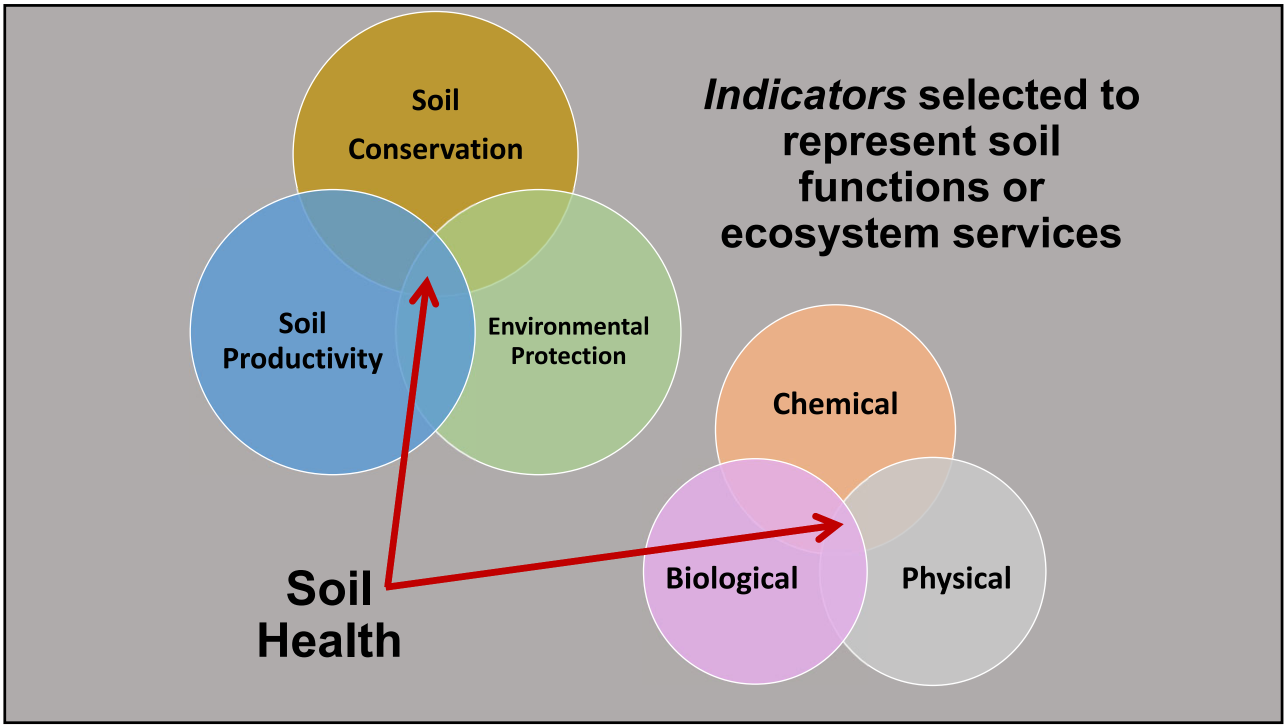

Developments in Soil Health Assessment
for producers
Kristen Veum
Research Soil Scientist
USDA Agricultural Research Service

1


Soil and Water Quality Lab
USDA-ARS
Columbia MO

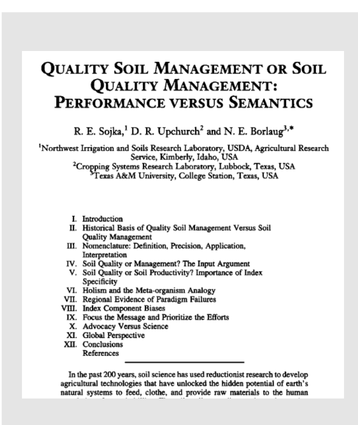
2



3

Arguments Against the Soil Health Concept (1990s)

Still Working On…



QUALITY SOIL MANAGEMENT OR SOIL QUALITY MANAGEMENT: PERFORMANCE VERSUS SEMANTICS

R. E. Sojka,[1] D. R. Upchurch[2] and N. E. Borlaug[3,*]

[1]Northwest Irrigation and Soils Research Laboratory, USDA, Agricultural Research Service, Kimberly, Idaho, USA
[2]Cropping Systems Research Laboratory, Lubbock, Texas, USA
[3]Texas A&M University, College Station, Texas, USA

I. Introduction
II. Historical Basis of Quality Soil Management Versus Soil Quality Management
III. Nomenclature: Definition, Precision, Application, Interpretation
IV. Soil Quality or Management? The Input Argument
V. Soil Quality or Soil Productivity? Importance of Index Specificity
VI. Holism and the Meta-organism Analogy
VII. Regional Evidence of Paradigm Failures
VIII. Index Component Biases
IX. Focus the Message and Prioritize the Efforts
X. Advocacy Versus Science
XI. Global Perspective
XII. Conclusions
References

In the past 200 years, soil science has used reductionist research to develop agricultural technologies that have unlocked the hidden potential of earth's natural systems to feed, clothe, and provide raw materials to the human

Reservations Regarding the Soil Quality Concept[1]

R. E. Sojka* and D. R. Upchurch

ABSTRACT

We consider the appropriateness of institutionalizing *soil quality* as a defined parameter in soil science. The soil management research of land grant universities and the Agricultural Research Service (ARS) and the mission and goals of state, federal, and private conservation agencies stand to be significantly affected. We feel that a non-advocative examination of this concept could provide a positive contribution. The definition of soil quality has proven elusive and value laden. There is concern by some that the concept has developed arbitrary policy overtones. Our reservations stem from concerns regarding premature acceptance and institutionalization of an incompletely formulated and largely untested paradigm, potential unintended negative outcomes, promotion of a narrowly defined environmental policy in a context normally associated with value-neutral science, and taxonomic and/or regional bias in establishing the paradigm. To date, soil quality assessments have drawn from a relatively narrow crop production and ecological perspective to positively or negatively weight soil quality assessment factors. Although the soil quality paradigm acknowledges *multi-defined* soil functions, it has yet to operationally recognize and integrate the *simultaneity* of diverse and often conflicting functions and soil property requirements. Thus, we are attempting to articulate the concerns of many of our colleagues who are reluctant to endorse redefining the soil science paradigm away from the value-neutral tradition of edaphology and specific problem solving to a paradigm based on variable, and often subjective societal perceptions of environmental holism. Traditionally, it has been the soil science profession's role to perform the science to enable resource management policy and problem solving, not to establish relational-based value systems within the science. We suggest emphasizing quality soil management rather than soil quality management as a professional and scientific goal.

THE SOIL SCIENCE SOCIETY OF AMERICA (SSSA) has provided several written forums promoting the soil quality concept (Allan et al., 1995; Doran et al., 1994; Doran and Jones, 1996; Karlen et al., 1997). These and several non-SSSA publications have described a soil quality paradigm to assess the condition and sustainability of soil and to guide soil research and conservation policy. No comprehensive critical examination of the scientific basis of the concept or the paradigm shift's ramifications has been published.

There can be no argument with the high goals of improving our ability to assess soil condition and promote sustainability. However, many soil scientists fear that in the emerging soil quality paradigm, those high goals have led to advocating a value system as an end unto itself, supplanting otherwise value-neutral science and prematurely accepting interpretations and assertions of soil quality before the concept has been thoroughly and analytically challenged. Indexing of soil properties for specific outcomes is not new. In the past, however, the scope of the indices were limited and specific. Soil quality indexing, while perhaps originally focused on indexing and optimization of limited collections of specific attributes, has evolved to assessment of highly generalized, sometimes unspecific *overall* worth, value, or condition of soil. This approach risks certain pitfalls. As Lackey (1998a) noted, "quality" of managed natural systems is not an objective scientific attribute. Such quality definitions are contextual, subjective, value laden, outcome driven, and infinite in possibilities. While individuals (especially non-scientists) assessing soil quality may be familiar with the assessment parame-

