USDA

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Recommended Standard Methods for Use as Soil Health Indicator Measurements

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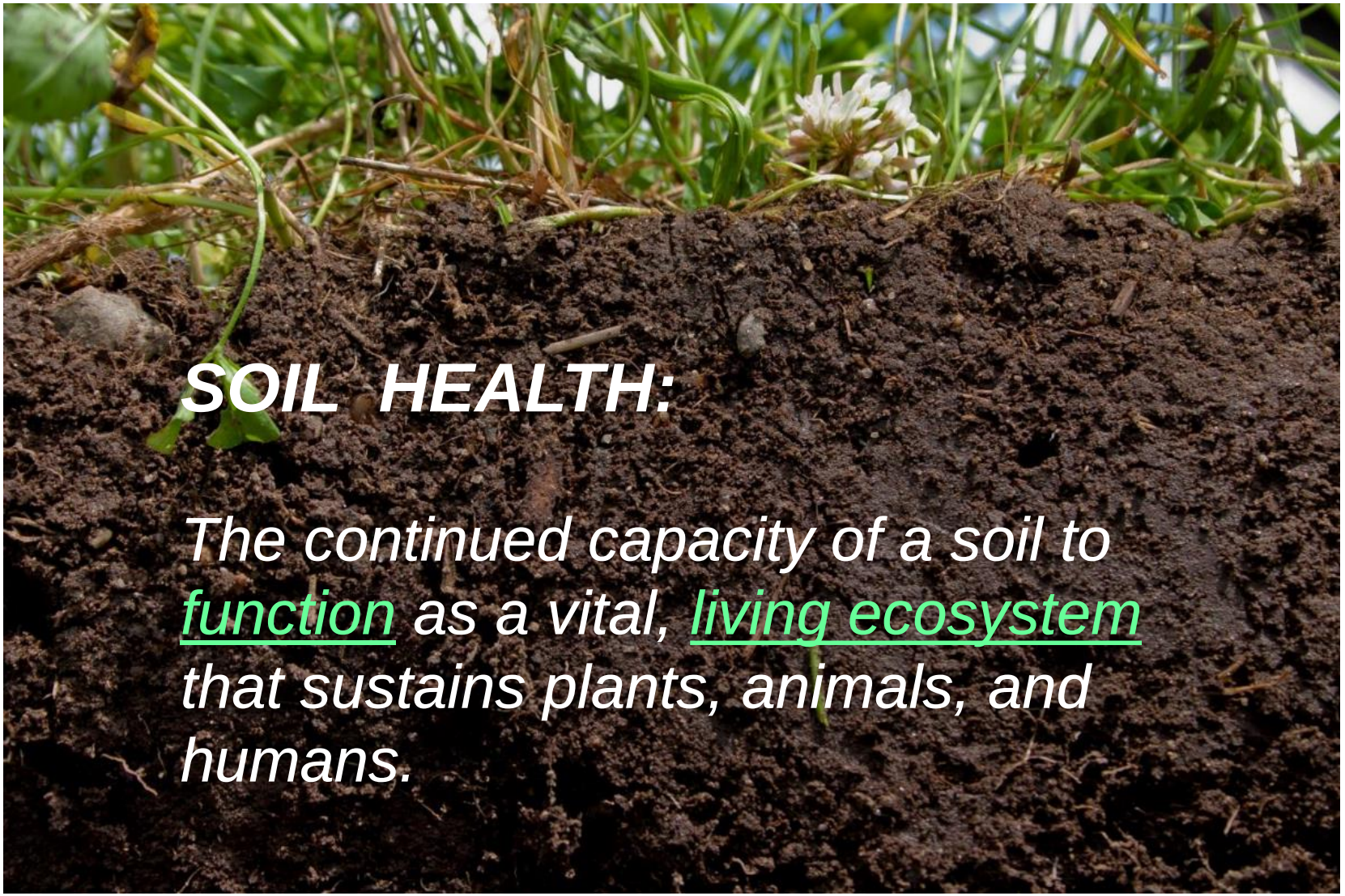
SOIL HEALTH:
The continued capacity of a soil to function as a vital, living ecosystem that sustains plants, animals, and humans.

