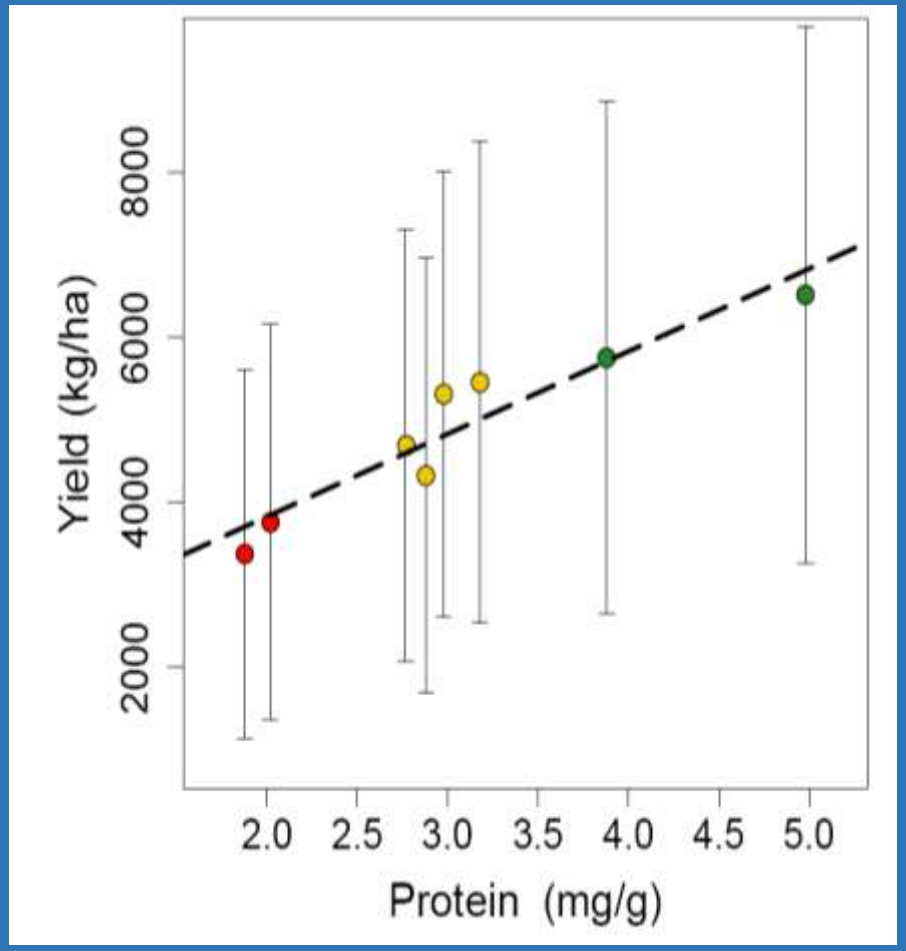
Rubio et al., 2025: Digitally mapping soil health at regional scale… (Geoderma)

