

# Soil health testing: What we can measure and what is useful

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South Dakota Agronomy Conference  
11-12 December 2019



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AGVISE Northwood Laboratory  
40,000 sq. feet - New in 2007

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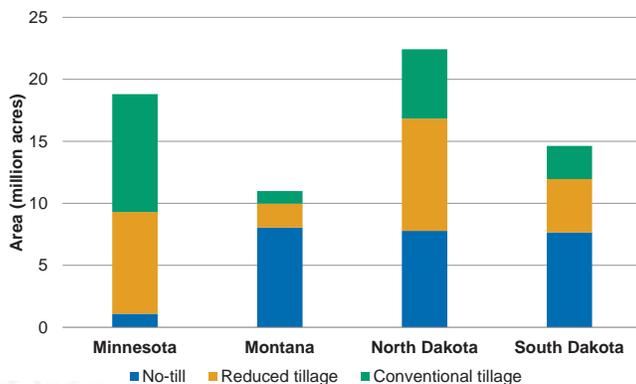
## Today's outline

1. How do we talk about soil health
2. What a soil health test must do
3. Soil health tests
  - 24-h CO<sub>2</sub> respiration (Solvita)
  - Haney Soil Health Assessment
  - Active carbon (POXC)
  - Bioavailable nitrogen (ACE protein)
  - Soil aggregate stability
4. Interpretation of soil health data



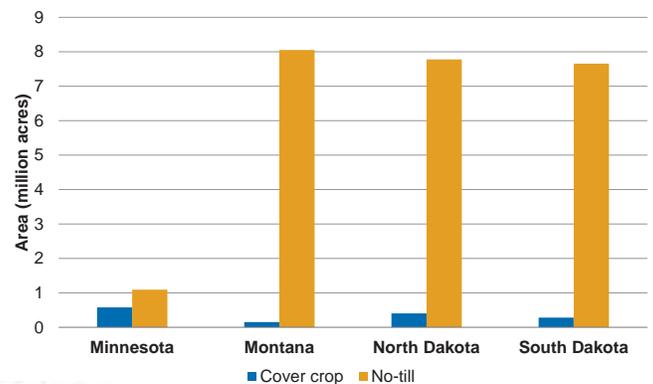
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## Conservation tillage adoption 2017 U.S. Census of Agriculture



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## Cover crop adoption 2017 U.S. Census of Agriculture



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## Define: soil health versus soil quality

- Soil health: the continued capacity of the soil to **function** as a vital living ecosystem that sustains plants, animals, and humans (USDA-NRCS, 2012)
- Soil health: the **maintenance** of soil ecology and properties aimed at sustaining plants, animals, and humans (USDA-NRCS, 2018)
- Soil quality: the soil's fitness for **use**
  - Agricultural? Environmental? Engineering?



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## Soil health in context (oh, you mean the whole system?)

- Physical properties
  - Soil texture, soil structure, soil aggregate stability, bulk density, water infiltration rate, water holding capacity
- Chemical properties
  - pH, salinity, organic matter, plant-available nutrients (N, P, K, Ca, Mg, S, B, Cl, Cu, Fe, Mn, Mo, Ni, Zn)
- Biological properties
  - Microorganism communities (bacteria, fungi, arthropods, earthworms), mineralization rates, enzyme activity, CO<sub>2</sub> respiration



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## How about a working definition

Basic goals of soil health

- Reduce soil erosion
- Improve soil structure
- Enhance nutrient use efficiency
- Increase crop yield



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## Where does soil health start?



J.S. Breker, AGVISE Laboratories, Northwood, ND.

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## Soil health assessment with laboratory testing

Early 2010s, 24-h CO<sub>2</sub> respiration (Solvita) introduced to measure biological activity

2014 Farm Bill included Conservation Stewardship Program (CSP)

- NRCS programming allowed enhancement SQL15 Soil Health Nutrient Tool (Haney Test), so farmers started requesting the Haney Test
- AGVISE has provided the Haney Test since 2015



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## Soil health is so confuddled, even economists are taking a stab at it

Soil Science Issues - Pedology

### New Soil Index Development and Integration with Econometric Theory

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Sabine Grunwald  
Dep. of Soil and Water Science  
Univ. of Florida  
2181 McCarty Hall, PO Box 110290  
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Michelle A. Phillips  
Economics Dept.  
Univ. of Florida  
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Gainesville, FL 32611

Soil scientists have worked on the conceptualization and contextualization of soil-related notions, such as soil quality, soil health, and soil security, over the past few decades. We reviewed the massive amount of literature regarding those major concepts, and summarized definitions, visions, and constraints. Indicators (In) and indices (Ix) are well suited to aggregate soil and environmental data to assess soil quality, health, and security quantitatively. Our literature review showed that (i) more sophisticated quantification methods are necessary; (ii) often only a single soil property and/or class is modeled rather than more complex soil functions, risks, or services; (iii) there is a lack of harmonization, standardization, and reference frameworks that allow soil comparisons across regions and time; and (iv) methods frequently used to calculate soil In/Ix, such as ordination and factor analysis, do not consider rigorous axiomatic criteria of scientific sound indication systems. In summary, the complex soil concepts stand in sharp contrast to the applied indication methods in the soil science discipline. We investigated the potential to apply econometric methods to assess soil quality, health, and security that serve as alternatives to more traditional In/Ix in soil science. A case study demonstrated the profound transformative potential of linking econometrics-soil-environmental sciences.