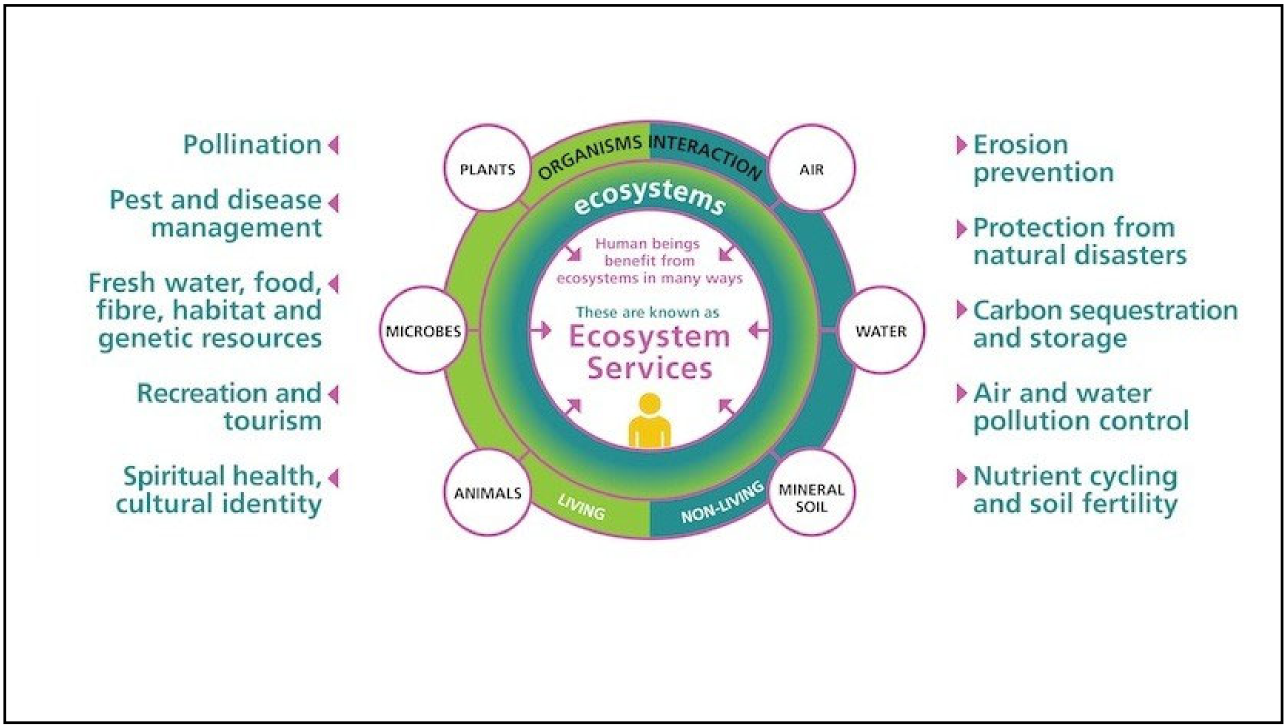
R.E. Sojka, USDA-ARS Northwest Irrigation and Soils Research Laboratory, Kimberly, ID 83341-5076; D.R. Upchurch, Cropping Systems Research Laboratory, 3810 Fourth St., Lubbock, TX 79415. Received 26 Feb. 1999. *Corresponding author (sojka@kimberly.ars.pn.usbr.gov).

Published in Soil Sci. Soc. Am. J. 63:1039–1054 (1999).

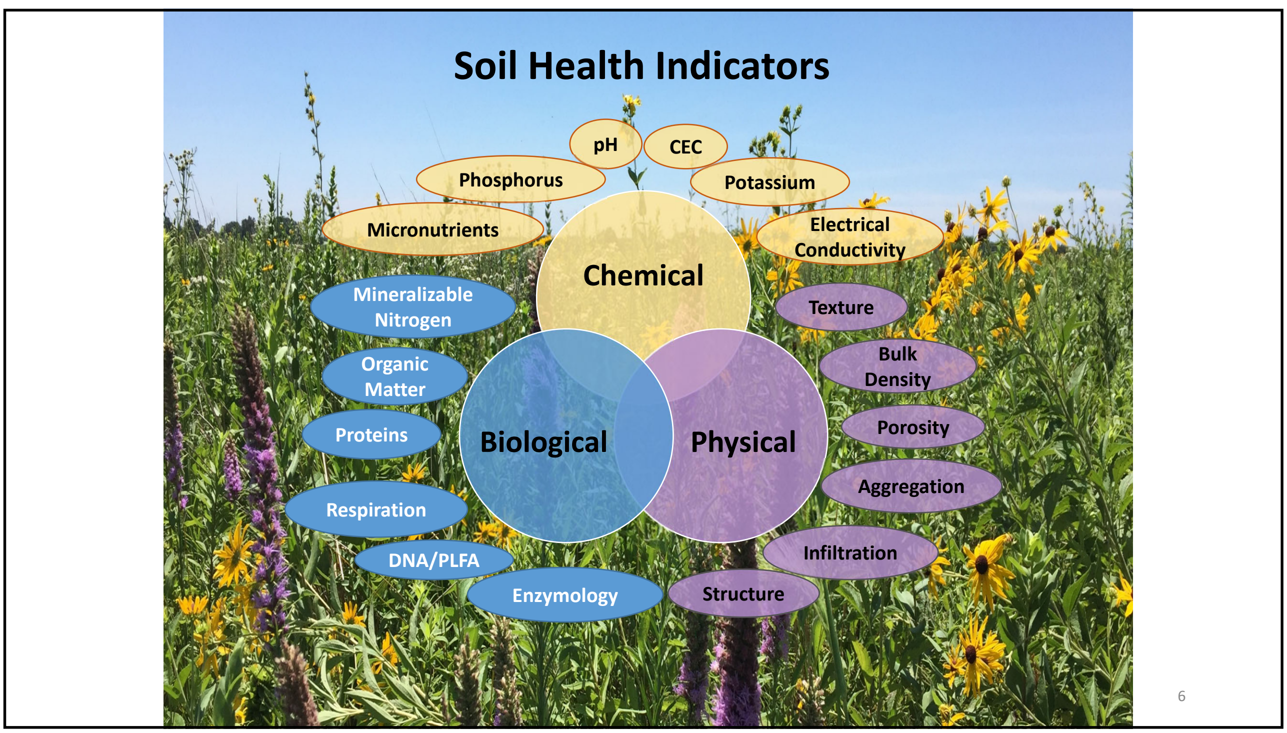
[1] In 1994 the Soil Science Society of America established ad hoc Committee S-581 to define and describe the emerging soil quality concept. Committee members solicited the SSSAJ Editor for an opportunity to present their views in a guest editorial for the express purpose of addressing what they acknowledged was a contentious and emotionally charged issue. Because of the solitary perspective presented by the committee in its editorial (SSSAJ 61:4-10), the SSSA Editor-in-Chief and SSSAJ Editor recognized a need for and solicited an alternative comment. This paper is that invited response, and is written in the spirit of scientific discourse called for in the 1997 editorial.

- Socioeconomic concerns
- Regulatory concerns
- Qualitative vs. quantitative
- Measurable and interpretable?
- Soil use varies
- Multiple, competing soil functions
- **Soil functions/ecosystem services difficult to directly measure**
  - **Indicators**
- **Inherent soil properties vary**
  - **Defines dynamic 'soil potential'**

4


Pollination
Pest and disease management
Fresh water, food, fibre, habitat and genetic resources
Recreation and tourism
Spiritual health, cultural identity
PLANTS
ORGANISMS INTERACTION
AIR
ecosystems
Human beings benefit from ecosystems in many ways
These are known as
Ecosystem Services
MICROBES
WATER
ANIMALS
LIVING
NON-LIVING
MINERAL SOIL
Erosion prevention
Protection from natural disasters
Carbon sequestration and storage
Air and water pollution control
Nutrient cycling and soil fertility

5


Soil Health Indicators
pH
CEC
Phosphorus
Potassium
Micronutrients
Electrical Conductivity
Chemical
Mineralizable Nitrogen
Texture
Organic Matter
Bulk Density
Proteins
Biological
Physical
Porosity
Aggregation
Respiration
Infiltration
DNA/PLFA
Enzymology
Structure
6

6

What are indicators and why do we use them?

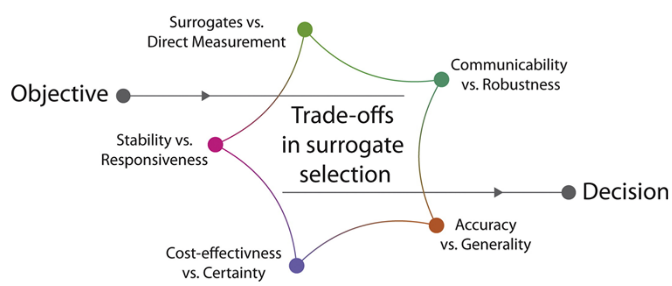
- **Indicator/Proxy/Surrogate**
  - An indirect measure of the desired outcome which is itself strongly correlated to that outcome.
  - Used when direct measures of the outcome are unobservable and/or unavailable.
  - Substitute/correlate.
  - Measurable variable used to represent a non-measured or non-measurable factor or quantity.