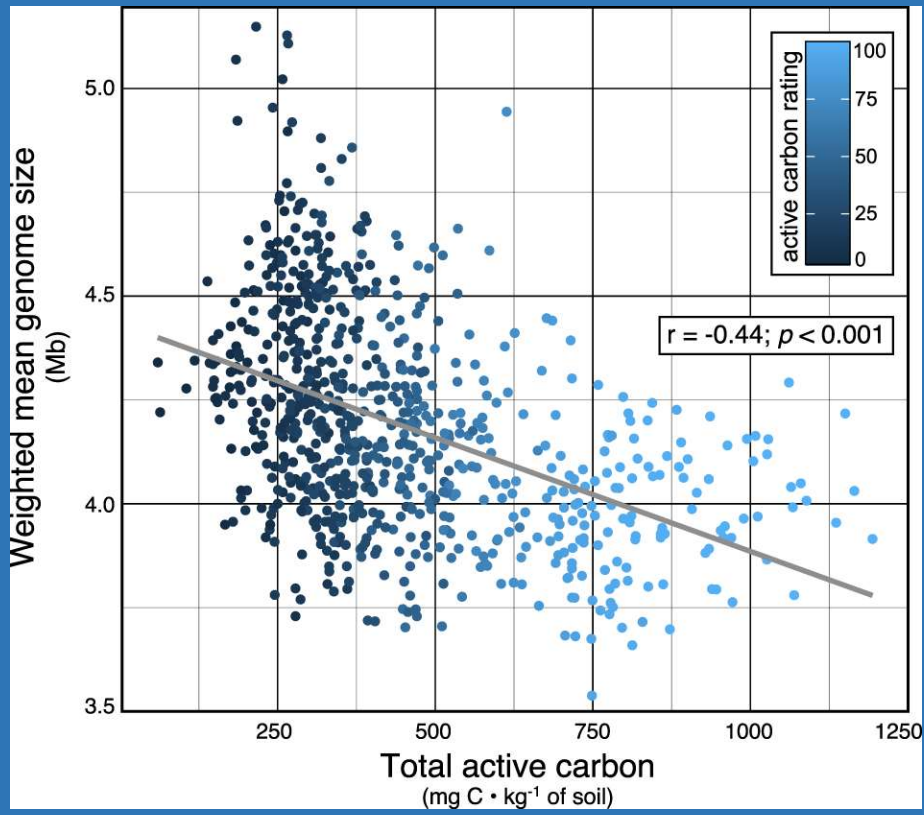
- Greater proportion of pasture and hay in rotation has large benefit for soil health outcomes
- Greater proportion of annual grain or processing vegetable in rotation leads to SH declines



Rubio et al., 2025: Digitally mapping soil health at regional scale… (Geoderma)