Mizuta, K., S. Grunwald, and M.A. Phillips. 2018. New soil index development and integration with econometric theory. Soil Sci. Soc. Am. J. 82(5):1017-1032.

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## To improve soil health...

“You cannot manage what you do not measure.”

1. Do we measure what is measurable, rather than what is important?
2. Does this measurement actually measure something we can manage?
3. Are we ignoring other items that should be measured?



Mizuta, K., S. Grunwald, and M.A. Phillips. 2018. New soil index development and integration with econometric theory. Soil Sci. Soc. Am. J. 82(5):1017-1032.

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## What questions are we trying to answer with soil health testing?

- Is reduced tillage actually doing anything?
- Has that root-restricting tillage pan disappeared?
- How are cover crops improving my soil?
- Is soil salinity decreasing?
- Can my soil store more water?
- Will there be greater nitrogen mineralization?
- Can I reduce fertilizer rates?



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## Useful or simply measurable?

Parameter	Can you measure it?	Can you change it?	Can you reliably track it?	Can you use it?
Soil texture	✓	X	n/a	✓
Soil organic matter	✓	✓	✓	✓
Nitrogen mineralization	X	?	X	?



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## Requirements of any soil health test

- Sensitive to soil management changes
- Rapid, repeatable procedure
- Inexpensive (at least affordable if done every few years)
- University validation to define interpretation



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## AGVISE Soil Health Tracking Project

Long-term cropping sequence  
~10 years, near Hatton, ND

LaDelle silt loam  
(Cumulic Hapludolls)

Crop	Soil organic matter (LOI, %)
Alfalfa	5.5
Corn (C-S rot.)	5.4
Soybean (C-S rot.)	4.7
CRP	7.6



Conventional tillage after each crop,  
only CRP without tillage



J.T. Lee, AGVISE Laboratories (personal communication, 2019)

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## 24-h CO<sub>2</sub> respiration (Solvita)

- Amount of CO<sub>2</sub> respiration from microorganisms, measured 24 hours after soil is rewetted
- General biological activity
- More biological activity, more organic matter decomposition and N mineralization?



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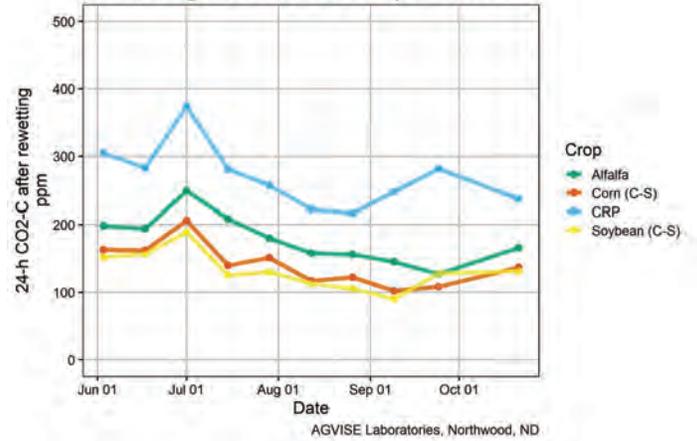
## 24-h CO<sub>2</sub> respiration (Solvita)

- Equipment and method have changed: jars may leak, CO<sub>2</sub> paddles may saturate (highly active soils)
- AGVISE uses pressure-checked jars and infrared CO<sub>2</sub> determination



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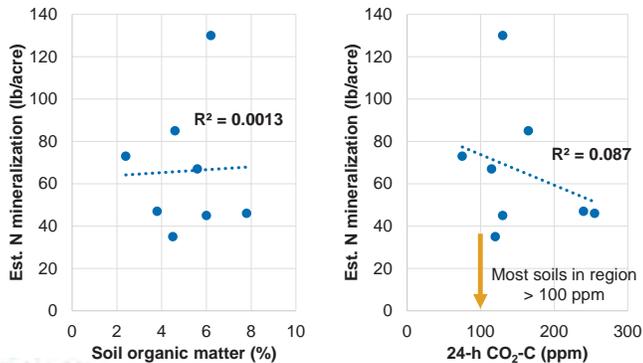
## Tracking 24-h CO<sub>2</sub> respiration



J.T. Lee, AGVISE Laboratories (personal communication, 2019)

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## Does 24-h CO<sub>2</sub> respiration predict N mineralization?



