The North American Project to Evaluate Soil Health Indicators (NAPESHM)

Indian Head Agricultural Research Foundation – Soil and Crop Management Seminar & AGM
February 5, 2020 Balgonie, Saskatchewan

Paul W. Tracy – Soil Health Institute
Measurements & Indicators:
Traditional Soil Productivity Indices

Does Productivity = Healthy?

Putnam Soil Series

Scrivner, CL., B.L. Conkling and P.G. Koenig, 1985
Soil Health Indicators: Key Considerations

- Properties related to functions
- Inherent vs. management-sensitive properties
- Scale? How healthy is this soil? How healthy can we get it?

Reference states

Poor | Good | Better | Best
Soil Health Measurements: How do we Select Them?

**Soil Health ~ fx (Inherent soil properties X management)**

1. Inherent Soil Properties
   1. Clay Content

2. Soil Health Indicators
   1. Aggregate Stability
   2. Organic Carbon (Carbon Stock)
   3. Organic Carbon Fractions
   4. Structure
   5. Health Indexes (Haney, SMAF, Cornell)

3. Biomass or Plant Performance
   1. Evapotranspiration
   2. Roots growth and vigor (carbon, carbon, carbon)

Intact vs. processed
*in situ* vs. lab
cheap vs. expensive
quantitative vs. qualitative
Soil Health Measurements

- Physical
- Chemical
- Biological

SOIL HEALTH
# Tier 1 Soil Health Indicators

<table>
<thead>
<tr>
<th>Chemical/Biological Lab</th>
<th>Physical Lab/Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>Particle Size</td>
</tr>
<tr>
<td>Electrical Conductivity</td>
<td></td>
</tr>
<tr>
<td>Cation Exchange Capacity</td>
<td>Bulk Density</td>
</tr>
<tr>
<td>Percent Base Saturation</td>
<td>Water Stable Aggregation</td>
</tr>
<tr>
<td>Organic Carbon</td>
<td>Available Water Holding Capacity</td>
</tr>
<tr>
<td>Short-Term C Mineralization</td>
<td>Hydraulic Conductivity Surface</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>Crop Yield</td>
</tr>
<tr>
<td>Nitrogen Mineralization</td>
<td>Others</td>
</tr>
<tr>
<td>Extractable P and K</td>
<td></td>
</tr>
<tr>
<td>Sec./Micro. (Ca, Mg, S, Fe, Zn, Cu, Mn)</td>
<td></td>
</tr>
</tbody>
</table>
Tier 2 & 3 Soil Health Indicators Identified

- Sodium Adsorption Ratio
- Enzymes: B-Glucosidase, B-Glucosaminidase, Phosphatase, Arylsulfatase
- Soil Protein Index – Autoclave Citrate Extractable
- Active Carbon – Permanganate Oxidizable C
- Phospholipid Fatty Acid (PLFA)
- Ester-Linked Fatty Acid Methyl Ester (EL-FAME)
- Genomics
- Reflectance (visNIR)
Soil Ecosystem Services – Soil Health Indicator Needs

1) **Biomass Production** – Yield

2) **Carbon Cycling** – SOC, Short-term C mineralization, Permanganate Oxidaizable C (POXC), Enzymes, Protein Index (ACE), Phospholipid Fatty Acid (PLFA)

1) **Nutrient Cycling** – Total Nitrogen, N mineralization, P,K, Micronutrients, biological measures above

2) **Water Cycling** – Saturated Hydraulic Conductivity, Plant-Available Water, Bulk Density
Soil Health Indexes being considered

• **SMAF** – Soil Management Assessment Framework

• **CASH** – Cornell’s Comprehensive Assessment of Soil Health

• **Haney** Test
Comprehensive Assessment of Soil Health CASH

**Standard Indicators:**
- Soil Texture
- Available Water Holding Capacity
- Surface and Subsurface hardness (penetrometer)
- Wet Aggregate Stability (rainfall simulator)
- Organic matter (LOI)
- Soil Protein Index (ACE)
- Soil Respiration (4-day CO$_2$ incubation)
- Active Carbon (POXC)
- Standard nutrient analysis (Modified Morgan)