7

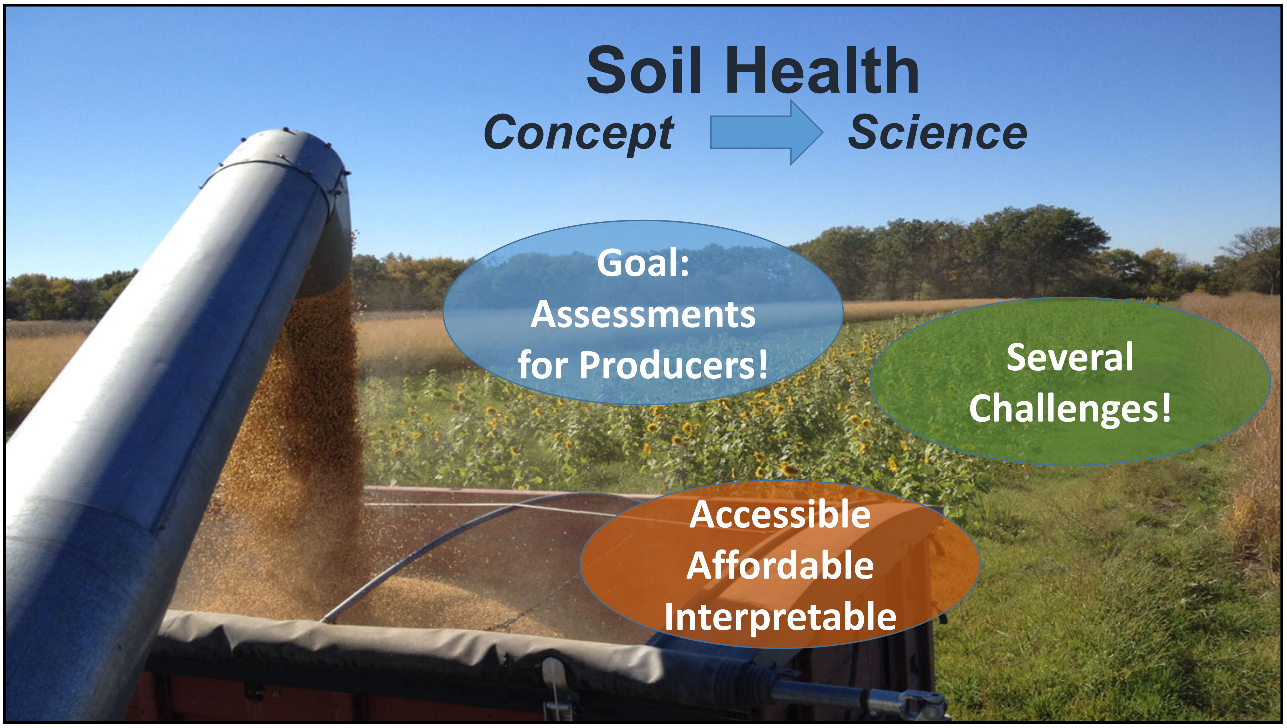
Indicators or Direct Measurements? Trade-Offs

- Accuracy/specificity vs. generality/approximation
- Temporal sensitivity vs. stability (ability to detect change over time)
- Complex details vs. simple and easy to communicate
- Certainty vs. high efficiency and low cost

Is it good enough?



8



9

Carbon flux from soil to air?
The right tool for the job

- **Producer soil health assessment**
  - Relative change or trends
  - Feasible for landowner assessment
  - Link back to outcomes (yield)
  - Simplified lab test
- **Closing the carbon budget**
  - Quantify the flux of C from soil to the atmosphere
  - Spatial and temporal variability
  - Expensive and complex experiment

10

Producer Soil Health Assessment

Laboratory Soil Respiration

Integrates information on soil organic matter and the size and activity of the microbial community.

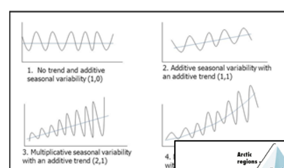
Farmers can collect their own samples and service labs can provide results.

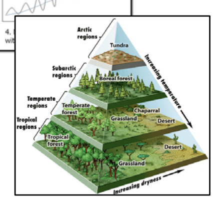
Indicator **for carbon mineralization; provides relative differences and trends**

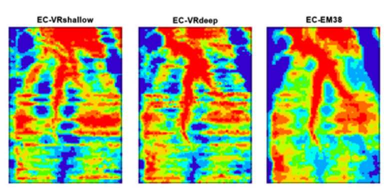
11

What Should I Measure?

- What is your objective?
- What are your budget, time, and labor constraints?
- What measurements contribute to your objectives?
  - Is an ***indicator*** sufficient and useful?
  - In-field or laboratory?
  - Method/protocol?







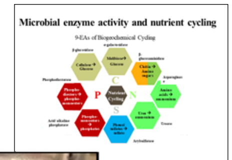
➢ ***Think critically about what, how, and why you are measuring***

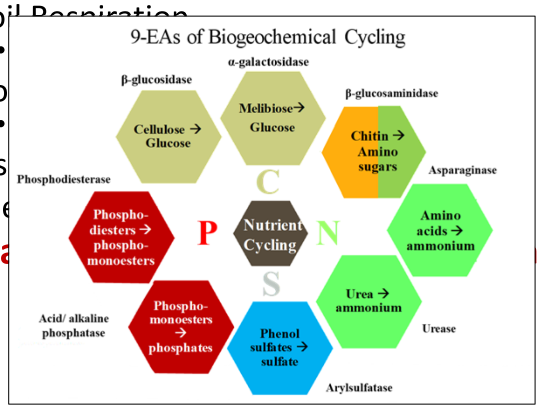
12

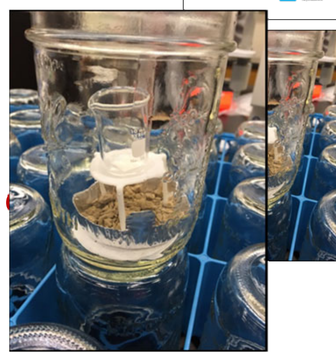
Applied Research Efforts to Reduce Cost for Soil Health Indicators

- Laboratory Measurements vs. Field Measurements
- High-throughput Methods
- Multi-enzyme/Simultaneous enzyme testing
  - Veronica Acosta-Martinez (ARS – TX)
- Soil Respiration
  -
- Co
  -
- Us
- Me

Bala







13

INTERPRETATION?

14

What do we know about soil health?
Agricultural Continuum of Soil Health

Higher ← → Lower

- Perennial Systems: Cool/Warm-Season CRP; Pasture/Forage/Hay/Biofuel; Restored Prairie
- Annual Cropping Systems: No-Till + Cover Crop + Rotation; No-Till + Rotation; Tillage + Rotation; Tillage + Manure + Monoculture; Tillage + Monoculture

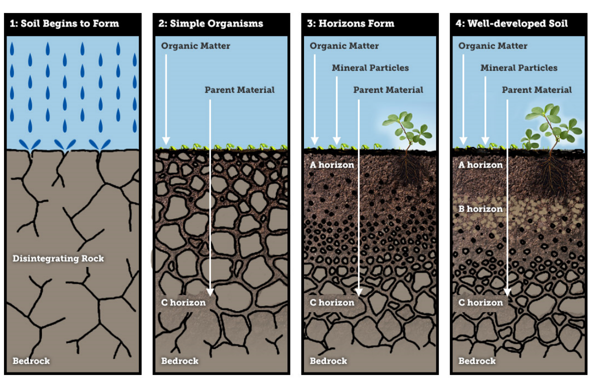
Veum KS, Goyne KW, Kremer RJ, Miles RJ, Sudduth KA (2014) Biological indicators of soil quality and soil organic matter characteristics in an agricultural management continuum. **Biogeochemistry**

Veum KS, Kremer RJ, Sudduth KA, Kitchen NR, Lerch RN, Baffaut C, Stott DE, Karlen DL, Sadler EJ (2015) Conservation effects on soil quality indicators in the Missouri Salt River Basin. **J. Soil Water Conserv.**