Platen, D., A. Marglin, T. Fraser, J. Seward, and J. Heard. 2018. Estimating the nitrogen supplying power of Manitoba soils. In: Lee, J.T., chair, 1<sup>st</sup> AGVISE Soil Fertility Seminar - Canada, Portage la Prairie, MB, 14 Mar. 2018. AGVISE Laboratories, Northwood, ND.

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## Useful or simply measurable?

Parameter	Can you measure it?	Can you change it?	Can you reliably track it?	Can you use it?
Soil texture	✓	✗	n/a	✓
Soil organic matter	✓	✓	✓	✓
Nitrogen mineralization	✗	?	✗	?
24-h CO <sub>2</sub> respiration	✓	✓	✗	✗



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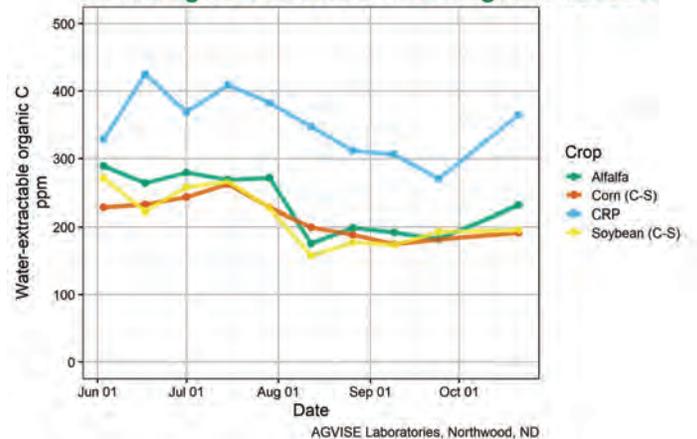
## Haney Soil Health Assessment (HSHA)

- Soil health calculation based on
  - 24-h CO<sub>2</sub> respiration
  - Water-extractable organic C and N
- H3A chemical extraction
  - Alternative method for P, K, and micronutrients
  - Weak acid extractant (lithium citrate, citric acid, malic acid, oxalic acid, EDTA, DTPA)
  - Formulation has changed, now on version 4
  - Estimation of mineralizable P from organic matter



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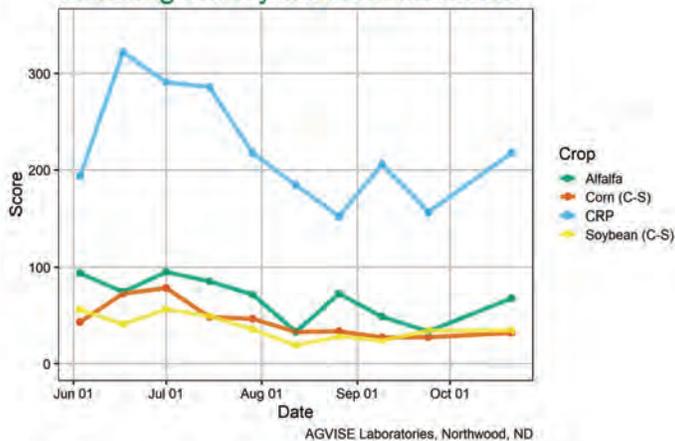
## Tracking water-extractable organic carbon



J.T. Lee, AGVISE Laboratories (personal communication, 2019)

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## Tracking Haney Soil Health Score

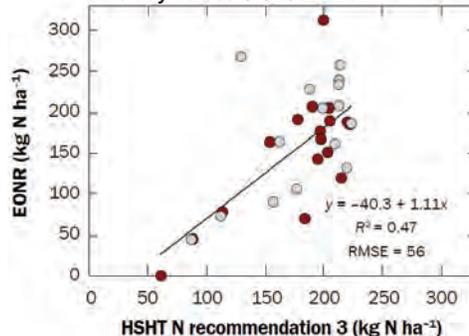


J.T. Lee, AGVISE Laboratories (personal communication, 2019)

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## HSHA is poor predictor of economically optimum nitrogen rate (EONR) in corn

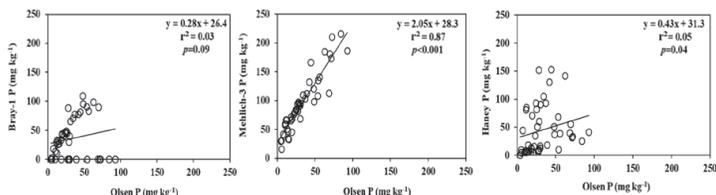
Eight-state corn nitrogen calibration study across U.S. Corn Belt



Yost, M.A., K.S. Veum, N.R. Kitchen, J.E. Sawyer, J.J. Camberto, P.R. Carter, R.B. Ferguson, F.G. Fernandez, D.W. Franzén, C.A. Labaki, and E.D. Natziger, 2018. Evaluation of the Haney Soil Health Tool for corn nitrogen recommendations across eight Midwest states. *J. Soil Water Conserv.* 73(5):587-592.

