Soil Health Assessment

Concept to Science

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Kristen Veum and Ken Sudduth, USDA – Agricultural Research Service
History of the soil health concept in the US: Started with “soil conservation”

- Dust Bowl early 1930s
- 1935 Congress passed Public Law 74-46
  - "the wastage of soil and moisture resources on farm, grazing, and forest lands . . . is a menace to the national welfare"
  - established the Soil Erosion Service (SES) = Soil Conservation Service (SCS) = Natural Resources Conservation Service (NRCS)
- Edward H. Faulkner's *Plowman's Folly* (1943) -- Early criticism of intensive farming
- 1950s-1970s pressure to conserve soil and water was increasing; no-till, residue return
- 1990s soil quality/health research
1990s Concerns about Soil Health Concept Still Working On

• Qualitative/Descriptive vs. Quantitative
• Soil use varies
• Multiple, competing soil functions
• Measurable and Interpretable?
• Soil functions difficult to directly measure
  • “Not measurable”
• Inherent soil properties vary
  • Defines ‘soil potential’
• Socio-economic concerns
• Regulatory concerns
Climate-Plant-Soil-Microbe Interactions

- Climate
  - Precipitation
  - Temperature
  - Soil moisture

- Plant
  - Grasses
  - Legumes
  - Forbs

- Soil
  - Chemical
  - Physical
  - Biological

- Microbe
  - Fungi
  - Bacteria
Research
Climate-Plant-Soil-Microbe Interactions

Agroecosystems
Forest Systems
Native and Reconstructed Prairie
Soil Microbes: Why do we care?

• Fungi
  • Saprophytic: decomposition & nutrient cycling
  • Mycorrhizal: phosphorus and water

• Rhizobacteria
  • Phytohormones (auxins)
  • N-fixation
  • Induction of systemic resistance
What are soil microbes doing?
Disease Suppression and Plant Interactions

- Nutrient cycling and uptake of nutrients
  - N-fixation, K and P-solubilizing microorganisms
  - >90% of plants associate with microorganisms
- Preventing plant nutrient and water deficiencies
- Niche competition and predation
- Metabolites: antibiotics, lytic agents, enzymes, volatile compounds, phytohormones (auxins)
- Induction of systemic resistance (ISR) in plants, quorum sensing
- Antagonists to soil-borne plant pathogens.
  - *Pseudomonas, Burkholderia* and *Bacillus* are known to be involved in disease suppression
Research in Soil Microbes

• **How Many?** Microbial Population/Census
  - Microbial Biomass, Total Phospholipid Fatty Acids

• **Who’s There?** Microbial Community Structure
  - Microbial DNA – can be species specific
  - Microbial PLFA – general microbial groups

• **What Are They Doing?**
  - Microbial Enzyme Activity
    - nutrient cycling, etc.
  - Soil Respiration

• **Link microbial information to soil functions and soil processes/ecosystem services:**
  - Outcome based
  - Agronomically meaningful interpretation

**New USDA-NRCS Soil Health Division**
Bianca Moebius-Clune, Director

**Soil Health Community**
American Society of Agronomy
Microbial Community Structure
Phospholipid Fatty Acids

Diversified Rotation with Cover Crops

Eukaryotes
AMF
Fungi
Actinobacteria
Anaerobes
Gram-
Gram+

Sanborn Field

Phospholipid Fatty Acids (nmol/g)

Tucker Prairie
CRP
NTCSW
MTCS
Restored Prairie
NTCC Full
CTCC None
Soil Health Concept Science

Assessments for Producers!
Steps for Agronomically Meaningful Soil Health Assessment

1. Select important soil functions
2. Select indicator(s) for each function
3. Select laboratory method for each indicator
4. Quantify the relationship between the measured indicator and soil function(s)
5. Quantify effects of management on indicators/functions to provide recommendations for management
Characteristics of Soil Health Indicators for Producer Testing

- Meaningful & Reflect Soil Functions
  - Scientific, agronomic, environmental relevance
- Optimal Sensitivity
  - Reflect short-term changes (< 10 years)
  - Not too sensitive (hyper-sensitivity/high variability)
- Measurable
  - Standardized field and lab protocols
  - Repeatable/reproducible
- Affordable
  - Minimal equipment, consumables, labor, and skill
- Interpretable
  - Scientifically-based
  - Provide decision tools for management
Method Selection

- Laboratory method is selected for service labs (not research labs)
  - Time/cost of sample collection and preparation
  - Cost per analysis of consumables and labor
  - Capital equipment costs
  - Required skill level

- Balanced with interpretability
Cost of Soil Health Analyses (U.S. Dollars)