15

15

Interpretation of Soil Health Indicators
Incorporating Inherent Soil Properties

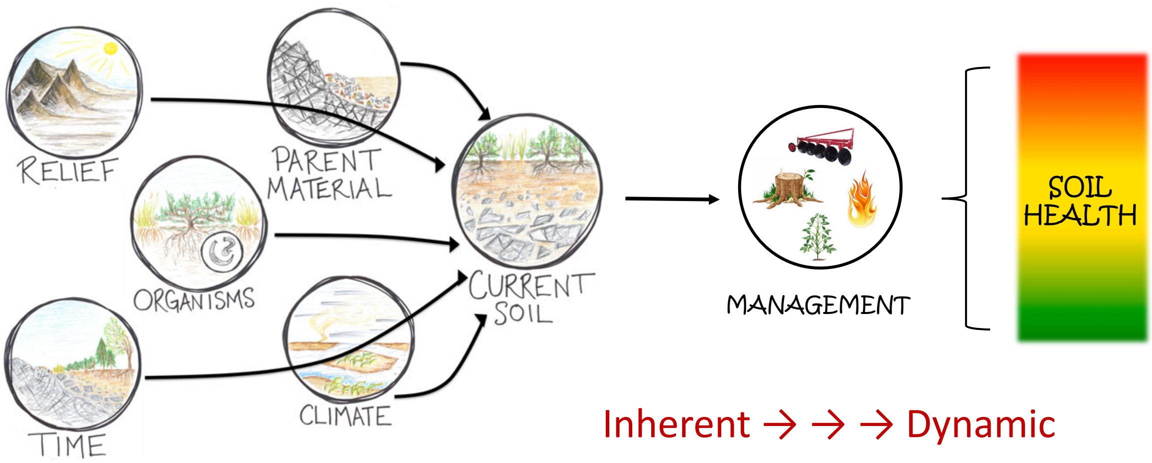


- Vegetation
- Climate
- Parent Material
- Time
- Topography/Relief
- ➢ Management (Human Factor)

16

16

Pedology → Management → Soil Health



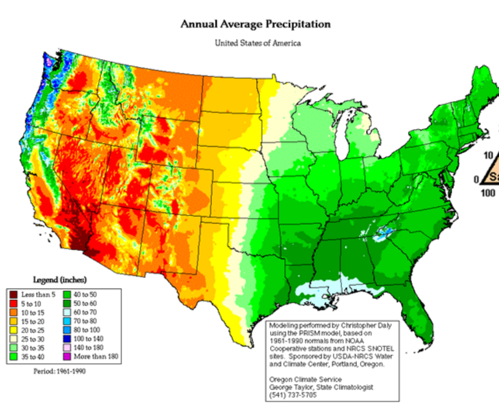
Inherent → → → Dynamic

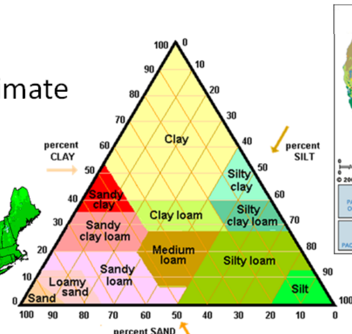
17

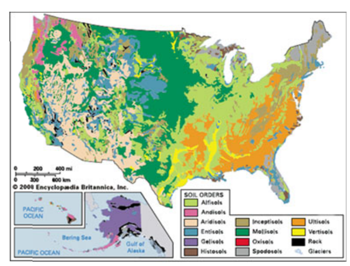
17

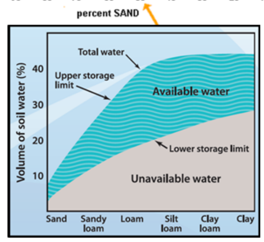
Why do inherent (site-specific) conditions matter?

- Different Regions
  - Crops, soils, management, climate





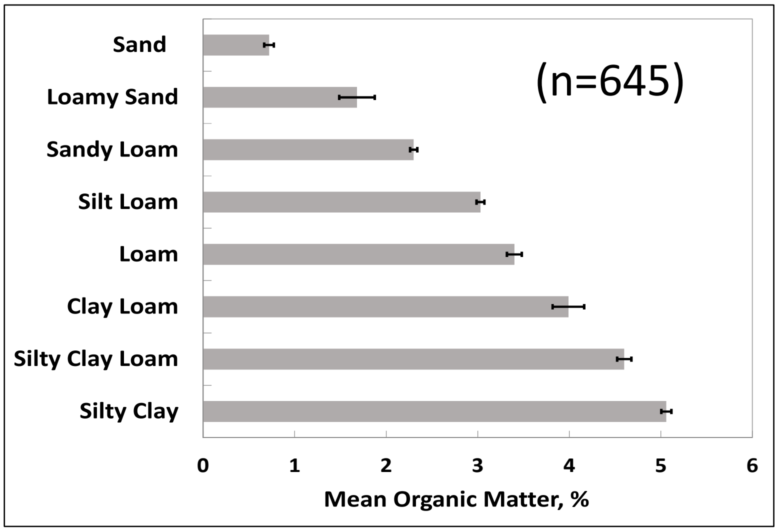




18

18

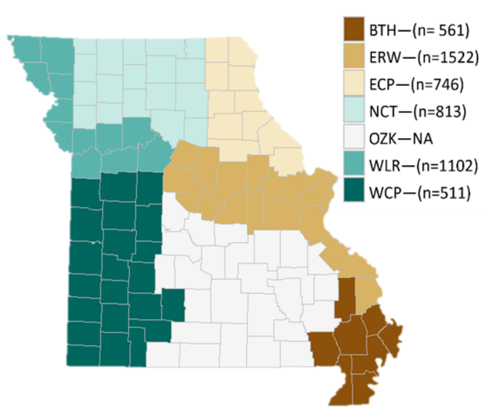
Multistate Soil Health Partnership Data



Karlen, D. L., Goeser, N. J., **Veum, K. S.**, & Yost, M. A. (2017). On-farm soil health evaluations: Challenges and opportunities. *Journal of Soil and Water Conservation, 72*(2), 26A-31A.

19

Example: Missouri DNR Cover Crop Cost-Share Program

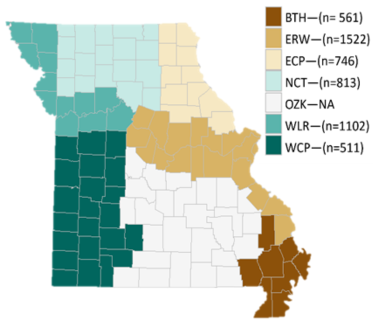


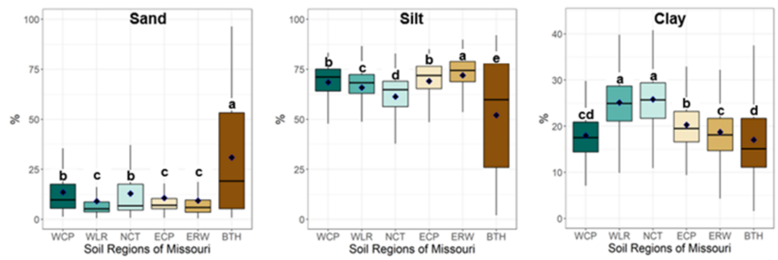
- Program initiated to evaluate cover crops
- Baseline samples from 5300 fields before cover crops
- Samples from 6 regions across MO to compare regional differences
- Management information collected
- Follow-up samples collected will compare before and after cover crops.

Zuber, S. M., Veum, K. S., Myers, R. L., Kitchen, N. R., & Anderson, S. H. (2020). Role of inherent soil characteristics in assessing soil health across Missouri. *Agricultural and Environmental Letters, 5(1), e20021. https://doi.org/10.1002/ael2.20021* 20

20

Regional Differences
in soil properties



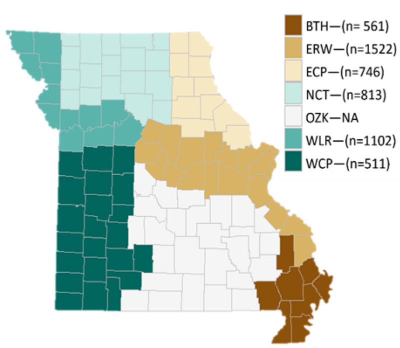


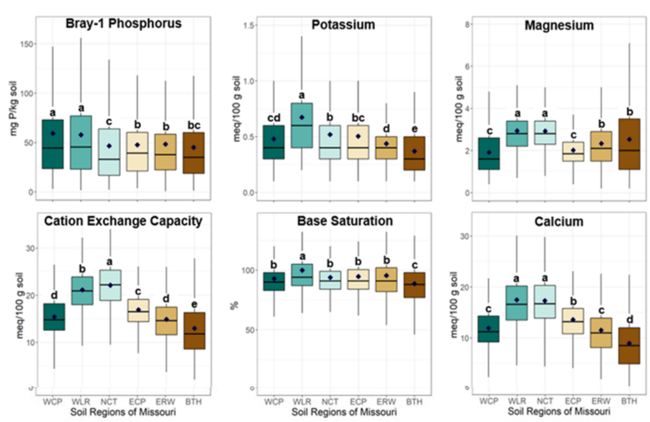
Zuber, S. M., Veum, K. S., Myers, R. L., Kitchen, N. R., & Anderson, S. H. (2020). Role of inherent soil characteristics in assessing soil health across Missouri. *Agricultural and Environmental Letters, 5(1), e20021. https://doi.org/10.1002/ael2.20021*