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## Haney phosphorus (H3A-P) fails on calcareous soils



Just like Bray-1 P, the weak acid H3A extractant is neutralized by carbonate



Dani, B., C.W. Rogers, A.B. Leytem, and K.L. Schroeder. 2019. Evaluation of soil test phosphorus extractants in Idaho soils. *Soil Sci. Soc. Am.* 1:83(3):817-824.

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## Useful or simply measurable?

Parameter	Can you measure it?	Can you change it?	Can you reliably track it?	Can you use it?
Soil texture	✓	✗	n/a	✓
Soil organic matter	✓	✓	✓	✓
Nitrogen mineralization	✗	?	✗	?
24-h CO <sub>2</sub> respiration	✓	✓	✗	✗
Water-extractable organic carbon (WEOC)	✓	✓	?	✗
Haney Soil Health Score	✓	✓	✗	✗



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## The new methods

- Active carbon (permanganate-oxidizable carbon, POXC)
- Soil protein (autoclave citrate-extractable protein, ACE protein)
- Soil aggregate stability (water-stable aggregation)

These “new” methods have long been used in soil quality research with no reason to commercialize, until now with recent farmer demand in the soil health era

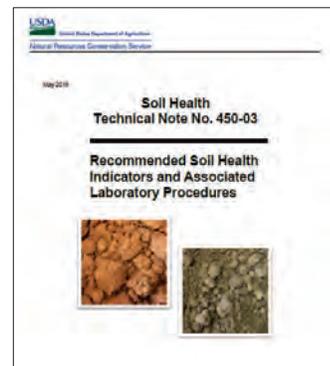


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## NRCS Technical Note No. 450-03 Released May 2019

### Basic soil health package

- Organic matter and carbon sequestration (total organic C)
- General microbial activity (CO<sub>2</sub> respiration)
- Carbon food source (active C, POXC)
- Bioavailable nitrogen (ACE protein)
- Soil structural stability (water-stable macroaggregates)



Stott, D.E. 2019. Recommended soil health indicators and associated laboratory procedures. Soil Health Technical Note No. 450-03. USDA-NRCS, Washington, DC.

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## Active carbon (POXC)

- The biologically active carbon fraction, that is living and particulate organic matter, involved in nutrient cycling (i.e., microorganism food)
- Responds to changes in crop and soil management more quickly than total organic matter, leading indicator of soil organic matter stabilization
- Laboratory analysis is fast, repeatable, low cost



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## Active carbon (POXC)

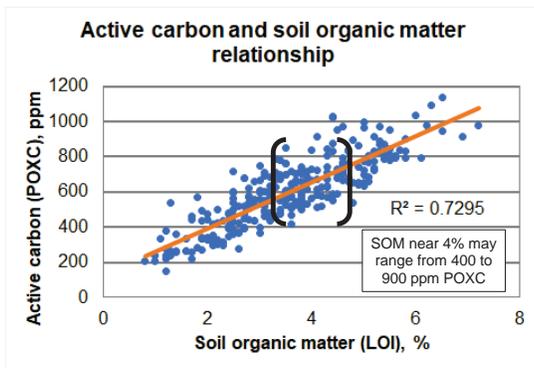


Potassium permanganate oxidizes readily available C, colorimetric determination



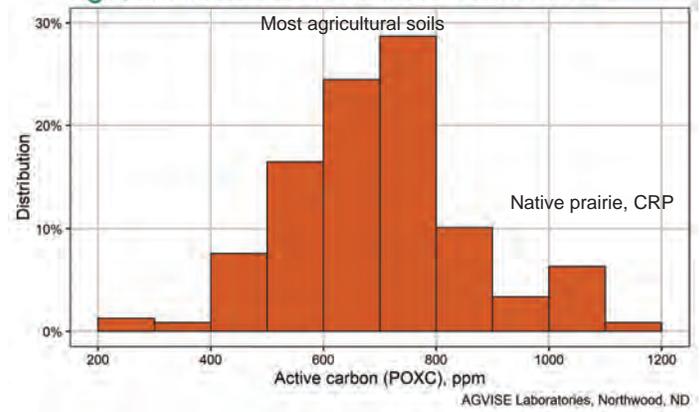
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## Active carbon (POXC) is one fraction of soil organic matter



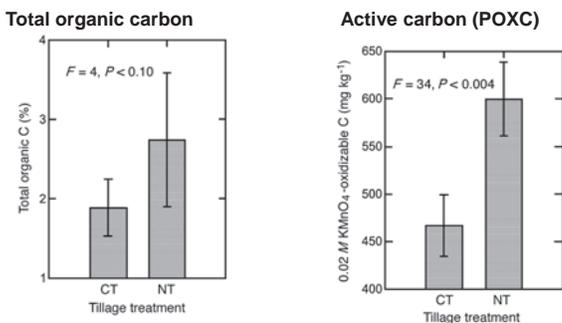
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## Active carbon (POXC) distribution among agricultural soils of the Northern Plains