• Chemical/Nutrient
  • Phosphorus $6
  • Potassium (CEC) $12
  • pH $5

• Biological
  • Soil Respiration $4-15
  • Soil organic matter $6
  • Mineralizable nitrogen $12
  • Microbial biomass C $10-15
  • Enzyme activity $10-15
  • Active Carbon $10
  • EL-FAME $30
  • PLFA $25-50
  • DNA $50-100

• Physical
  • Aggregate stability $10
  • Bulk density $5
Research Efforts to Reduce Cost

- Multi-enzyme/Simultaneous enzyme testing
  - Veronica Acosta-Martinez (ARS – TX)
- Soil respiration
- Comparing PLFA with EL-FAME
- EL-FAME 50-60% cheaper
- Using smaller sample sizes/volumes
- Methods for dry soil samples

Balance information and value with cost

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9-EAs of Biogeochemical Cycling

- Phenol sulfates $\rightarrow$ sulfate
- Phosphodiesterase $\rightarrow$ phosphomonoesters
- Phosphodiesters $\rightarrow$ phosphomonoesters
- Acid/alkaline phosphatase
- $\beta$-glucosidase
- $\alpha$-galactosidase
- Melibiose $\rightarrow$ Glucose
- Chitin $\rightarrow$ Amino sugars
- Phosphodiesterase
- C
- N
- S
- P
- Urea $\rightarrow$ ammonium
- Urease
- Amin acids $\rightarrow$ ammonium
- Phosphomonoesters $\rightarrow$ phosphates
- Phosphodiesters $\rightarrow$ phosphomonoesters
- $\beta$-glucosaminidase
- Phenol sulfates $\rightarrow$ sulfate
- Arylsulfatase

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Microbial enzyme activity and nutrient cycling
Interpretation of Data: Soil Health Index

Translating measured soil health indicators into interpretable scores:

1) Measure important soil properties (i.e., soil health indicators)

2) Assign score to lab value
   • Various ways to do this

3) Combine scores into one final number
   • Additive, Non-linear/weighted, other
Interpretation of Data
Why score soil health?

• Soil Health Score ~ GPA
  • Interpretability for producers and non-soil scientists (land appraisal)
  • Comprehensive
  • Rapid identification of where a soil is not performing

• Aids in prioritizing management decisions
Soil Health Index
Rating Soil Function using Lab Data

Select Minimum Data Set (MDS)

- Physical Indicators
- Chemical Indicators
- Biological Indicators

(indicators chosen based on site-specific factors)

Interpret Indicators

Scoring Functions

Calculate Soil Quality Index

\[ f(\text{scored MDS Indicators}) \]

Andrews et al. 2001
Soil Health Indices - Examples

• Soil Management Assessment Framework (SMAF)
  • Uses soil taxonomy and site characteristics plus up to 13 indicators (chemical, physical, biological).
  • Uses non-linear scoring curves.
  • May need regional validation (like Missouri claypan).

• Comprehensive Assessment of Soil Health (CASH)
  • Cornell’s version of the SMAF.
  • Cumulative Normal Distribution
  • Recently expanded algorithms to Midwest

• The Haney Test aka Soil Health Nutrient Tool (SHNT)
  • Uses Solvita respiration, H3A extractable nutrients, and water-extractable nutrients.

• Others (forest soils, wetland soils, prairie soils, etc.)
A “Good” Soil Health Index

• Accounts for site-specific characteristics
  ➢ Inherent soil and climate characteristics

• Includes soil chemical, physical, and biological measurements
  ➢ This includes soil fertility

• Provides meaningful interpretations based on agronomic and/or environmental thresholds
  ➢ Rapid identification of where/how a soil is not performing
  ➢ Aids in prioritizing management decisions
Pedology & Soil Forming Factors

- Vegetation
- Climate
- Parent Material
- Time
- Topography/Relief
- Management (Human Factor)
Site Considerations: Climate

Annual Average Precipitation
United States of America

Legend (inches)
- Less than 5
- 5 to 10
- 10 to 15
- 15 to 20
- 20 to 25
- 25 to 30
- 30 to 35
- 35 to 40
- More than 180

Modeling performed by Christopher Daily using the PRISM model, based on 1981-1990 normals from NOAA
Cooperative stations and NRCG SHORETEL sites. Sponsored by USDA-SCS Water and Climate Center, Portland, Oregon.