21

21

Regional Differences
in soil properties



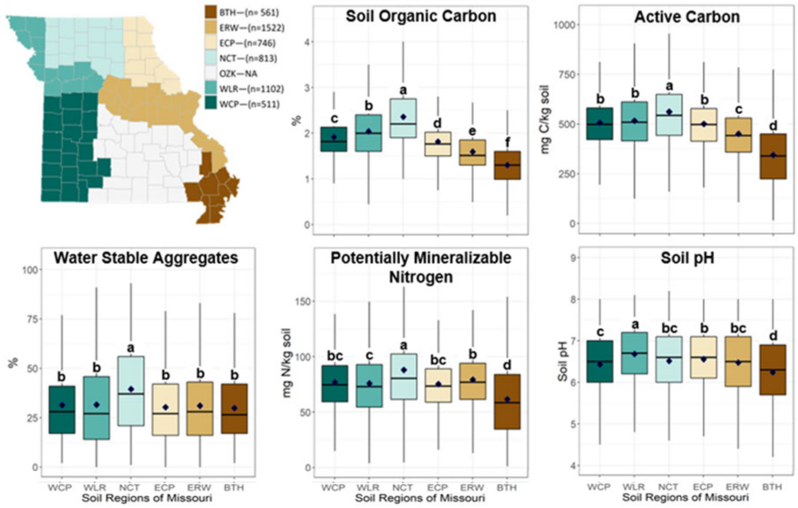


Zuber, S. M., Veum, K. S., Myers, R. L., Kitchen, N. R., & Anderson, S. H. (2020). Role of inherent soil characteristics in assessing soil health across Missouri. *Agricultural and Environmental Letters, 5(1), e20021. https://doi.org/10.1002/ael2.20021*

22

22

Soil Health / Dynamic Soil Properties



Zuber, S. M., Veum, K. S., Myers, R. L., Kitchen, N. R., & Anderson, S. H. (2020). Role of inherent soil characteristics in assessing soil health across Missouri. *Agricultural and Environmental Letters, 5(1), e20021. https://doi.org/10.1002/ael2.20021*

23

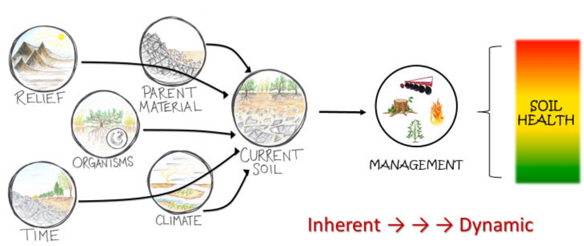
23

What is driving these regional differences?

- Topography
- Weather
- Crops
- Parent material

- Tillage and crop practices
- Amendment type (manure)

Pedology → Management → Soil Health



What about management?

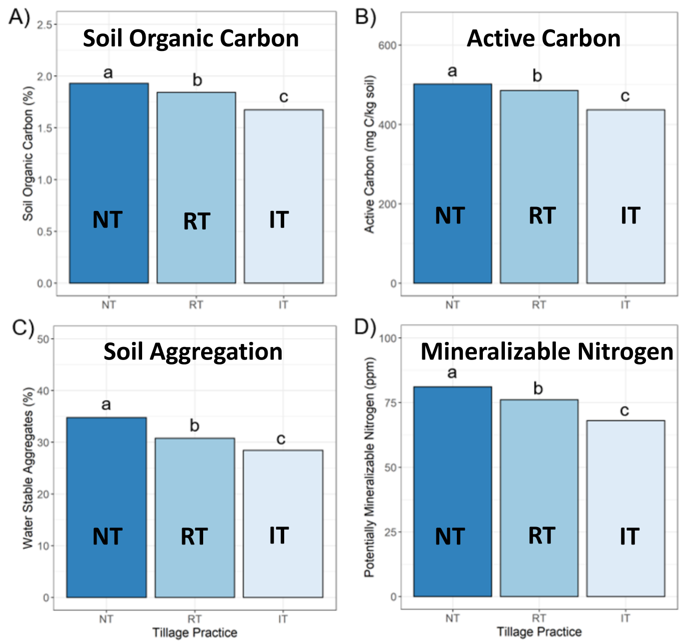
24

24

Management Effects?

Tillage

- No-till (NT)
- Reduced tillage (RT)
- Intensive tillage (IT)



Veum, K. S., Zuber, S. M., LaRose, J, Myers, R. L., Kitchen, N. R., & Anderson, S. H. (*in prep*). Rotational Diversity and Reduced Tillage Improve Soil Health in Missouri.

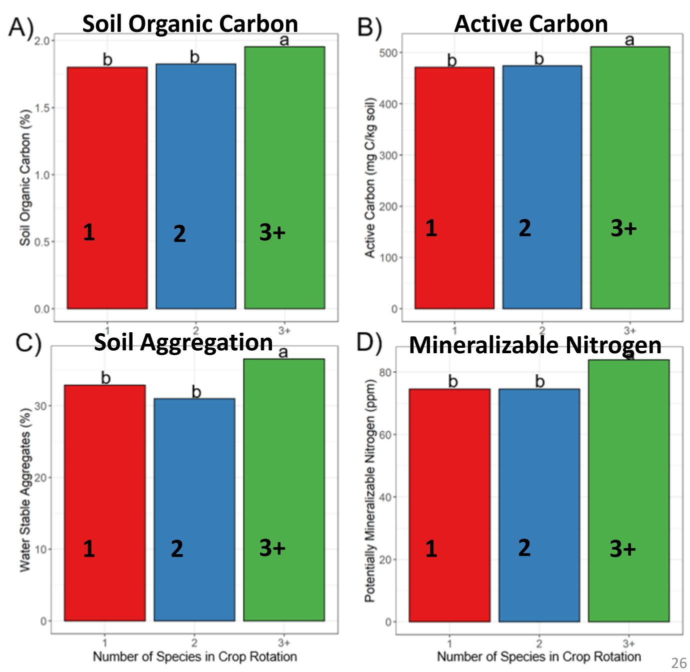
25

25

Management Effects?

Rotational Diversity

- Single Crop (1)
- Two Crops (2)
- Three-plus Crops (3+)



Veum, K. S., Zuber, S. M., LaRose, J, Myers, R. L., Kitchen, N. R., & Anderson, S. H. (*in prep*). Rotational Diversity and Reduced Tillage Improve Soil Health in Missouri.

26

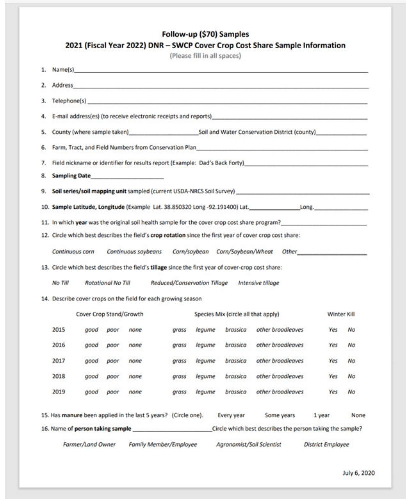
26

Continuing Work with the MO-DNR Cover Crop Cost-Share Program….