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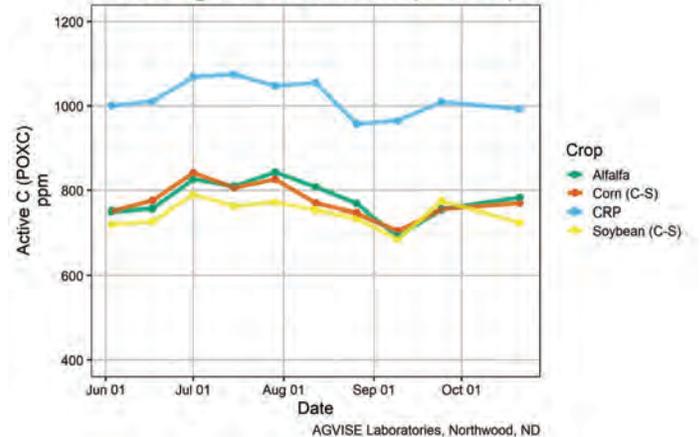
## Active carbon (POXC) is a more sensitive indicator than total organic carbon North Dakota, 17 year experiment



Wei, R.R., K.R. Islam, M.A. Stine, J.B. Gruver, and S.E. Samson-Liebig. 2003. Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use. *Am. J. Altern. Agric.* 18(1):3-17.

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## Tracking active carbon (POXC)



J.T. Lee, AGVISE Laboratories (personal communication, 2019)

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## Useful or simply measurable?

Parameter	Can you measure it?	Can you change it?	Can you reliably track it?	Can you use it?
Soil texture	✓	X	n/a	✓
Soil organic matter	✓	✓	✓	✓
Nitrogen mineralization	X	?	X	?
24-h CO <sub>2</sub> respiration	✓	✓	X	X
Water-extractable organic carbon (WEOC)	✓	✓	?	X
Haney Soil Health Score	✓	✓	X	X
Active carbon (POXC)	✓	✓	✓	X



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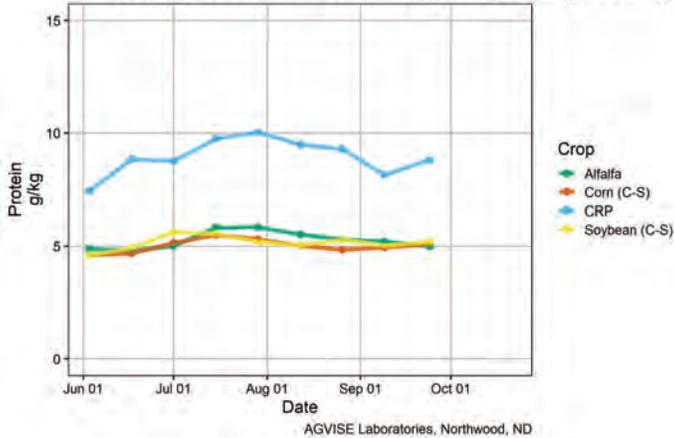
## Bioavailable nitrogen (ACE protein)

- The protein-like organic nitrogen fraction in soil organic matter accessible for microbial mineralization
- Organic matter quality for N mineralization (greater mineralizable N pool)
  - Amount actually mineralized will depend on environment (i.e., soil water, soil temperature)
  - Requires further university research for its ability to predict N mineralization
- Laboratory analysis is fast, repeatable, affordable (not as expensive)



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## Tracking bioavailable nitrogen (ACE protein)



J.T. Lee, AGVISE Laboratories (personal communication, 2019)

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## Useful or simply measurable?

Parameter	Can you measure it?	Can you change it?	Can you reliably track it?	Can you use it?
Soil texture	✓	X	n/a	✓
Soil organic matter	✓	✓	✓	✓
Nitrogen mineralization	X	?	X	?
24-h CO <sub>2</sub> respiration	✓	✓	X	X
Water-extractable organic carbon (WEOC)	✓	✓	?	X
Haney Soil Health Score	✓	✓	X	X
Active carbon (POXC)	✓	✓	✓	X
<b>Bioavailable nitrogen (ACE protein)</b>	✓	✓	✓	X



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## Soil aggregate stability

- The strength of soil aggregates to resist physical degradation and maintain soil structure
- Strong soil aggregates are the building blocks of good soil structure
- Soils with high aggregate stability have:
  - Less soil erosion
  - Better equipment trafficability
  - Faster water infiltration
  - Less surface crusting
  - More diverse habitat for soil microorganisms