Need for Standardization of Soil Health Assessment

Soil health assessment (or measurement and interpretation) and monitoring protocols are largely non-existent and/or non-standardized beyond nutrient testing:

- Sampling protocols
- **Indicator choice**
- **Laboratory Methodology**
- Interpretation
- Management Recommendations

(Friedman, 2001; Bastida et al., 2008; among many others)

Soil Health Assessment

Standard soil testing beyond nutrient availability needed to facilitate progress on interpretation and use in national and regional programs, tools, policies, and services.

Need indicators that inform about functioning of:

- Organic matter cycling and C sequestration
- Soil structural stability and water partitioning
- General microbial activity
- Carbon food source
- Bioavailable nitrogen
- Microbial community structure and diversity

Key Outcomes – Opportunities to Collaborate

- **Standardized soil health measures**
  - Nationwide data sharing
  - Faster, better interpretation development, soil-specific at a national scale
  - Public availability and adoption
  - Protocol for updating methods with new science with partners
- **Actionable, easily understood results for management decisions**
- **Integration of acquired findings into Conservation Planning and Implementation**
- **Mobile apps and databased to leverage partner resources**
- **Broad collaboration**
- **Consistent message to farmers**
  - from across the Ag Service Provider Community to speed adoption of SHMS
- **Benefits to Society at large**

Acknowledgements

2011-2016	NRCS Unlock the Secrets of the Soil Campaign
2013-2016	Soil Renaissance – multi-organizational collaboration identified need for standards; funded by Samuel Roberts Noble Foundation and the Farm Foundation
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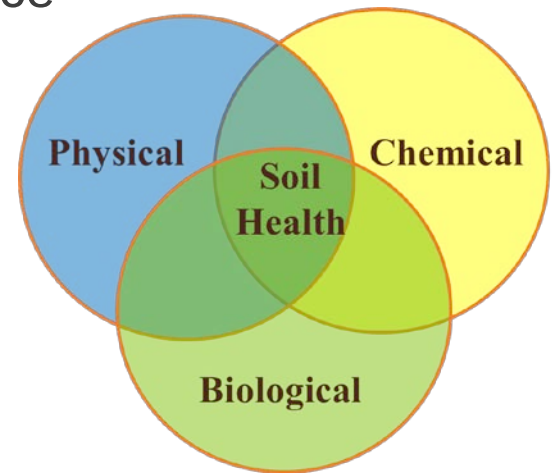
Criteria for Good Soil Health Indicators

- Scientific, agronomic, environmental relevance
- Represent diverse processes
- Sensitive to agricultural management
- Ability to show short term change
- Standardized methods
- *Easy and inexpensive to sample & measure*
- *Repeatable*
- *Minimal infrastructure/investment*
- *Interpretations – Trends & limits known in all regions of the U.S.*
- ***Actionable:** ability to provide science-based indicator-informed recommendations for management*



(Doran et al., 1994; Larson and Pierce, 1991; Mausbach and Seybold, 1998; Moebius et al., 2007; Bastida et al., 2008; Moebius-Clune 2010)