**Add-on Indicators:**
- Potentially mineralizable N (7-day incubation)
- Root pathogen pressure (bioassay)
- Heavy metal contamination (Modified Morgan)
- Salinity and Sodicity (EC & Na)

- Scoring functions based upon soil texture
- Scoring curves calculate percentile rating
- Output includes overall score (ave. scoring functions)
- Individual indicators (targeted improvement)

Soil Management Assessment Framework
SMAF

Wet Aggregate Stability
Bulk Density
Electrical Conductivity
pH
Sodium Adsorption Ratio
Extractable P
Extractable K
Soil Organic Carbon
Microbial Biomass Carbon (MBC)
Potentially Mineralizable N,
B-Glucosidase activity

-Utilizes soil taxonomy groups (soil suborders)
-Allows for soil and site-specific factors to be considered
-Designed for flexible improvements
-Equal weight assigned to each indicator analyzed
The Haney Test (Ward Laboratories)

**Measurements**

- Soil pH
- Soil soluble salts (EC)
- Soil organic matter (LOI)
- Total N
- Inorganic N (NO₃⁺NH₄), organic N
- Inorganic P + Organic P
- Soil Respiration (24-hour CO₂-C)
- Water extractable organic C (WEOC) and organic N (WEOC)
- H₃A Extractable NO₃, NH₄, Total P, Inorganic P, K, Zn, Fe, Mn, Cu, S, Ca, Mg, Na and Al

**Purpose**

- Provide nutrient and cover crop recommendations
- Provide a soil health score

Score calculated as \( \frac{\text{Soil Respiration}}{10} + \frac{\text{WEOC}}{50} + \frac{\text{WEON}}{10} \)
**USDA NRCS Suite of Soil Health Indicators – Tech Note No. 450-03**

<table>
<thead>
<tr>
<th>Soil Health Indicator</th>
<th>Recommended Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routine Soil Test</td>
<td>Based primarily on state universities</td>
</tr>
<tr>
<td>Soil organic carbon (SOC)</td>
<td>Dry Combustion</td>
</tr>
<tr>
<td>Aggregation</td>
<td>ARS wet macroaggregate stability (MAS)</td>
</tr>
<tr>
<td>Short-term carbon mineralization</td>
<td>4-day respiration</td>
</tr>
<tr>
<td>Enzyme Activity (EA)</td>
<td>B-Glucosidase</td>
</tr>
<tr>
<td></td>
<td>N-acetyl B-D-glucosaminidase</td>
</tr>
<tr>
<td></td>
<td>Phosphomonoesterases</td>
</tr>
<tr>
<td></td>
<td>Arlysulfatase</td>
</tr>
<tr>
<td>Readily Available Carbon Pool</td>
<td>Permanganate Oxidizable Carbon (POXC)</td>
</tr>
<tr>
<td>Available Organic N Pool</td>
<td>Autoclaved citrate extractable protein (ACE)</td>
</tr>
<tr>
<td>Phospholipid fatty Acid (PLFA)</td>
<td>PLFA</td>
</tr>
</tbody>
</table>
Correlating Soil Health Indicators – Looking for Opportunities to Improve Efficiencies and Cost