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## Soil aggregate stability

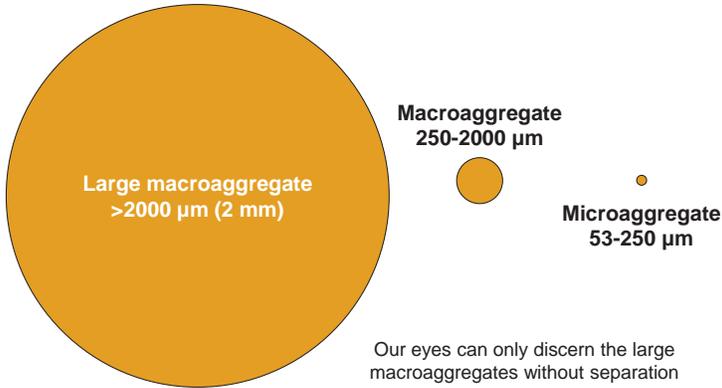
- Common parameter in soil quality research for decades
- Wet-sieving separates aggregate size and strength
- Manual method is expensive and time-consuming



Photo from John A. Kelley, USDA Natural Resources Conservation Service. <https://www.flickr.com/photos/jakelley/28395479059/> (accessed 16 Mar, 2019)

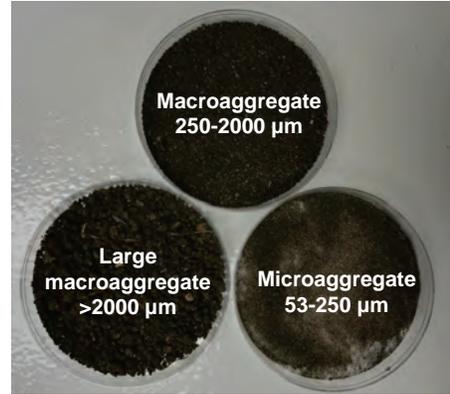
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## Soil aggregate classes



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## Soil aggregate classes



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## Worm channel infilled with aggregates, conduit for air and water transport

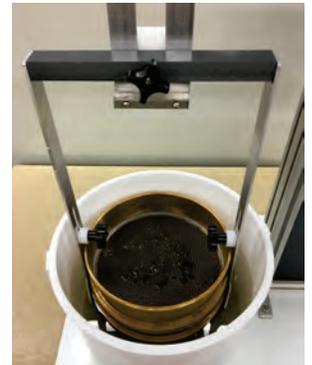


J.S. Breker, AGVISE Laboratories, Northwood, ND.

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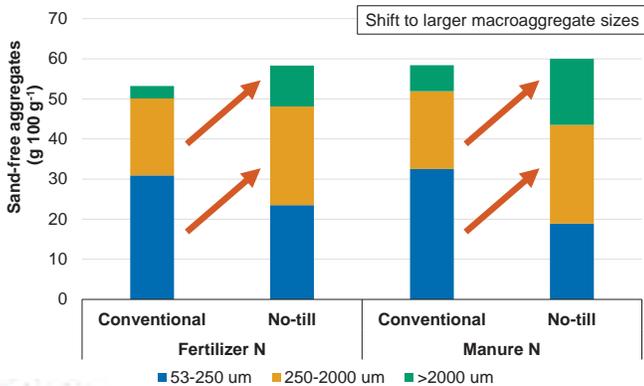
## Soil aggregate stability

- AGVISE built an automated sieve-dunking system
- Quicker, repeatable results
- Reduced person-to-person method error



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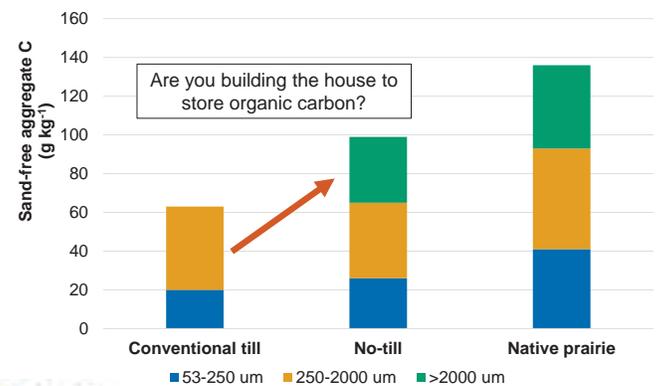
## Soil aggregate stability increased with reduced tillage



Mikha, M.M., and C.W. Rice. 2004. Tillage and manure effects on soil and aggregate-associated carbon and nitrogen. Soil Sci. Soc. Am. J. 68(3):809-816.

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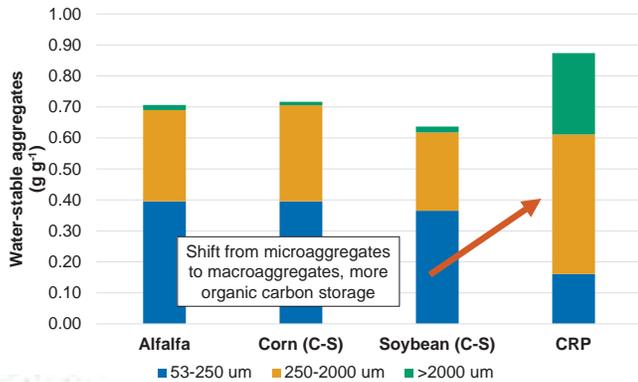
## Stable macroaggregates hold more organic carbon



Six, J., E.T. Elliott, K. Paustian, and J.W. Doran. 1998. Aggregation and soil organic matter accumulation in cultivated and native grassland soils. Soil Sci. Soc. Am. J. 62(5):1367-1377.