Measurement & Standards

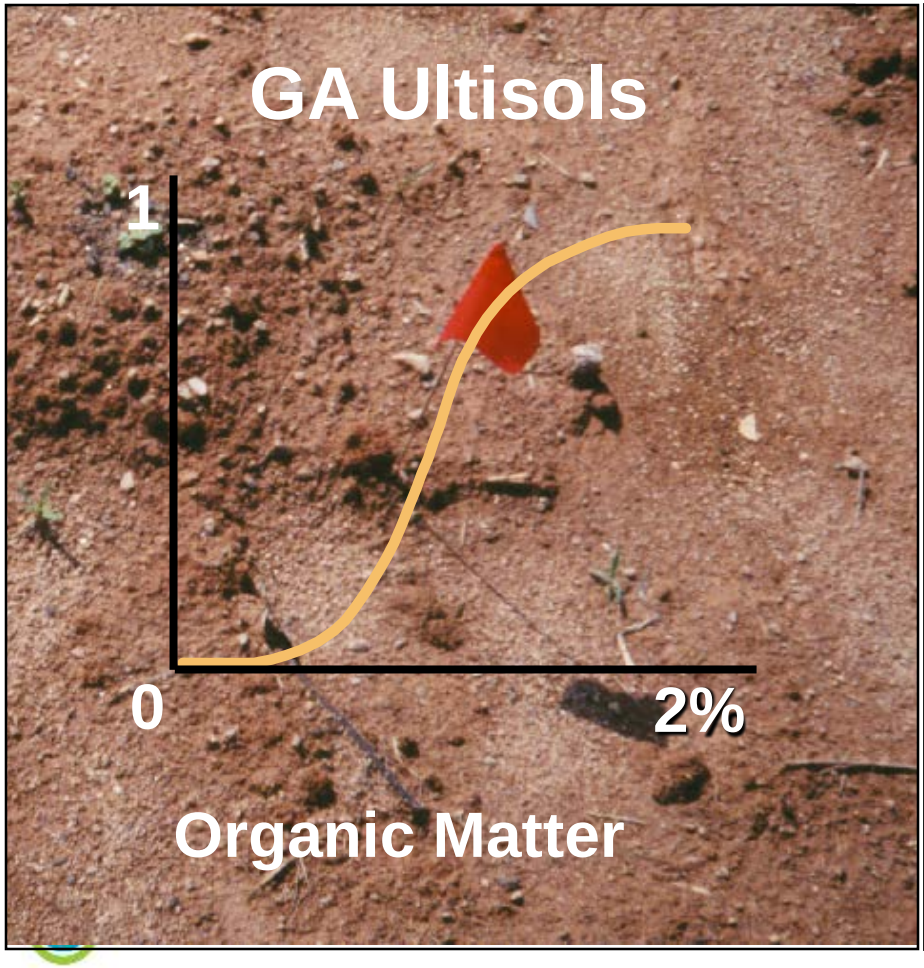
Three tiers of Soil Health Indicators were identified:

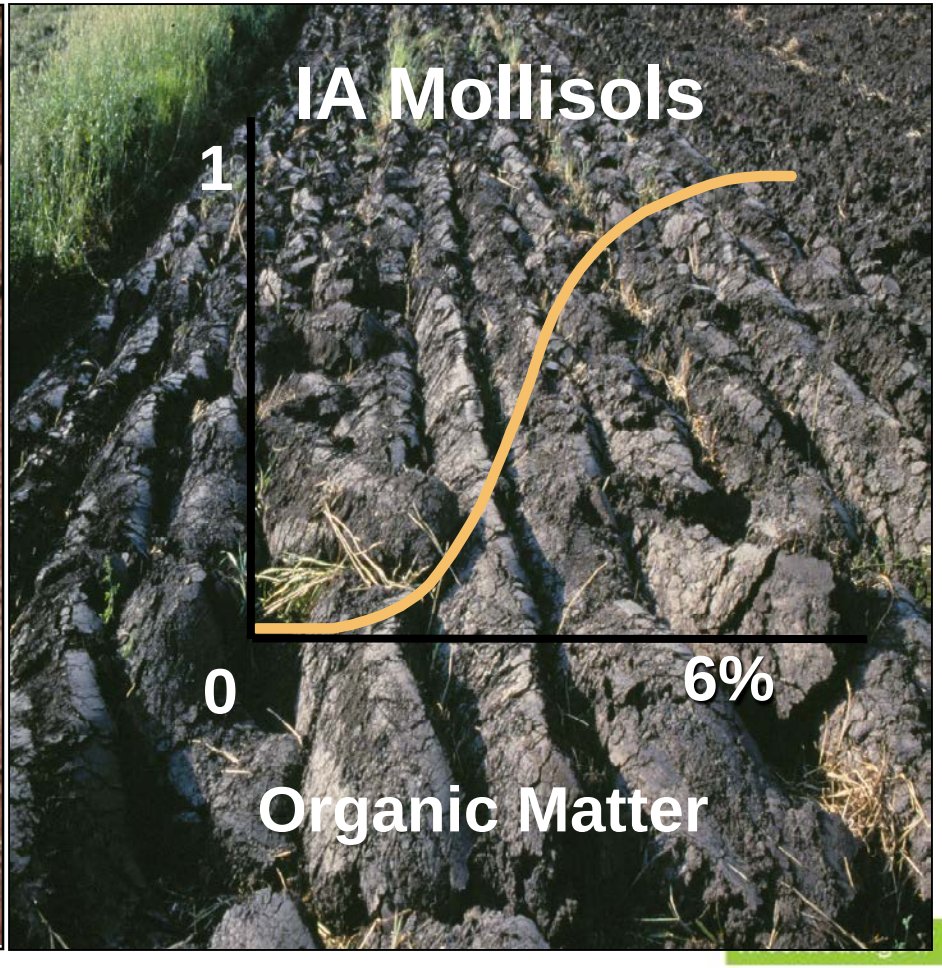
- **Tier 1**
  - Effective indicator
  - Defined regionally and by soil groupings across nation
  - Have thresholds to at least indicate "Poor", "Adequate", "Good" that are outcome based (i.e. yield, environmental, etc.)
  - Management can be suggested to improve soil functioning

