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

John S. Breker
Soil Scientist, AGVISE Laboratories

South Dakota Agronomy Conference
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AGVISE Laboratories
Established 1976
Northwood, ND & Benson, MN
AGVISE Northwood Laboratory
40,000 sq. feet - New in 2007
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$_2$ respiration (Solvita)
   • Haney Soil Health Assessment
   • Active carbon (POXC)
   • Bioavailable nitrogen (ACE protein)
   • Soil aggregate stability
4. Interpretation of soil health data
Conservation tillage adoption
2017 U.S. Census of Agriculture

Cover crop adoption
2017 U.S. Census of Agriculture

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?
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, \( \text{CO}_2 \) respiration
How about a working definition

Basic goals of soil health
• Reduce soil erosion
• Improve soil structure
• Enhance nutrient use efficiency
• Increase crop yield
Where does soil health start?
Soil health assessment with laboratory testing

Early 2010s, 24-h CO$_2$ 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
Soil health is so confused, even economists are taking a stab at it.

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?

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?
## Useful or simply measurable?

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<td>✗</td>
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The highlighted cells indicate parameters that are both measurable and usable.
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
### AGVISE Soil Health Tracking Project

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

<table>
<thead>
<tr>
<th>Crop</th>
<th>Soil organic matter (LOI, %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa</td>
<td>5.5</td>
</tr>
<tr>
<td>Corn (C-S rot.)</td>
<td>5.4</td>
</tr>
<tr>
<td>Soybean (C-S rot.)</td>
<td>4.7</td>
</tr>
<tr>
<td>CRP</td>
<td>7.6</td>
</tr>
</tbody>
</table>

Conventional tillage after each crop, only CRP without tillage

LaDelle silt loam  
(Cumulic Hapludolls)

J.T. Lee, AGVISE Laboratories (personal communication, 2019)
24-h CO$_2$ respiration (Solvita)

- Amount of CO$_2$ respiration from microorganisms, measured 24 hours after soil is rewetted
- General biological activity
- More biological activity, more organic matter decomposition and N mineralization?
24-h CO$_2$ respiration (Solvita)

- Equipment and method have changed: jars may leak, CO$_2$ paddles may saturate (highly active soils)
- AGVISE uses pressure-checked jars and infrared CO$_2$ determination
Does 24-h CO$_2$ respiration predict N mineralization?

\[ R^2 = 0.0013 \]

\[ R^2 = 0.087 \]

Most soils in region > 100 ppm

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Haney Soil Health Assessment (HSHA)

• Soil health calculation based on
  • 24-h CO₂ 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
Tracking water-extractable organic carbon

AGVISE Laboratories, Northwood, ND

Crop
- Alfalfa
- Corn (C-S)
- CRP
- Soybean (C-S)

Water-extractable organic C
ppm

Date
Jun 01  Jul 01  Aug 01  Sep 01  Oct 01

J.T. Lee, AGVISE Laboratories (personal communication, 2019)
Tracking Haney Soil Health Score

Score

Date

Jun 01  Jul 01  Aug 01  Sep 01  Oct 01

Crop
- Alfalfa
- Corn (C-S)
- CRP
- Soybean (C-S)

AGVISE Laboratories, Northwood, ND

J.T. Lee, AGVISE Laboratories (personal communication, 2019)
HSHA is poor predictor of economically optimum nitrogen rate (EONR) in corn

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

\[ y = -40.3 + 1.11x \]

\[ R^2 = 0.47 \]

\[ \text{RMSE} = 56 \]
Haney phosphorus (H3A-P) fails on calcareous soils

Just like Bray-1 P, the weak acid H3A extractant is neutralized by carbonate
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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.
Basic soil health package

- Organic matter and carbon sequestration (total organic C)
- General microbial activity (CO₂ respiration)
- Carbon food source (active C, POXC)
- Bioavailable nitrogen (ACE protein)
- Soil structural stability (water-stable macroaggregates)
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
Active carbon (POXC)

Potassium permanganate oxidizes readily available C, colorimetric determination
Active carbon (POXC) is one fraction of soil organic matter

SOM near 4% may range from 400 to 900 ppm POXC
Active carbon (POXC) distribution among agricultural soils of the Northern Plains

Most agricultural soils

Native prairie, CRP

AGVISE Laboratories, Northwood, ND
Active carbon (POXC) is a more sensitive indicator than total organic carbon.