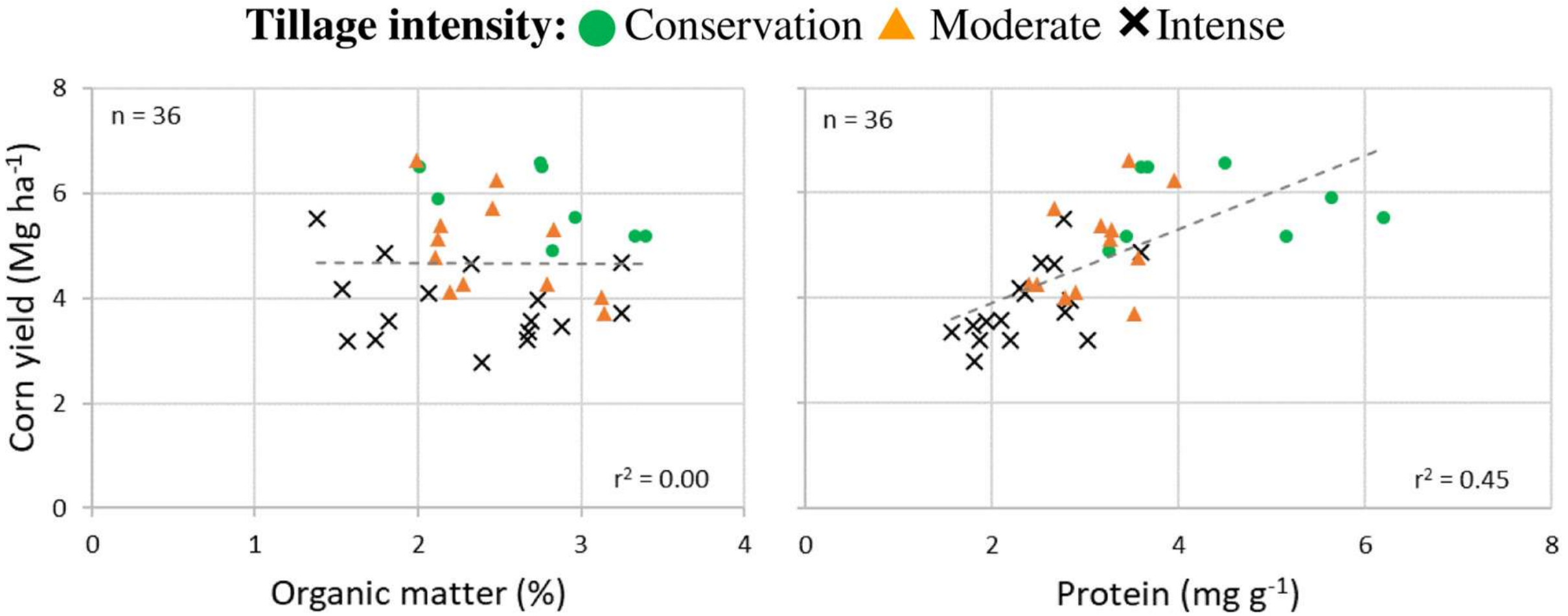
Insights into Soil Health Indicators





Soil protein had good correlation with corn yield, but SOM had no relationship

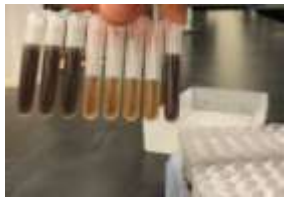
Long-Term Tillage Studies, North Carolina



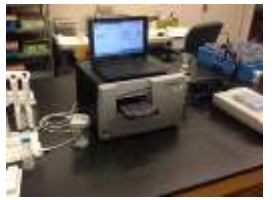
van Es and Karlen, 2019; Data source: Roper et al., 2017.

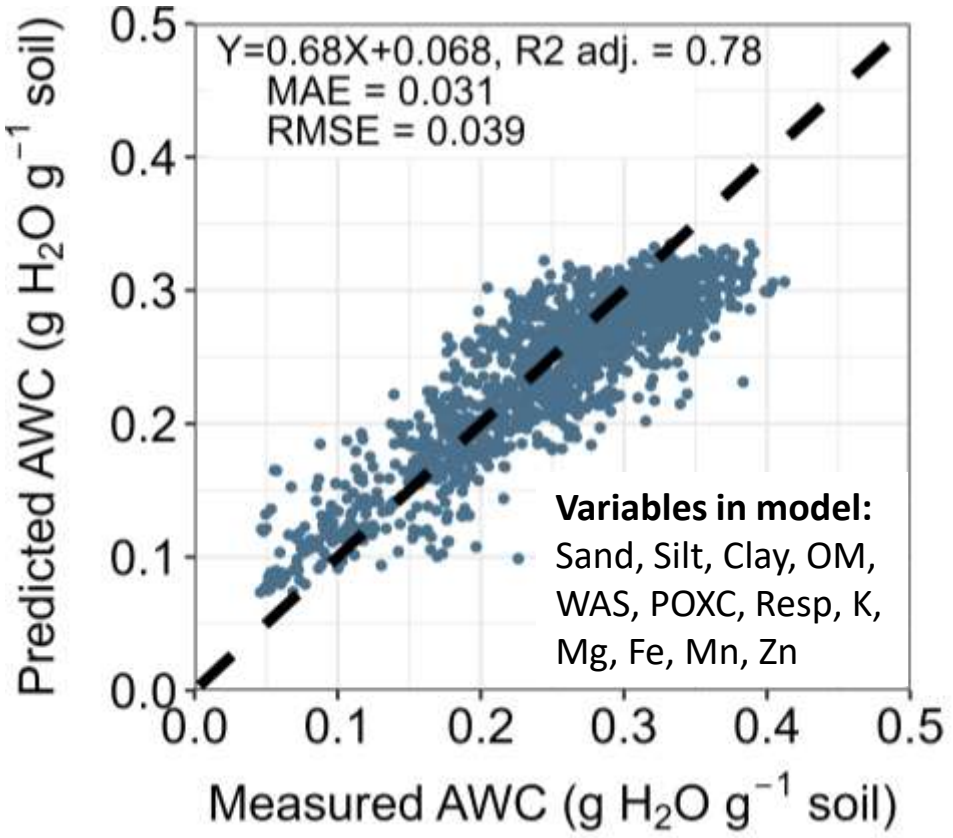
Pedotransfer Functions to Predict AWC and ACE Protein → more efficient assessment of soil health