Measurement & Standards

- **Tier 2**
  - Effective indicator
  - Know the trends/directionality, may have good idea of potential ranges in some regions but not nationally
  - Do not know thresholds for adequate functioning in a healthy soil in various regions (not outcome-based)
  - Have some idea of which management practices can change indicator and processes it informs us about
- **Tier 3**
  - Has potential to add significant information not available from other indicators if we learn more
  - Is somewhat effective
  - Still needs a lot of work for production laboratory implementation, interpretation, understanding regionality, management impacts.
  - We should learn more

Indicator Interpretation via soil based scoring functions



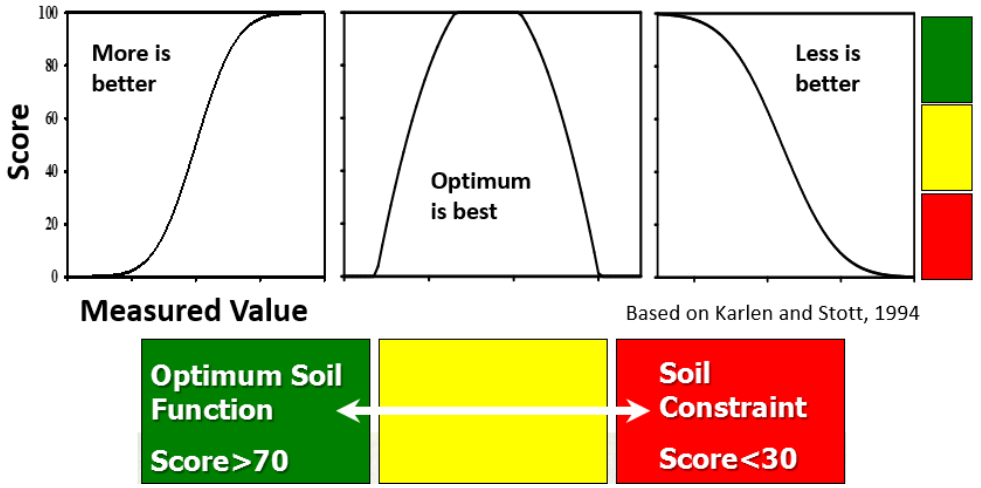


SCORING METHODS for new indicators

LOCAL CONDITIONS

- Analogous to standardized testing and medical approaches
- Calculate mean and standard deviation within a group
- Assess where individual falls in frequency distribution
- **Can be done based on a regional dataset before outcome thresholds are identified**