Example: Correlating visNIR and SMAF scoring functions

<table>
<thead>
<tr>
<th>SMAF score category</th>
<th>Oven-dry soil Direct</th>
<th>Oven-dry soil Indirect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall SMAF</td>
<td>0.82***</td>
<td>0.81***</td>
</tr>
<tr>
<td>Biological SMAF category</td>
<td>0.87***</td>
<td>0.88***</td>
</tr>
<tr>
<td>Organic C</td>
<td>0.94***</td>
<td>0.94***</td>
</tr>
<tr>
<td>β-glucosidase</td>
<td>0.92***</td>
<td>0.92***</td>
</tr>
<tr>
<td>Microbial biomass C</td>
<td>0.70***</td>
<td>0.80***</td>
</tr>
<tr>
<td>Mineralizable N</td>
<td>0.45***</td>
<td>0.53***</td>
</tr>
<tr>
<td>Physical SMAF category</td>
<td>NS†</td>
<td>NS</td>
</tr>
<tr>
<td>Bulk density</td>
<td>NS</td>
<td>0.28*</td>
</tr>
<tr>
<td>Water-filled pore space</td>
<td>0.35**</td>
<td>0.27*</td>
</tr>
<tr>
<td>Water-stable aggregates</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Chemical SMAF category</td>
<td>0.52***</td>
<td>0.36*</td>
</tr>
<tr>
<td>pH</td>
<td>0.25*</td>
<td>0.71***</td>
</tr>
<tr>
<td>Electrical conductivity</td>
<td>0.63***</td>
<td>0.23*</td>
</tr>
<tr>
<td>Nutrient SMAF category</td>
<td>0.50***</td>
<td>0.45***</td>
</tr>
<tr>
<td>Extractable P</td>
<td>0.49***</td>
<td>0.75***</td>
</tr>
<tr>
<td>Extractable K</td>
<td>0.58***</td>
<td>0.51***</td>
</tr>
</tbody>
</table>

How can we use Measurements to Efficiently Account for Spatial Variability?

**Surfing**

High resolution surface (x,y) mapping

Image from Veris Technologies

e.g. Christy, 2008; Bricklemyer and Brown 2010

**Diving**

High resolution profile mapping (z)

e.g. Ackerson et al. Geoderma
North American Project to Evaluate Soil Health Measurements (NAPESHM)

**GOAL:** Identify most effective indicators of soil health

**APPROACH:** Evaluate soil health indicators on long-term agricultural research sites

**Funders:**
- General Mills
- FFAR

**Partners:**
- Many universities
- USDA
- AAFC
- CIMMYT
• Identified & published Tier 1, 2, 3 indicators or measurements (31)
• Technical panel selected methods for evaluating each indicator
• Issued RFA for long-term site applications; Technical Panel selected 124 long-term agricultural research sites/partners
• Hired team of 8 Ph.D. scientists (positioned across N. America)
• Issued RFA for Labs; Selected labs for analyses
• Held 2-day planning workshop for participating scientists
• Developed & distributed Data Management Plan
• Soils sampled 2019; Data interpretation/publication 2020+
NAPESHM Long-Term Research Sites (124)
NAPESHM – Interesting Preliminary Results
Saturated Hydraulic Conductivity (Ksat) NAPESHM Project Selected: Saturo (Meter Group, Inc)

- Manufactured by Meter Group, Inc
- Performed in the field
- Automated tool
- Utilizes multiple pressure heads to correct for three-dimensional flow
- No post-processing required
Illinois, Missouri, 2 Kentucky

- Box plots showing Ksat (cm hr⁻¹) for No-Till and Till treatments.
- Box plots showing Organic Matter (%) for No-till and Till treatments.
Saturated Hydraulic Conductivity – Texcoco, Mexico Site 2

WC= Wheat/Corn, CW = Corn/Wheat, CT=Conventional till, NT = No-till, RB = Raised Seedbed, PB = Permanent Seedbed, R+ = Residue Retained, R- = Residue Removed
Available water capacity by textural class and tillage intensity for delivered data. Note strong relationship by texture with slight variation by tillage. 163 samples, bars represent standard error.

Saturated hydraulic conductivity by textural class and tillage intensity for delivered data. Note inverse relationship to water holding capacity. 141 samples, bars represent standard error.
Available water capacity by cover crop and tillage intensity. Note AWC relationship to tillage with cover crop. 1053 samples, bars represent standard error.