As the program continues:

- Identify how management and regional factors impact soil health
- Follow-up sampling to compare before and after cover crop data (4-5 years)
- The Soil Health Assessment Center (SHAC) at University of Missouri
  - New Co-director Dr. Jordan Wade with Dr. Steve Anderson

MISSOURI DEPARTMENT OF NATURAL RESOURCES



Follow-up ($70) Samples
2021 (Fiscal Year 2022) DNR – SWCP Cover Crop Cost Share Sample Information
(Please fill in all spaces)

1. Name(s)________________
2. Address________________
3. Telephone(s) ________________
4. E-mail address(es) (to receive electronic receipts and reports)____________
5. County (where sample taken)__________Soil and Water Conservation District (county)__________
6. Farm, Tract, and Field Numbers from Conservation Plan____________
7. Field nickname or identifier for results report (Example: Dad's Back Forty)____________
8. **Sampling Date**__________
9. **Soil series/soil mapping unit** sampled (current USDA-NRCS Soil Survey) ____________
10. **Sample Latitude, Longitude** (Example Lat. 38.850320 Long -92.191400) Lat.__________Long.__________
11. In which **year** was the original soil health sample for the cover crop cost share program?__________
12. Circle which best describes the field's **crop rotation** since the first year of cover crop cost share:

    Continuous corn *Continuous soybeans* *Corn/soybean* *Corn/Soybean/Wheat* *Other*__________
13. Circle which best describes the field's **tillage** since the first year of cover-crop cost share:

    No Till *Rotational No Till* *Reduced/Conservation Tillage* *Intensive tillage*
14. Describe cover crops on the field for each growing season

	Cover Crop Stand/Growth			Species Mix (circle all that apply)				Winter Kill	
2015	*good*	*poor*	*none*	*grass*	*legume*	*brassica*	*other broadleaves*	*Yes*	*No*
2016	*good*	*poor*	*none*	*grass*	*legume*	*brassica*	*other broadleaves*	*Yes*	*No*
2017	*good*	*poor*	*none*	*grass*	*legume*	*brassica*	*other broadleaves*	*Yes*	*No*
2018	*good*	*poor*	*none*	*grass*	*legume*	*brassica*	*other broadleaves*	*Yes*	*No*
2019	*good*	*poor*	*none*	*grass*	*legume*	*brassica*	*other broadleaves*	*Yes*	*No*

15. Has **manure** been applied in the last 5 years? (Circle one). Every year Some years 1 year None
16. Name of **person taking sample** __________Circle which best describes the person taking the sample?

    Farmer/Land Owner *Family Member/Employee* *Agronomist/Soil Scientist* *District Employee*

July 6, 2020

Soil Health Testing
Where to get soil samples analyzed taken by landowners

27

27

28

Developing a Soil Health Assessment

Select	Select important soil functions
Select	Select indicator(s) for each function
Select	Select laboratory method for each indicator
Quantify	**Account for inherent site characteristics and differences**
Quantify	Quantify effects of management to provide recommendations

29

29

Applied Agricultural Soil Health Indices
Based on Laboratory Indicators

Soil Management Assessment Framework (SMAF)

- Uses soil taxonomy and site characteristics for up to 13 indicators
- Non-linear scoring curves based on limited data and expert opinion

Comprehensive Assessment of Soil Health (CASH)

- Developed for the New York area, expanded to the Midwest
- Cumulative Normal Distribution (CND); some texture

30

30

SHAPE
Funding and Support

2017-2021: USDA-NRCS Soil Health Division. Agreement 67-3A75-17-391. *ARS Soil Management Assessment Framework meta-analysis for indicator interpretations and tool development for use by NRCS Conservation Planners*

- Funded ORISE Postdoctoral Fellows, John Obrycki and Marcio Nunes

2021-2026: USDA-NRCS Soil and Plant Science Division. Agreement 60-5070-1-002. *Sensitivity and Reproducibility of Dynamic Soil Properties*

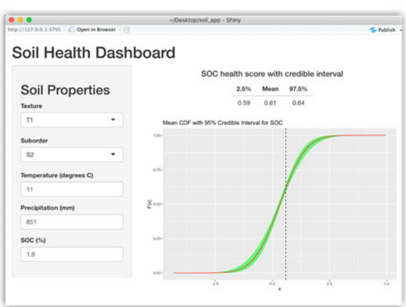
- Data to improve SHAPE curves

31

31

Soil Health Assessment Protocol and Evaluation (SHAPE)

SOC, Active C, Respiration, and ACE Protein Scoring Curves



Collaborators

Kristen Veum, Marcio Nunes, Doug Karlen: ARS/ORISE

Skye Wills & Cathy Seybold: NRCS-SPSD

Scott Holan: University of Missouri, Dept. of Statistics

Paul Parker: University of CA Santa Cruz

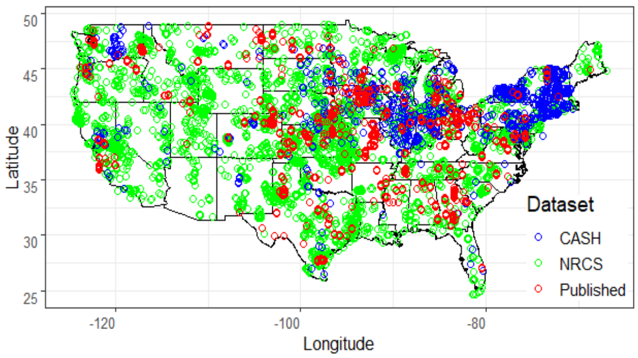
Harold van Es & Joseph Amsili: Cornell University

USDA United States Department of Agriculture
Agricultural Research Service

32

Soil Organic Carbon

Observations across the US n = 14680



Data summary

Published:
- From the literature
- N = 4129 (456 articles)
- Topsoil (≤ 15-cm)

Cornell/CASH:
- N = 4183
- Topsoil (0- to 15-cm)
- Mostly from commercial farms

NRCS/KSSL:
- N = 6368
- Surface A horizon

Combined:
- Several land uses and management
- Commercial farms
- Experimental plots
- Native systems

33

33

Potential Climate and Edaphic Factors

Potential inherent factors affecting Soil Organic C within the dataset

Inherent covariates	Unit	Source	Type	Range	N
Climate					-
Mean annual precipitation	mm	USGS	Quantitative	42 – 3671	-
Mean annual temperature	°C	USGS	Quantitative	-5.6 – 25.3	-
Potential evapotranspiration	mm/yr	UMTS	Quantitative	845 – 2539	-
Wetness index	-	Calculated	Quantitative	0.03 – 4.16	-
de Martone aridity index	-	Calculated	Quantitative	1.6 – 305.5	-
Soil					
Order	-	SSURGO	Categorical	-	10
Suborder group	-	SSURGO	Categorical	-	58
Texture class	-	SSURGO	Categorical	-	12
Drainage class	-	SSURGO	Categorical	-	8

USGS: United States Geological Survey.
UMTS: University of Montana Terradynamic Simulation Group.
SSURGO: Soil Survey Geographic Database.

34

34

Potential Climate and Edaphic Factors

Selected inherent factors to score Soil Organic-C

Inherent covariates	Unit	Source	Type	Range	N
Climate					-
Mean annual precipitation	mm	USGS	Quantitative	42 – 3671	-
Mean annual temperature	°C	USGS	Quantitative	-5.6 – 25.3	-
Potential evapotranspiration	mm/yr	UMTS	Quantitative	845 – 2539	-
Wetness index	-	Calculated	Quantitative	0.03 – 4.16	-
de Martone aridity index	-	Calculated	Quantitative	1.6 – 305.5	-
Soil					
Order	-	SSURGO	Categorical	-	10
Suborder group	-	SSURGO	Categorical	-	58
Texture class	-	SSURGO	Categorical	-	12
Drainage class	-	SSURGO	Categorical	-	8

USGS: United States Geological Survey.
UMTS: University of Montana Terradynamic Simulation Group.
SSURGO: Soil Survey Geographic Database.

35

35

Statistical Approach and Dataset

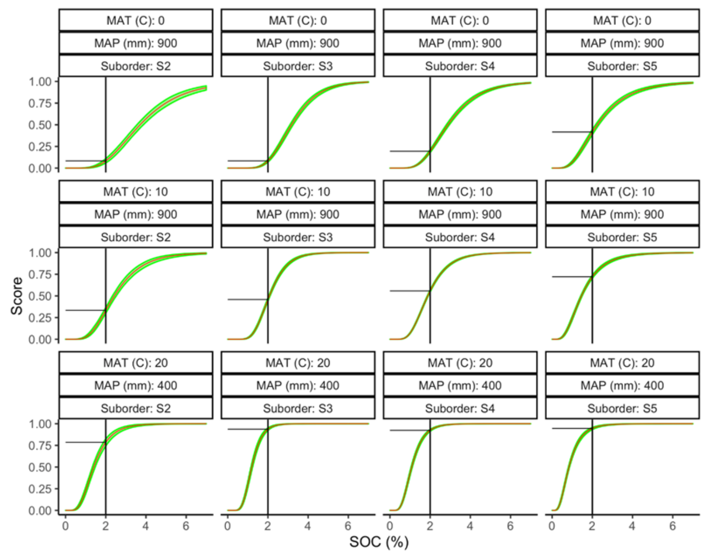
- Expands on concepts from the Soil Management Assessment Framework (SMAF) and the Comprehensive Assessment of Soil Health (CASH)
- Accounts for edaphic and climate factors at the continental scale and assigns scores relative to a defined **soil peer group, or cohort.**
  - Peer groups are defined by five soil texture groups and five soil suborder groups, and adjusted for continuous climate variables: mean annual temperature and precipitation
  - Scoring curves are **Bayesian model-based estimates** of the conditional cumulative distribution function (CDF) for a given soil peer group.
  - Produce scores between 0 and 1 (0 to 100%) for measured SOC values that reflect the quantile or position within the conditional CDF along with **measures of uncertainty**.
- Soil organic carbon (SOC) curves developed using a dataset of 14,680 observations from across the U.S. (literature, CASH, KSSL)
- Active C, ACE protein, and respiration developed on ~6,000 observations

36

36

Example SOC scoring curves

Vertical bars = hypothetical SOC of 2.0%; horizontal bars = scores within each peer group.