3 types of Scoring Functions interpret degree of soil process constraint:



Based on Karlen and Stott, 1994

Processes

Soil Organic Matter Accumulation

- Critically important for nutrient storehouse, soil structure, and support of the underground biota, among other impacts
- Tier 1: Soil Organic Carbon (dry combustion)
- Tier 2: Loss on Ignition

Nutrient Availability (out of scope of Technical Note)

- Tier 1: NPK – Major plant nutrients
- Tier 2: Trace Elements

Chemical Reactivity (out of scope of Technical Note)

- Tier 1: pH
- Tier 2: Salinity / Sodicity

Soil Structure / Water Partitioning

- Tier 2: Macroaggregate Stability

Processes

General Microbial Activity

- Tier 2: Short-term Carbon Mineralization
- Tier 2: Metabolic (Enzyme) Activity

Available Carbon Source

- Tier 2: Active Carbon (permanganate oxidizable)

Bioavailable Nitrogen

- Tier 2: Soil Protein concentrations

Microbial Community and Diversity

- Tier 2 or 3: Phospholipid Fatty Acid Profiles (PLFA)
- Tier 3: Many methods show promise, but still require a lot of work before they are ready for deployment to soil test labs.

Methods Technical Note

- **Title: Recommended Soil Health Indicators and Associated Laboratory Procedures**
- **Federal Register Docket No. NRCS-2018-0006**
- **Download a draft at https://go.usa.gov/xUFJE**
- **Instructions for submitting comments can be found at the *Federal eRulemaking Portal*: http://www.regulations.gov/**

FOR FURTHER INFORMATION CONTACT:

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NRCS Technical Note on Recommended Soil Health Indicators and Associated Laboratory

Submitted to the Federal Register in Sept. 2018.

SOIL PROCESS	SOIL HEALTH INDICATORS	METHODS CONSIDERED	NOTES
Organic Matter Cycling & C Sequestration	Soil Organic Carbon Content	Dry Combustion	**Recommended Method**. Nelson and Sommers (1996). The standard operating procedure (SOP) is from Soil Survey Staff (2014), pp. 464–471. If the soil sample is above pH 7.2, then it must be corrected to inorganic carbon (Sherrod et al. 2002).
		Wet Oxidation	Gives same numbers as dry combustion, but has chemical wastes and is more labor intensive.
	Mass Loss	Loss-on Ignition	Used by many soil test labs, but must be re-calibrated for each small region (several regions per state).

Soil Organic Carbon by Dry Combustion

	Meets	Partially Meets	Does Not Meet
Scientific, agronomic, environmental relevance	✓		
Represents diverse processes	✓		
Sensitive to agricultural management	✓		
Ability to show short-term change	✓		
Standardized methods	✓		
Easy and inexpensive to sample & measure	✓		
Repeatable	✓		
Minimal infrastructure/investment		✓	
Trends and limits known	✓		
Actionable: able to provide science-based indicator-informed management recommendations	✓		

NRCS Technical Note on Recommended Soil Health Indicators and Associated Laboratory

Soil Structural Stability (Infiltration)	Aggregation	ARS Wet Macroaggregate Stability	**Recommended Method.** Kemper & Rosenau (1986). Subsequently published by Nimmo and Perkins (2002). SOP from Mikha and Rice (2004).
		NRCS Wet Aggregation	Based on Kemper and Rosenau (1986), this method pre-wets the samples (Soil Survey Staff 2014, pp. 213–216).
		Cornell Sprinkle Infiltrometer	Schindelbeck et al. (2016). Values from this method have not yet been correlated with the wet-sieve method.