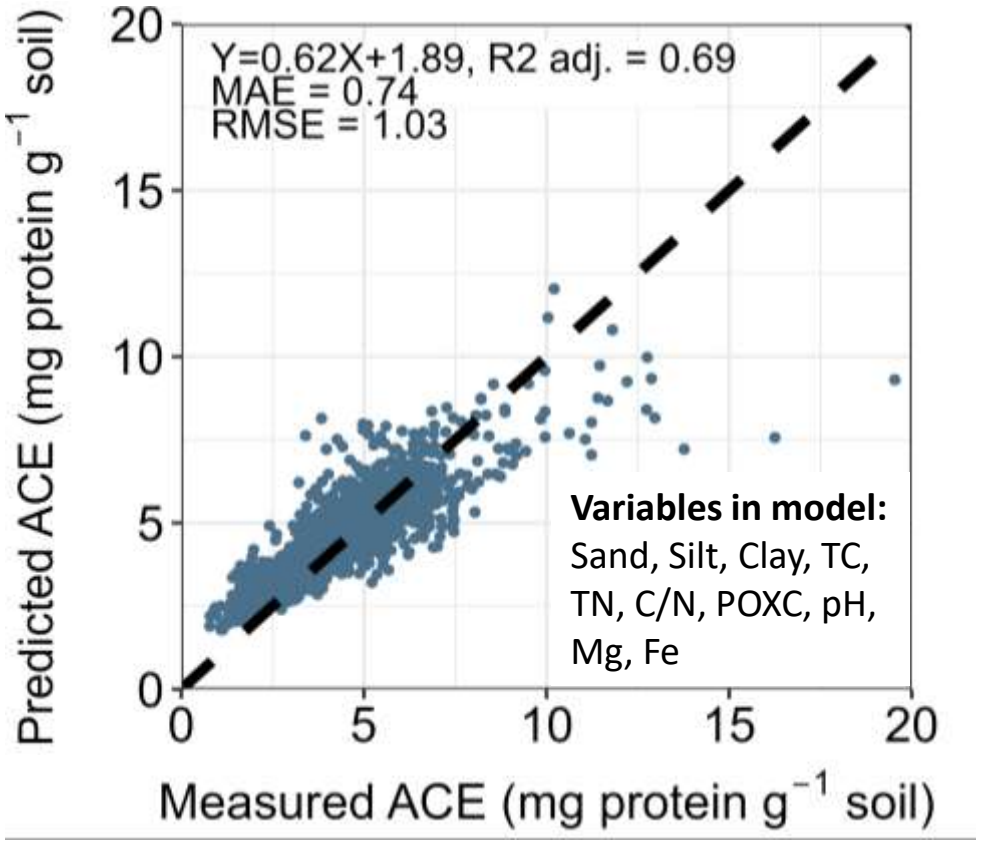
Available Water Capacity



ACE Protein





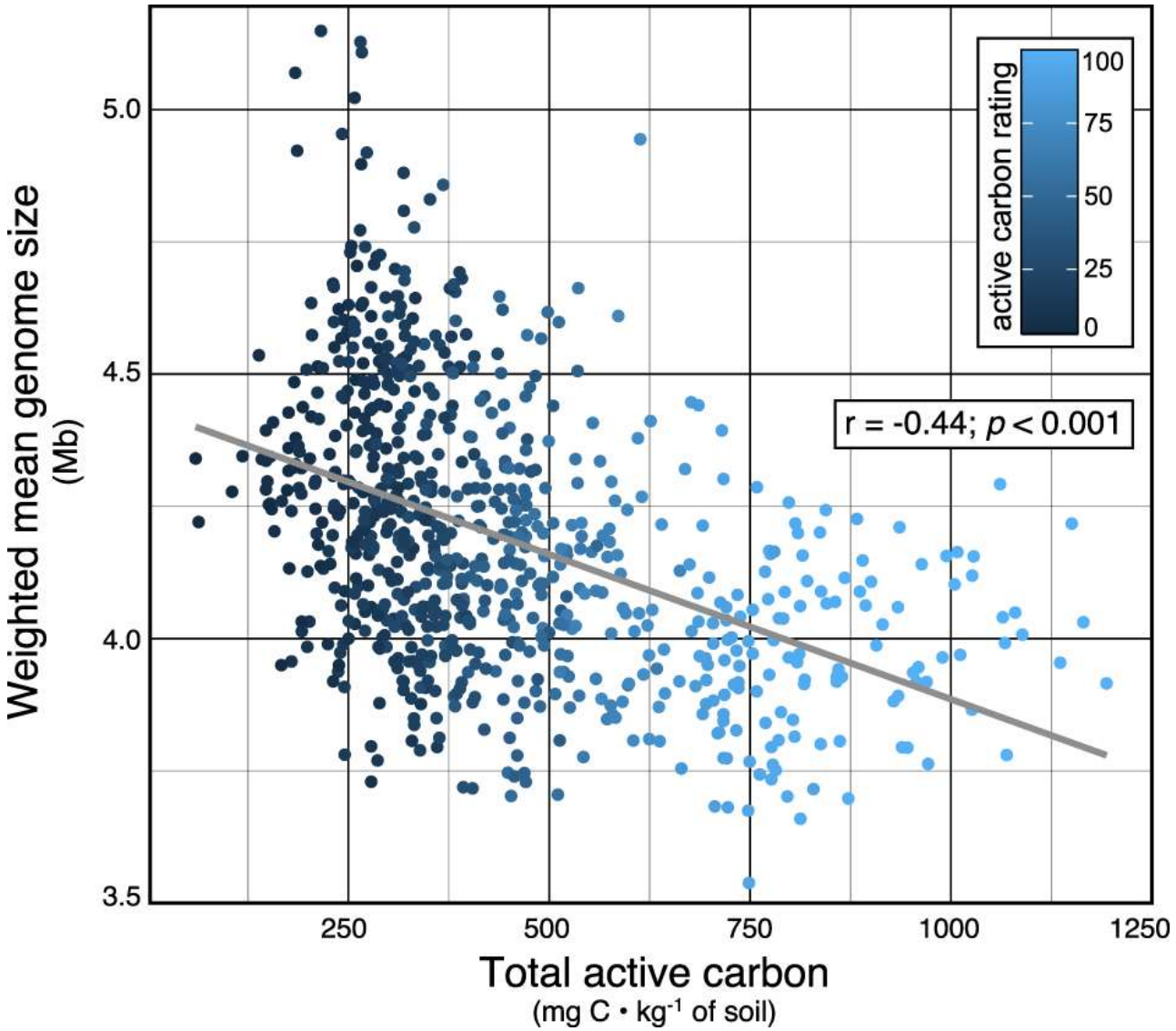


Soil Health Manual Series Fact Sheets

https://bpb-us-e1.wpmucdn.com/blogs.cornell.edu/dist/7/9922/files/2021/11/05bWater_Capacity-Predicted.pdf

Ecological Insights on Soil Health: Microbiome Data

Bacteria with larger genomes tend to be more abundant in soils with lower soil health



Wilhelm et al., 2023

Advanced Soil Health and Regenerative Ag

Certificate Course

MAR 10 - APR 28, 2026

VIRTUAL COURSE: GUIDED SELF-STUDY & LIVE ONLINE SESSIONS

$75 - $300

- To learn more and register: soilhealthtraining.org

NEW YORK SOIL HEALTH

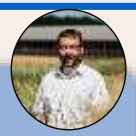
SCSL SUSTAINABLE CROPPING SYSTEMS LAB

Cornell CALS College of Agriculture and Life Sciences

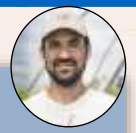
NEW YORK CENTER FOR Organics Recycling and Education

Instructors:

Harold van Es
Professor
Soil and Water Management



Matt Ryan
Professor
Sustainable Cropping Systems



Joseph Amsili
Director
NY Soil Health Program

Debbie Aller
Director, NY Center for Organics Recycling and Education

Thank you!

Free Resources!