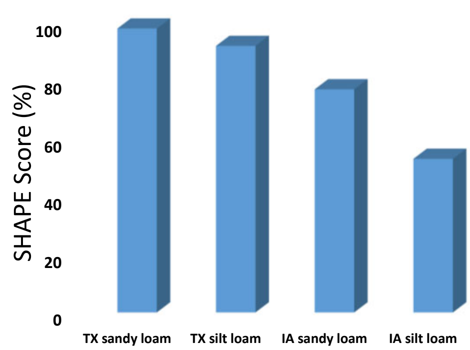
37

37

SHAPE Accounts for Climate and Soil

Texas versus Iowa climate -- sandy loam versus silt loam texture

- **Same soil carbon content: 2.0%**
- **Climate**: soils from a warmer climate with less precipitation (Texas) score higher than soils from a cooler climate with higher precipitation (Iowa).
- **Soil texture**: Coarse textured sandy soils are not expected to retain as much soil carbon as finer textured silt loam soils, so they score higher when the carbon content is equal.



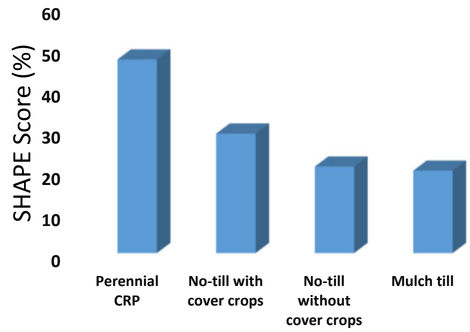
38

38

SHAPE and Management Systems

USDA-ARS Long-Term Agroecosystem Research site in Columbia, MO

- Local soil and climate characteristics are the same and have been accounted for.
- Across management systems, increased disturbance and reduced crop diversity reduces SOC and SHAPE scores.

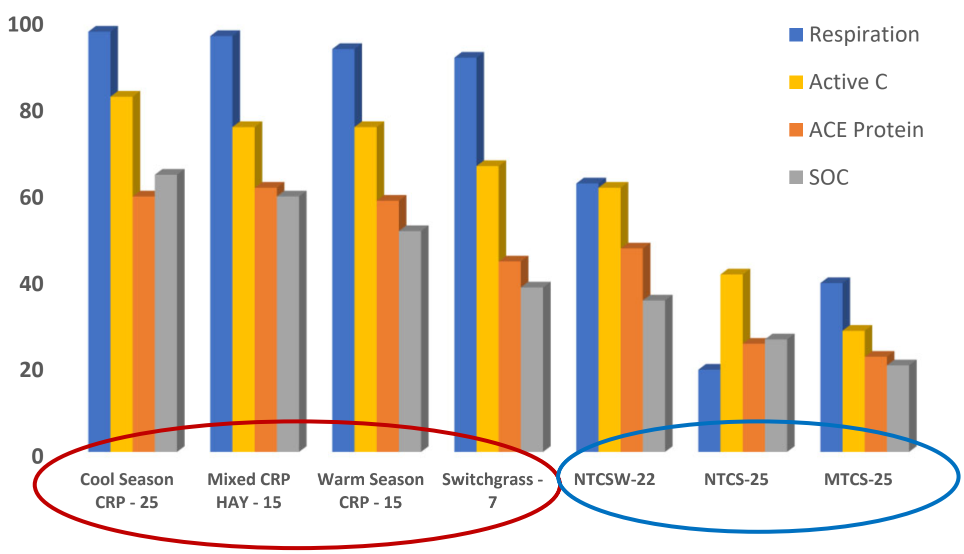


39

39

Soil Health Assessment Protocol and Evaluation (SHAPE)

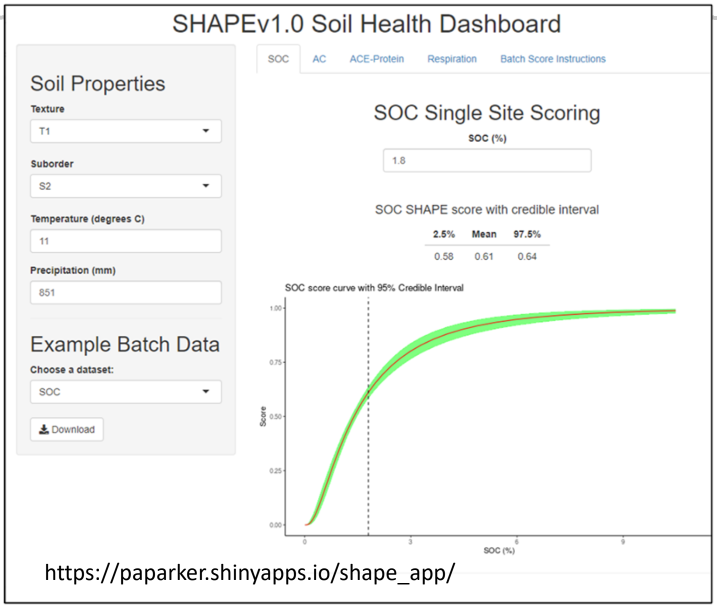
USDA-ARS Long-Term Agroecosystem Research site in Columbia, MO



40

40

SHAPE Shiny App



USDA United States Department of Agriculture Agricultural Research Service

41

Current and Future SHAPE Work

Not "one and done"

Dynamic Tool

- Completed SHAPE v1.0
  - Soil organic carbon, active carbon, ACE protein, respiration
- ***SHAPE v2.0***
  - **Spatially explicit version complete**
- Aggregate stability: CASH and KSSL methods
- Continuously enhance models (requires data)
  - ***New factors!***
  - Fill in regional data gaps
  - **Add new indicators and conversions**
  - Soil profile information
  - Land use categories and native soils
- Refine SHAPE Dashboard App: user-friendly
- NRCS SPSD is operationalizing it for DSP data hub and other platforms
- Validating with data: Soil Health Demo Trials, DSP
- Collaborating with Cornell and potentially two other major service labs

42

42

SHAPE Challenges

- Obtaining data to improve spatial density & coverage (representation)
- **Lab to lab variability and hurdles facing labs new to soil health measurements**
- Standardized methods and protocols.
- Provide decision-based recommendations
- Link indicator values back to ecosystem services
  Thresholds and expectations
- Right tool for the right job?

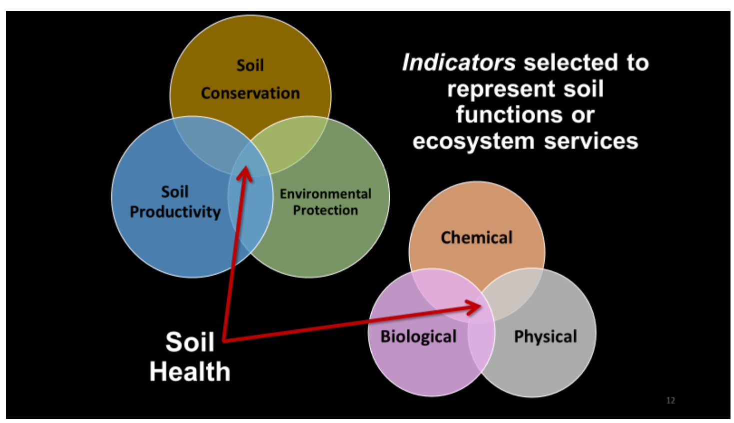
43

43

Future Work - SHAPE

Addressing ecosystem services

- Regionally specific
- Trade-offs
- Value laden
- Change over time



Provisioning versus environmental protection?
Regional: water quality and runoff versus water quantity and wind erosion?
Economic volatility