Wet Aggregate Stability

	Meets	Partially Meets	Does Not Meet
Scientific, agronomic, environmental relevance	✓		
Represents diverse processes	✓		
Sensitive to agricultural management	✓		
Ability to show short-term change	✓		
Standardized methods	✓		
Easy and inexpensive to sample & measure	✓		
Repeatable	✓		
Minimal infrastructure/investment	✓		
Trends and limits known		✓	
Actionable: able to provide science-based indicator-informed management recommendations	✓		

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SOIL PROCESS	SOIL HEALTH INDICATORS	METHODS CONSIDERED	NOTES
General Microbial Activity	Short-term C mineralization (a.k.a. respiration)	A 4-day soil incubation	**Recommended Method.** Schindelbeck et al. (2016). A 4-day soil incubation (CO2 measured by electrical conductivity, gas chromatography, or titration).
		CO_2, respired, 24-hr	Like the previous method, but with a shorter incubation time, e.g., Haney et al. 2017, Solvita®, or other 24-hr methods). Often has high variability amongst replicates.

Short-term Carbon Mineralization

	Meets	Partially Meets	Does Not Meet
Scientific, agronomic, environmental relevance	✓		
Represents diverse processes	✓		
Sensitive to agricultural management	✓		
Ability to show short-term change	✓		
Standardized methods	✓		
Easy and inexpensive to sample & measure	✓		
Repeatable	✓		
Minimal infrastructure/investment	✓		
Trends and limits known		✓	
Actionable: able to provide science-based indicator-informed management recommendations		✓	

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SOIL PROCESS	SOIL HEALTH INDICATORS	METHODS CONSIDERED	NOTES
General Microbial Activity	Enzyme activity A suite of enzymes is recommended	β-Glucosidase	**Recommended Method.** Eivazi and Tabatabai (1988) as presented by Deng and Popova (2011). Also in Soil Survey Staff (2014), pp. 513–518. Involved in the C-cycle.
		N-acetyl-β-D-glucosaminidase (NAG)	**Recommended Method.** Parham and Deng (2000) as presented by Deng and Popova (2011). Involved in the C- & N-cycles.
		Phosphomono-esterases (acid/alkaline phosphatase)	**Recommended Method.** Eivazi and Tabatabai (1977) as presented by Acosta-Martínez and Tabatabai (2011). Involved in the P-cycle. Both present in all soils, with acid phosphatase dominating in soils ≤7.2 and alkaline phosphatase in soils >7.2.
		Arylsulfatase	**Recommended Method.** Tabatabai (1970) presented by Klose et al. (2011). Involved in the S-cycle.
	Another 10 enzymes were considered, but for various reasons they were eliminated (couldn't be done on air-dried samples; not enough papers in the literature to ascertain trends and thresholds; too expensive).		

Suite of Enzyme Activities

	Meets	Partially Meets	Does Not Meet
Scientific, agronomic, environmental relevance	✓		
Represents diverse processes	✓		
Sensitive to agricultural management	✓		
Ability to show short-term change	✓		
Standardized methods	✓		
Easy and inexpensive to sample & measure	✓		
Repeatable	✓		
Minimal infrastructure/investment	✓		
Trends and limits known		✓	
Actionable: able to provide science-based indicator-informed management recommendations		✓	

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SOIL PROCESS	SOIL HEALTH INDICATORS	METHODS CONSIDERED	NOTES
Carbon Food Source	Readily Available Carbon Pool	Permanganate Oxidizable C (POXC)	**Recommended Method.** Weil et al. 2003. SOP from Schindelbeck et al. 2016. Also in Soil Survey Staff (2014), pp. 505–509.
		Particulate Organic Matter	Good method. The fraction is operationally defined, with many methods in use. Currently not appropriate for soil test labs.
		28-day C Mineralization	Too long (same method as the 4-day method, but has a longer incubation)
		Cold/Hot Water Extractable Organic C (WEOC)	Cold WEOC (Haney et al. 2017). Hot WEOC (Ghani et al. 2003). Gives a snapshot of C availability in the soil solution at sampling time. May not reflect total pool.
		Soluble Carbohydrates	An older method no longer in wide use.
		Substrate-induced Respiration	Research method; it is labor intensive.
		Microbial Biomass C	Fumigation-incubation or fumigation-extraction. A research method that is time/labor intensive.