Joseph Amsili, PhD
Director of Cornell Soil Health Program
jpa28@cornell.edu

Join our Listserve:
www.newyorksoilhealth.org

NEW YORK SOIL HEALTH

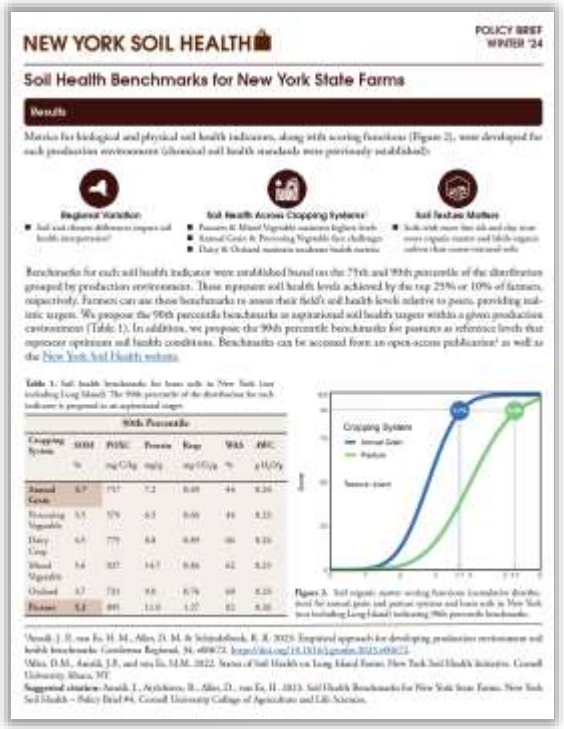
POLICY BRIEF WINTER '24

Soil Health Benchmarks for New York State Farms

Overview

Background

Policy Considerations


NEW YORK SOIL HEALTH

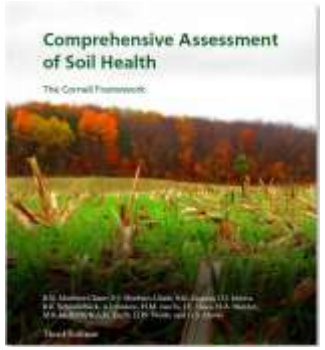
POLICY BRIEF WINTER '24

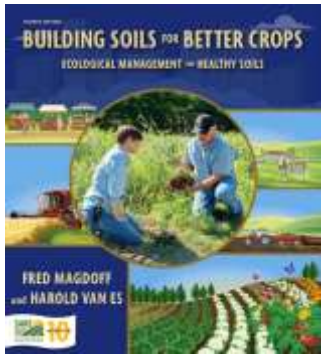
Soil Health Benchmarks for New York State Farms

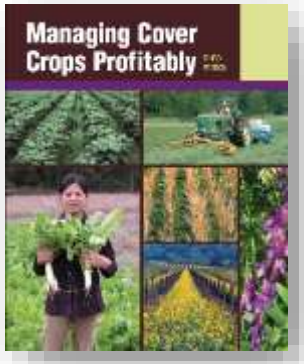
Results

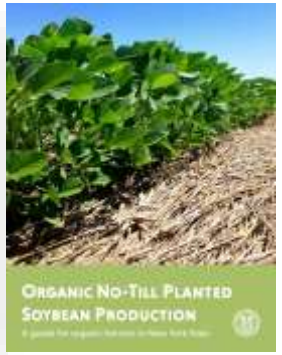
Harold van Es
Original Lead Developer of Cornell Soil Health
hmv1@cornell.edu

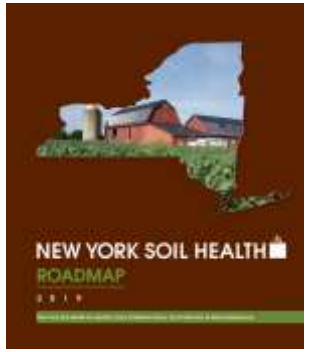
Cornell Soil Health Website:
soilhealth.cals.cornell.edu

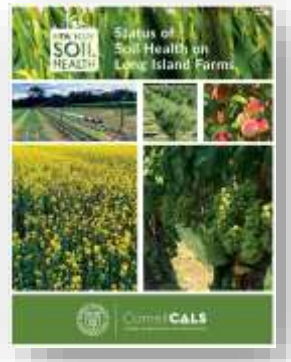












CornellCALS
College of Agriculture and Life Sciences