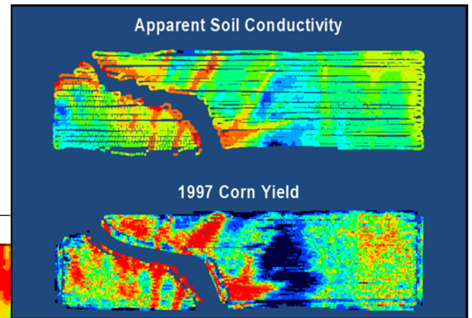
44

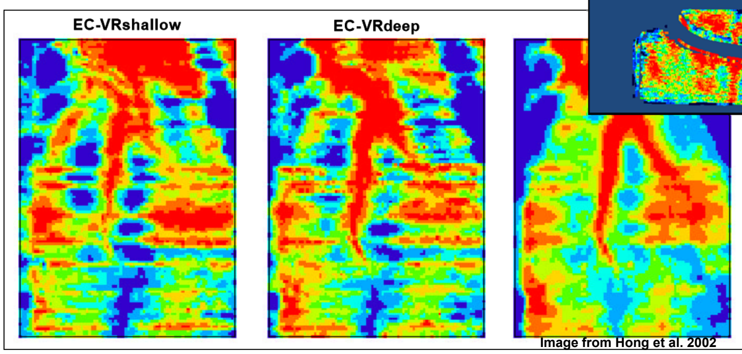
44

Soils vary across the field

Spatial variation

High lab costs





When we combine the high cost of analysis with the need to understand spatial variability, we have a problem

45

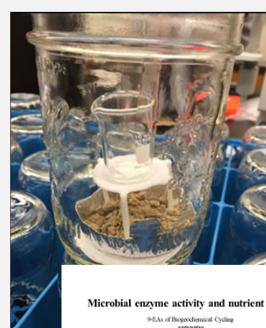
45

How do we reduce cost?
How do we improve link to soil functions?

- Laboratory
  - Combination testing
  - Cheaper supplies
  - Less supplies
  - Shorter/faster methods
  - Using smaller sample sizes/volumes
  - Less sophisticated/expensive instruments

You still have to collect a sample and send it to a lab

Laboratory conditions will never reflect real world soil conditions – especially for soil biology



46

Soil Health and Soil Sensing

47

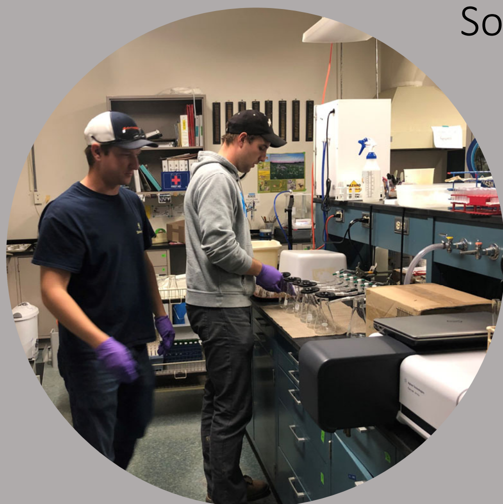
Proximal Soil Sensing
in-field "on-the-go" data collection

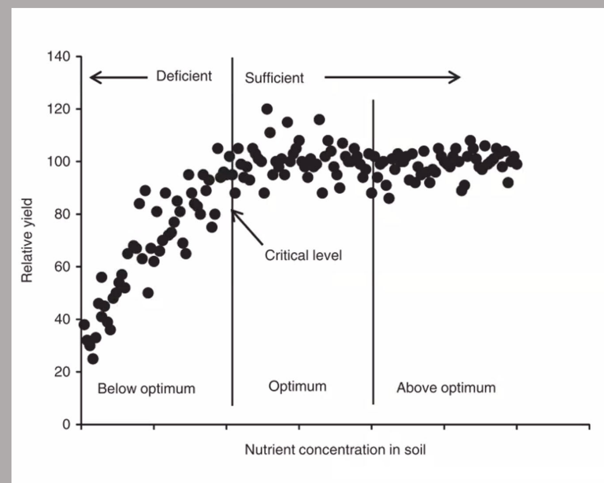
- Non-invasive, non-destructive
- Inexpensive and low-tech
- High resolution (spatial/temporal)
- **Goal: no lab required**

48

48

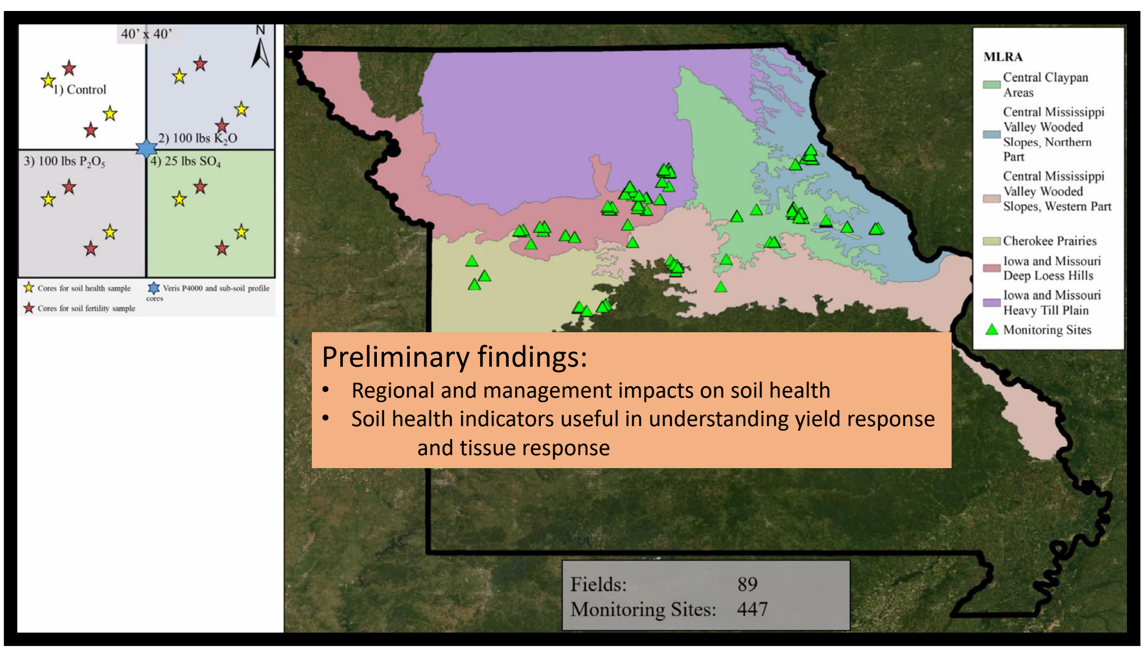
New Research
Soil Health and Soil Fertility





49

49

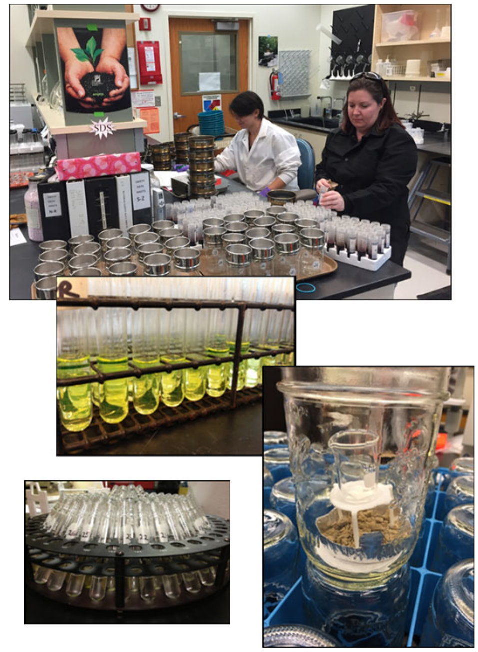


Preliminary findings:
- Regional and management impacts on soil health
- Soil health indicators useful in understanding yield response and tissue response

50

Where are we now?

- ➢ Reducing cost and increasing availability of labs for soil health testing
  - NRCS Tech Note 450-03; Dynamic Soil Properties
  - Several new university and private labs
- ➢ Developing in-field sensors
  - Enzymes, nutrients, other indicators
  - ***Ditch the lab!***
- ➢ Linking soil health to regional outcomes
  - Water quality, C-sequestration, greenhouse gas production
  - Crop yield, disease pressure, nutrient and water use efficiency, weed management
- ➢ Developing SHAPE
  - Decision-based information to landowners



51

Thank you

Nunes, M. R., Veum, K. S., Parker, P. A., Holan, S. H., Wills, S., Seybold, C. A., Van Es, H. M., Amsili, J., Karlen, D., & Moorman, T. B. (2021). **The Soil Health Assessment Protocol and Evaluation (SHAPE) applied to soil organic C.** Soil Science Society of America Journal, https://doi.org/10.1002/saj2.20244.

USDA United States Department of Agriculture
Agricultural Research Service

52