Readily Available C Source (POxC)

	Meets	Partially Meets	Does Not Meet
Scientific, agronomic, environmental relevance	✓		
Represents diverse processes	✓		
Sensitive to agricultural management	✓		
Ability to show short-term change	✓		
Standardized methods	✓		
Easy and inexpensive to sample & measure	✓		
Repeatable		✓	
Minimal infrastructure/investment	✓		
Trends and limits known		✓	
Actionable: able to provide science-based indicator-informed management recommendations	✓		

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SOIL PROCESS	SOIL HEALTH INDICATORS	METHODS CONSIDERED	NOTES
Bioavailable Nitrogen	Available Organic Nitrogen Pool	Autoclaved Citrate Extractable (ACE) Protein Content	**Recommended Method.** Schindelbeck et al. (2016). Modification, published by Hurisso et al. (2018), from Wright and Upadhyaya (1998).
		Cold Water Extr. Organic N (WEON)	Haney et al. 2017. Not enough data available at this time.
		Correlation with Short-Term C Mineralization	Picone et al. (2002). Has promise but requires more evaluation with broader number of soils and management systems.
		7-day Anaerobic Pot.Mineralizable Nitrogen (PMN)	Drinkwater et al. (1996). The 7-day incubation is too long for high-throughput labs.
		28-day Aerobic PMN Incubation	Used in the USDA/ARS Conservation Effects Assessment Projects (CEAP) soil health assessments (e.g., Stott et al. 2011). Too long.
		Illinois Soil N Test (ISNT)	Nitrogen available as amino-sugar (e.g., Sharifi et al. 2007). Measures a constant fraction of total soil N. Usually evaluated against yield rather than soil health.
		β-glucosaminidase activity (NAG)	See soil enzyme activity above
		Protease	Must use fresh soil

Bioavailable N (ACE Protein)

	Meets	Partially Meets	Does Not Meet
Scientific, agronomic, environmental relevance	✓		
Represents diverse processes	✓		
Sensitive to agricultural management	✓		
Ability to show short-term change	✓		
Standardized methods	✓		
Easy and inexpensive to sample & measure	✓		
Repeatable	✓		
Minimal infrastructure/investment	✓		
Trends and limits known		✓	
Actionable: able to provide science-based indicator-informed management recommendations	✓		

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SOIL PROCESS	SOIL HEALTH INDICATORS	METHODS CONSIDERED	NOTES
Microbial Diversity	Community Structure	Phospholipid Fatty Acid (PLFA) Profile	**Recommended Method.** PLFA (Buyer and Sasser 2012). PLFA is an older method. It gives coarse community structural information.
		Ester-Linked Fatty Acid Methyl Ester (EL-FAME) Profile	This is a newer method and less expensive, but is less suitable due to lack of fungal markers
		"Sampling for Life"	**Recommended.** If appropriate storage is available, we recommend archiving samples until newer methods are available.

Microbial Communities (PLFA / EL-FAME)

	Meets	Partially Meets	Does Not Meet
Scientific, agronomic, environmental relevance	✓		
Represents diverse processes	✓		
Sensitive to agricultural management	✓		
Ability to show short-term change	✓		
Standardized methods	✓		
Easy and inexpensive to sample & measure		✓	
Repeatable	✓		
Minimal infrastructure/investment		✓	
Trends and limits known			✓
Actionable: able to provide science-based indicator-informed management recommendations			✓

Key Outcomes – Opportunities to Collaborate

- **Standardized soil health measures**
  - Nationwide data sharing
  - Faster, better interpretation development, soil-specific at a national scale
  - Public availability and adoption
  - Protocol for updating methods with new science with partners
- **Actionable, easily understood results for management decisions**
- **Integration of acquired findings into Conservation Planning and Implementation**
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Questions and Discussion

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