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## Tracking soil aggregate stability



J.T. Lee, AGVISE Laboratories (personal communication, 2019)

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## Useful or simply measurable?

Parameter	Can you measure it?	Can you change it?	Can you reliably track it?	Can you use it?
Soil texture	✓	✗	n/a	✓
Soil organic matter	✓	✓	✓	✓
Nitrogen mineralization	✗	?	✗	?
24-h CO <sub>2</sub> respiration	✓	✓	✗	✗
Water-extractable organic carbon (WEOC)	✓	✓	?	✗
Haney Soil Health Score	✓	✓	✗	✗
Active carbon (POXC)	✓	✓	✓	✗
Bioavailable nitrogen (ACE protein)	✓	✓	✓	✗
Soil aggregate stability	✓	✓	✓	✗



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## Picking a stable soil health indicator

Coefficient of variation (CV) across growing season

Parameter	Alfalfa	Corn (C-S)	Soybean (C-S)	CRP
24-h CO <sub>2</sub> respiration	19%	21%	20%	17%
Water-extractable organic carbon (WEOC)	18%	14%	18%	13%
Haney Soil Health Score	32%	41%	32%	25%
Active carbon (POXC)	5%	5%	4%	4%
Bioavailable nitrogen (ACE protein)	7%	6%	6%	9%



J.T. Lee, AGVISE Laboratories (personal communication, 2019)

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## Useful or simply measurable?

Parameter	Can you measure it?	Can you change it?	Can you reliably track it?	Can you use it?
Soil texture	✓	✗	n/a	✓
Soil organic matter	✓	✓	✓	✓
Nitrogen mineralization	✗	?	✗	?
24-h CO <sub>2</sub> respiration	✓	✓	✗	✗
Water-extractable organic carbon (WEOC)	✓	✓	?	✗
Haney Soil Health Score	✓	✓	✗	✗
Active carbon (POXC)	✓	✓	✓	✗
Bioavailable nitrogen (ACE protein)	✓	✓	✓	✗
Soil aggregate stability	✓	✓	✓	✗



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## Soil sampling protocol

- Active carbon (POXC) and ACE protein can be added onto any routine soil test
- Soil aggregate stability requires its own soil sample
  - Collect with spade, about 2-inch thick
  - Take soil slice from 3-4 locations in field or zone
  - Soil bag must be specially flagged (we do not want it to be accidentally dried and ground with routine samples)
- All locations should be GPS marked, these are tracking tools



J.T. Lee, AGVISE Laboratories (personal communication, 2019)

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## Soil health testing as a tracking tool

- Be consistent: Microbial communities are dynamic, collect soil samples at the same time each year
- Be patient: Soil ecosystems take time to change, do not expect big results from small changes
- Set benchmarks: Each soil is different, obtain baseline data for each soil



Cates, A. 2019. 5 tips for soil health testing. Minnesota Crop News 2 Oct. 2019. Univ. Minnesota Ext., St. Paul, MN. <https://blog-crop-news.extension.umn.edu/2019/10/5-tips-for-soil-health-testing-sampling.html> (accessed 20 Nov. 2019).

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## How high can you go?

- Recognize long-term, undisturbed perennial system is the best your soil type and climate can likely provide
- Collect soil sample from adjacent grass or woodland (CRP, fence line, shelterbelt)
  - Deposition of eroded soil?
- Cropland may have better soil nutrient levels considering fertilizer history



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## Don't forget the backbench: physical and chemical soil properties

- Soil pH
- Salinity (electrical conductivity, EC)
- Sodium adsorption ratio (SAR, %Na)
- **Total organic carbon**
- Bulk density
- Soil texture
- Available water holding capacity



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## Soil salinity, Public Enemy No. 1

Estimated 20% cropland in North Dakota affected by soil salinity



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## “Stop draggin’ my [soil] around.”

with apologies to Stevie Nicks and Tom Petty



Photo from Bohn, M., D. Hopkins, C. Gasch, D. Steele, and S. Tuscherer. 2018. Predicting soil health and function using remote-sensed evapotranspiration and terrain attributes for a benchmark soil. In: Franzén, D.W., chair. 2018 NDSU Soil and Soil Water Workshop, Fargo, ND. 17 Jan. 2018. North Dakota State Univ., Fargo, ND.