Oregon Climate Service
George Taylor, State Climatologist
(541) 732-5705
Site Considerations
Soils & Vegetation

Original extent of the tall, mixed, and short-grass prairie

2007 Cropland Acres
Soil Taxonomy
Pedology $\rightarrow$ Management $\rightarrow$ Soil Health
SMAF Accounts for Soil Taxonomy, Texture, Slope, Climate

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<td>sand</td>
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<tr>
<td>loamy sand</td>
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<tr>
<td>sandy clay loam</td>
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<tr>
<td>loam</td>
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<tr>
<td>silt loam</td>
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<td>Cryepnts</td>
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<td>Orthols</td>
<td>Silt</td>
<td>Fluvents</td>
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<tr>
<td>Orthels</td>
<td>All other suborders</td>
<td>Solvents</td>
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<td>Other</td>
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<th>5 to 9</th>
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SMAF Soil Health includes Soil Fertility

- **Chemical/Nutrient**
  - Phosphorus
  - Potassium
  - pH
- **Physical**
  - Aggregate stability
  - Bulk density
- **Biological**
  - Soil organic matter **
  - Mineralizable nitrogen
  - Microbial biomass C
  - Enzyme activity (β-glucosidase activity)

Traditional ‘soil fertility’ testing covers these measurements.
Soil Management Assessment Framework

pH Algorithm

\[ Y = a \times \exp \left( \frac{-\left(x-b\right)^2}{2c^2} \right) \]

- \( a = 1 \) (fixed)
- \( b = \) optimum pH\(^\S\)
- \( c = \) pH range\(^\S\)
- \( x = \) pH

\(^\S\) crop dependent

Soil Management Assessment Framework

Phosphorus Algorithm

- Series of logic statements and algorithms
  - plant P requirements
  - slope
  - weathering class
  - lab P method
  - OM class

"Optimum" curve to meet plant P needs without causing environmental harm

Soil Management Assessment Framework

Potentially Mineralizable N (28d aerobic)

- Score = \( \frac{a}{1+b \times \exp(-c\times x)} \)
  - \( a \) & \( b \) = fixed
  - \( c \) = dependent on
    - OM class
    - texture class
    - climate class

"More is better" until you reach a point of diminishing returns

Vary OM, texture, and climate class

SMAF: \( \beta \)-Glucosidase Logistic function

Score = \( \frac{a}{1+b \times \exp(-c \times x/1000)} \)

- \( x = \) \( \beta \)-glucosidase
  - \( a \) & \( b \) = fixed
  - \( c \) = dependent on
    - OM class
    - Texture
    - Climate

"More is better" until you reach a point of diminishing returns

Vary OM, texture, and climate class
Missouri Soil Health Assessments

Tillage
- No-Till
- Mulch-Till
- Conventional

Crop Rotation
- Corn-Soybean
- Corn-Soybean-Wheat/Red Clover

Perennial
- Hay
- Cool-season CRP
- Warm-season CRP
- Pasture/Forage
- Bioenergy
- Native Prairie
- Reconstructed Prairie
- Forest

0-5 cm
5-15 cm
Soil Health Indicators

• **Chemical/Nutrient**
  - Phosphorus
  - Potassium
  - pH
  - Electrical conductivity

• **Physical**
  - Aggregate stability
  - Bulk density

• **Biological**
  - Soil organic carbon
  - Mineralizable nitrogen
  - Microbial biomass C**
  - Active Carbon
  - Total Protein
  - Soil Respiration
  - Enzyme activity (β-glucosidase and others)
  - Phospholipid Fatty Acids
  - Metagenomics (with collaborators)
Centralia 2008 SMAF Scores

Sanborn Field & Tucker Prairie

Agricultural Continuum of Soil Health


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

What Indicators Contribute to the Differences in SMAF Scores?

• Biological
  • Soil Organic Carbon
  • β-glucosidase
  • Microbial Biomass Carbon
  • Mineralizable Nitrogen

• Physical
  • Bulk Density
Where Are We Now?
Development of Producer Soil Health Assessments

1. Identified important soil functions
2. Selection of appropriate indicators
3. Select indicator method (lab protocols)
4. Regional interpretation for management decisions
   - Benchmark/reference/regional soils
   - Regional database, cumulative normal distribution?
   - Link measured values to soil function and ecosystem services: **Outcome based and agronomically meaningful**
Future Research Needs

• How to achieve high-resolution spatial and temporal data in the face of high analytical costs?

• How do we collect and incorporate soil profile information?

• How can we leverage research in native ecosystems to optimize production in agroecosystems?

• How do we scale up from field studies to develop a global strategy for soil health assessment?

• What are the gaps in the data and what tools do we need to overcome the barriers?

• How do we simultaneously optimize agricultural production and environmental protection?
• Interpret soil health on a regional basis in the context of pedology
  • Soil forming factors and inherent characteristics
  • Remember that fertility is an integral part of soil health
  • Utilize soil profile information

• Develop producer recommendations that are meaningful, decision-based, and cost effective