North Dakota, 17 year experiment.

**Total organic carbon**

<table>
<thead>
<tr>
<th>Tillage treatment</th>
<th>Total organic C (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td>2</td>
</tr>
<tr>
<td>NT</td>
<td>3</td>
</tr>
</tbody>
</table>

*F = 4, *P* < 0.10*

**Active carbon (POXC)**

<table>
<thead>
<tr>
<th>Tillage treatment</th>
<th>0.02 M KMnO₄-oxidizable C (mg kg⁻¹)</th>
</tr>
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<tbody>
<tr>
<td>CT</td>
<td>450</td>
</tr>
<tr>
<td>NT</td>
<td>600</td>
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</table>

*F = 34, *P* < 0.004*

Tracking active carbon (POXC)

Crop
- Alfalfa
- Corn (C-S)
- CRP
- Soybean (C-S)

Active C (POXC) ppm

Date
- Jun 01
- Jul 01
- Aug 01
- Sep 01
- Oct 01

AGVISE Laboratories, Northwood, ND
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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)
Tracking bioavailable nitrogen (ACE protein)

- **Protein g/kg**
- **Date**
- **Crop**
  - Alfalfa
  - Corn (C-S)
  - CRP
  - Soybean (C-S)

AGVISE Laboratories, Northwood, ND

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

Soil aggregate classes

- Large macroaggregate >2000 μm (2 mm)
- Macroaggregate 250-2000 μm
- Microaggregate 53-250 μm

Our eyes can only discern the large macroaggregates without separation.
Soil aggregate classes

- Macroaggregate: 250-2000 μm
- Large macroaggregate: >2000 μm
- Microaggregate: 53-250 μm
Worm channel infilled with aggregates, conduit for air and water transport
Soil aggregate stability

• AGVISE built an automated sieve-dunking system
• Quicker, repeatable results
• Reduced person-to-person method error
Soil aggregate stability increased with reduced tillage

Shift to larger macroaggregate sizes

<table>
<thead>
<tr>
<th>Fertilizer N</th>
<th>Conventional</th>
<th>No-till</th>
</tr>
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<tbody>
<tr>
<td>53-250 um</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>250-2000 um</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>&gt;2000 um</td>
<td>10</td>
<td>5</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Manure N</th>
<th>Conventional</th>
<th>No-till</th>
</tr>
</thead>
<tbody>
<tr>
<td>53-250 um</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
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<td>20</td>
<td>10</td>
</tr>
<tr>
<td>&gt;2000 um</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Stable macroaggregates hold more organic carbon

Are you building the house to store organic carbon?

- Conventional till
- No-till
- Native prairie

53-250 um | 250-2000 um | >2000 um

Tracking soil aggregate stability

Shift from microaggregates to macroaggregates, more organic carbon storage

J.T. Lee, AGVISE Laboratories (personal communication, 2019)
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Picking a stable soil health indicator

Coefficient of variation (CV) across growing season

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<th>Soybean (C-S)</th>
<th>CRP</th>
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<td>17%</td>
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<td>Water-extractable organic carbon (WEOC)</td>
<td>18%</td>
<td>14%</td>
<td>18%</td>
<td>13%</td>
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<tr>
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<td>32%</td>
<td>41%</td>
<td>32%</td>
<td>25%</td>
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<tr>
<td>Active carbon (POXC)</td>
<td>5%</td>
<td>5%</td>
<td>4%</td>
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<td>Bioavailable nitrogen (ACE protein)</td>
<td>7%</td>
<td>6%</td>
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<td>9%</td>
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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
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

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
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
Soil salinity, Public Enemy No. 1

Estimated 20% cropland in North Dakota affected by soil salinity
“Stop draggin’ my [soil] around.”
with apologies to Stevie Nicks and Tom Petty
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
Basic soil health package

- Organic matter and carbon sequestration (total organic C)
- General microbial activity (CO₂ respiration)
- Carbon food source (active C, POXC)
- Bioavailable nitrogen (ACE protein)
- Soil structural stability (water-stable macroaggregates)
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?
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
“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
Cover crop nitrogen credit?

Earthworm abundance and tillage
North Dakota, 12 years

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

Campbell
Gender: male
Age: 53 years
Body mass index: 28 (overweight)
Blood pressure: 145/85 mm Hg
LDL cholesterol: 132 mg/dL
Alcohol use