Saturated hydraulic conductivity by cover crop and tillage intensity. Note inverse relationship to AWC and interaction with and without cover crops. 892 samples, bars represent standard error.
Ksat Measurements at Swift Current OMC Study 2019 (cm/sec)
Preliminary Data
Ksat Measurements at Swift Current, SK Rotation Study 2019 cm/sec
Preliminary Data
Ksat Measurements at Indian Head, SK 2019 cm/sec
Preliminary Data
Aggregate Stability as a Soil Health Indicator

Water & air movement
C storage
Erosion potential
Crop productivity
Sensitive to management & inherent properties
Soil disturbance
Cover cropping
Clay content

Photo courtesy of Kade Flynn
Aggregate Stability Methods – NAPESHM evaluated Four

Wet sieve procedure (Kemper and Roseneau, 1986)

SLAKES test
Water slaking image recognition (Fajardo, et al., 2016)

Soil stability
Combination of wet and dry sieving at multiple sieve sizes (Franzluebbers et al., 2000)

Sprinkle infiltrometer (Wet Aggregate Stability test)
(Schindelbeck et al., 2016)
SLAKES: an app for aggregate stability

• developed at the University of Sydney, Australia
  • based on methodology in Fajardo et al., 2016

• stability at 10 min
  • \( stab-10 = \frac{\text{initial area}}{\text{final area}} \)
  • larger \( stab-10 \) = more stable
  • smaller \( stab-10 \) = less stable
• lowest stability in conventional
• highest stability in perennial grass and strip-till
• tillage, cover crop as fixed effect; location as random effect
• $p < 0.0001$
• Tukey’s $\alpha = 0.1$
Aggregate Stability: SLAKES vs Wet Sieve

\[ y = 0.63x + 0.44 \]
\[ r^2 = 0.28 \]
\[ p \text{ value} < 0.0001 \]
Understanding the Soil Microbiome:
Pathogen Suppression, Nutrient Cycling, Cseq
PLFA Separations based upon Management – 6 sites in Canada

Management – Amendment - Manure

Management – Cover crop - Grass

[Graphs showing data points for PLFA separations based on management practices, including amendment and cover crop usage, across 6 sites in Canada.]
NAPESHM: Genomics Results AcrossLocations from a few Sites

Amplicon Sequencing

Address spatial heterogeneity
- Spatial and Temporal Influences
- Intrinsic soil properties
- Other natural influences

- Will this become a useful soil health indicator moving forward?
NAPESHM: Genomics results based upon land management

**Amplicon Sequencing**

Response to management factors across total data set and geographic zones
- Crop rotations
- Tillage
- Cover Crops
- Rangeland Groupings
- Fertilizer Quantity/Quality

The depth of analyses determined by preliminary data assessments
NAPESHM: First 200 samples: Comparison of Index’s Haney/SMAF Scores

Note: Missouri Sites Included
When complete = 2000+
samples from across
North America

$r^2 = 0.22$
NAPESHM: First 200 samples: Comparison of selected CASH functions to overall Cash Score

Note: When complete = 2000+ samples from across North America
Summary of Soil Health Measurements – Paul’s Perspective

1) Much work has been done over the past 30 years

2) We need standardization and uniformity with measurements and with soil health index programs

3) Intrinsic soil properties and local environments may mask the effect of management on many soil health measurements. However, several soil health indicators were greatly affected by management, especially within similar geographies and soils

4) Exciting new strategies of measuring soil health are being developed and the NAPESHM project is contribution to that effort. We are very excited about initial results and look forward to interpreting the data set.
What role do crop advisers and land managers play in soil health?

- Continue to make defendable rec’s
- Utilize client trust
- Keep learning
  - Measurements
  - Programs
  - Opportunities
- Initiate activity and new partnerships
- Lead the conversation – you have much to offer!
Summary Soil Health Crop Advising – Paul’s Perspective

1) Agribusiness and crop advising is a vital link in providing highly productive & sustainable agroecosystems. Always have – Always will!

2) Soil health enhancing practices are required in today’s agriculture.

3) Non-agriculture-based segments of society will continue to look to us to lead the way. A golden opportunity to promote our value.

4) Economic opportunities centered around soil health are out there for those who seek them.

5) Partnerships will be required as we move forward