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## For perspective

- Soil health testing is still in its infancy
- Soil fertility testing took decades to reach acceptance and adoption (1930s → 1970s)
  - 1845: first soil test method using carbonated water
  - 1894: first fertilizer recommendation for phosphorus
  - 1930/40s: extensive method and fertilizer studies
  - 1953: NDSU Soil Testing Laboratory started (public)
  - 1976: AGVISE Laboratories started (private)
- Various and sundry soil health methods will be introduced and evaluated by universities

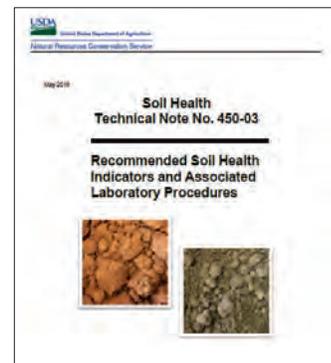


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## NRCS Technical Note No. 450-03 Released May 2019

### Basic soil health package

- Organic matter and carbon sequestration (total organic C)
- General microbial activity (CO<sub>2</sub> respiration)
- Carbon food source (active C, POXC)
- Bioavailable nitrogen (ACE protein)
- Soil structural stability (water-stable macroaggregates)



Stott, D.E. 2019. Recommended soil health indicators and associated laboratory procedures. Soil Health Technical Note No. 450-03. USDA-NRCS, Washington, DC.

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## Questions for you

- What should you expect soil health tests to provide you? Information on soil properties (facts) or nutrient management (functions)?
- What does soil aggregate stability say?
  - Important information for erosion, compaction, and field trafficability
  - Doubtful utility in nutrient management
- Are we expecting too much (or the right things) from new soil health tests?



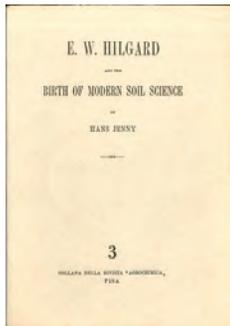
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## AGVISE Soil Fertility Seminars

- Topics on nitrogen and water quality, precision ag, saline and sodic soils, manure, soil health testing, demonstration project updates
- Locations for 2020
  - January 7: Granite Falls, MN
  - January 8: Watertown, SD
  - January 9: Grand Forks, ND



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“It is our right to use, but not abuse, the inheritance which is ours, and to hand it down to our children as a blessing, not as a barren, inert incubus, wherewith to drudge through life as a penalty for their fathers' wastefulness.

“That no land can be permanently fertile, unless we restore to it, regularly, the mineral ingredients which our crops have withdrawn.

– E.W. Hilgard (1860), *Report on the Geology and Agriculture of the State of Mississippi*

## Thank you for your kind attention!

Are there any questions?



johnb@agvise.com

@jsbreker

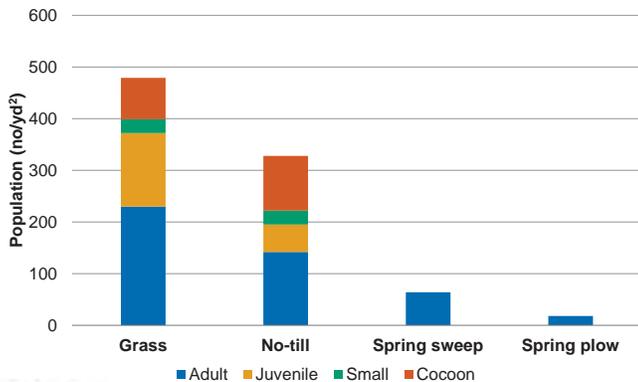
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Frantzen, D.W., and A. Wick. 2016. Nitrogen credit from cover crops? NDSU Crop Pest Rep. 16 July 2016. North Dakota State Univ. Ext. Serv., Fargo, ND. <https://www.ag.ndsu.edu/crops/soils/nitrogen-credit-from-cover-crops-07-16-16> (accessed 25 July 2019).

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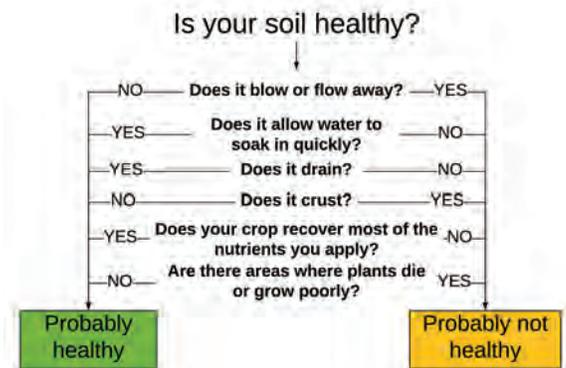
## Earthworm abundance and tillage North Dakota, 12 years



Deibert, E.J., R.A. Ulter, and D.P. Schweit. 1991. Tillage system influence on earthworms (Lumbricidae) in North Dakota. North Dakota Farm Res. 48(5):10-11.

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## Problem-based soil evaluation



McGuire, A. 2019. Soil (health) evaluation begins by asking "What's the problem with my soil?" WSU Center for Sustaining Agric. and Nat. Resour. (blog). 9 July 2019. Washington State Univ., Pullman, WA. <http://csanr.wsu.edu/whats-the-problem-with-my-soil/> (accessed 25 July 2019).

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Excuse me, sir. What seems to be the problem?

