SOIL HEALTH ASSESSMENT

Metrics and Methodologies

Soil Organic Matter (SOM)

SOM consists of 50-80% dead microorganisms and their byproducts, as well as decomposing plant and animal residues. It is about 50-58% carbon, and contains all the plant essential nutrients in a slow-release form. Similarly to clay, the exchange capacity of organic matter increases a soil's ability to hold nutrients and water, and improves aggregation. SOM also provides habitat and resources for soil organisms; improved resistance to pests and disease; resilience against droughts and flood; increased yields and nutritional quality, and more. While the exact language and metrics for defining soil health are still hotly debated within the scientific community, there is a strong consensus that SOM is at the heart of soil health.

Methodology: Dry Combustion

Sample is heated to 1000°C and injected with pure oxygen, converting all combustible materials into gases (carbon dioxide, nitrogen gas, sulfur dioxide, etc.). These gases are moved through a gas chromatograph, which measures the total amount of carbon and nitrogen in the sample. If the pH of the sample is >7.2 or carbonates are known to be present, the sample is treated with hydrochloric acid (HCl) to remove inorganic forms of carbon prior to combustion.

Available Carbon

Available Carbon is a measure of the most readily oxidizable pool of SOM, which provides food/energy to soil microbes. Active carbon has been shown to be very sensitive to changes in management and is a strong short-term indicator of long-term SOM dynamics.

Methodology: Permanganate Oxidizable Carbon

A weak, chemical oxidant (potassium permanganate) is added to 2mm sieved soil, shaken for 10 minutes and allowed to settle. Using a pipette, a representative sample is extracted and analyzed on a spectrophotometer. As the weak oxidizing solution (which has a deep purple color) reacts with the sample, the solution loses color in proportion to the amount of active, or available, carbon in the sample.

Available Nitrogen

The Autoclaved-Citrate Extractable (ACE) Protein Index is a measure of a functionally relevant and sensitive organic nitrogen pool in the soil. The proteins extracted by this procedure reflect a broad pool, which serves as an indicator of potentially available organic N and overall soil health.

Methodology: ACE Protein Index

Samples are reacted with a sodium citrate solution and autoclaved (at high temperature and pressure) to extract soil proteins. Protein content is quantified using the colorimetric bicinchoninic acid assay BCA).

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Respiration

Carbon dioxide (CO_2) is produced as soil microbes oxidize organic matter; the rate of CO_2 production indicates the activity the microbial community and/or the availability of SOM for decomposition. While this metric is an indicator of soil health, as it indicates biological activity and the turnover of organic matter, alone it can not determine how efficient or healthy a microbial community is. When compared to total microbial biomass, however, it is an indicator of the stress level of the microbial community. This test is very sensitive to changes in management.

Methodology: Potentially Mineralizable Carbon

Re-wet 8mm sieved soil and store in an air-tight jar with a rubber septum at room temperature for 24h. Gas samples will be collected from the jars and measured to quantify the amount of CO_2 released.

Microbial Biomass & Diversity

Phospholipid fatty acids, or PLFA, are found in the cell membranes of living organisms, from bacteria to plants and animals. However, they degrade relatively quickly when an organism dies, making extracting and quantifying PLFA from the soil a powerful tool for estimating living microbial biomass. PLFA biomarkers allow us to identify the presence/absence of various functional groups, such as actinomycetes, mycorrhizal fungi, Rhizobia, protozoa, etc, providing a snapshot of community structure and abundance at the time of sampling. Management heavily influences these communities, as do environmental conditions such as pH, temperature, and moisture. The ability of microbial communities to change rapidly provides producers with a tool to compare agricultural management techniques with respect to overall soil health and fertility.

Methodology: Phospholipid Fatty Acid Analysis. See Ward Lab's Guide.

pH

Soil pH is considered one of the master variables of soil. The pH indicates the level of acidity or alkalinity in a given soil and determines what nutrients will be available for plant uptake. When the pH is too high certain nutrients, such as phosphorus, iron, manganese, copper, and boron may become unavailable to the crop. Alternatively, when the pH is too low, calcium, magnesium, phosphorus, potassium, and molybdenum may become unavailable and heavy metals and aluminum may become more available, presenting potential toxicity problems. Optimum soil pH ranges from 6.2-6.8 for most crops. Organic matter provides buffering capacity in soils, allowing crops to perform better at high and low pH. Soil pH also is a major determinant of microbial community structure, influencing what organisms (beneficial or pathogenic) are able to colonize the roots and the surrounding area.

Methodology: 1:2 Soil to Water Solution

Soil sample is mixed with deionized water in a 1:2 ratio and hydrogen ion activity (pH) is measured with an electrode probe.

Soluble Salts

Soluble salts are measured by electrical conductivity and indicate whether levels of salts, such as Mg+2, Ca+2, Na+, K+, Cl-, SO4-2, and HCO3– could present problems with salinity (excessive salt levels) or sodicity (excessive sodium). While these conditions can occur naturally, they can also be exacerbated by the use of saline irrigation in semi-arid and arid regions, and/or application of manure, compost and fertilizers. Salinity is problematic because it decreases the water potential in the soil, reducing water flow from soil to plant. Furthermore, certain salts, such as chloride, can create toxicity problems for plants and microbes. Excess sodium can create problems with aggregation, surface crusting, and compaction.

Methodology: 1:1 Saturated Paste

1:1 mix of soil and deionized water is vacuum filtered to form an extract, which is tested for electrical conductivity using a platinum electrode.

Nutrient Analysis

A complete nutrient analysis utilizes a variety of extracts to assess levels of plant available macro- and micronutrients. While often offered in traditional soil tests for determining nutrient management, it is an estimate, at best, of what will be available in the soil at any given time. Roots and microbes are constantly releasing acids and other compounds that alter the pH and thus, the availability of any given nutrient at any given time. This analysis covers the three macronutrients needed by all plants (nitrogen, phosphorus, and potassium), the secondary nutrients (calcium, magnesium, and sulfur), and the micronutrients (boron, iron, manganese, zinc, copper, chloride, sodium).

Methodology: Ward Lab Complete Analysis (S-5 Cl). See Ward Lab's Guide.

Texture

Texture is one of the master variables regarding soil function. It is a measure of the relative proportion of variously sized mineral particles: sand (0.05 to 2 mm), silt (0.002 to 0.05 mm), and clay (less than 0.002 mm). While texture cannot be significantly altered by management, it is important for understanding soil health and for identifying best management practices. Generally speaking, higher clay content contributes to a soil's ability to store water, exchange nutrients, and sequester/stabilize organic matter. However, too much clay can lead to compaction, reduced infiltration, and restricted root growth. Too much sand can lead to poor aggregation, rapid drainage, and low nutrient holding capacity.

Methodology: Texture by Hydrometer Method

Soil sample is shaken overnight in a sodium hexametaphosphate solution, dispersing aggregates and separating out individual particles. Solution is poured into a cylinder. At 40 seconds and 6 hours, specific gravity is measured using a boycous hydrometer. The rate that particles settle is proportional to the percent sand, silt, and clay in the sample.

Infiltration

Infiltration is the rate at which water enters the soil and is an indicator of how freely water is able to move through a soil profile. It is crucial to soil health because when infiltration is compromised, water runs off the field and is not available for plants, microbes and other organisms. Runoff also carries away valuable topsoil and applied amendments, polluting rivers and waterways downstream.

Methodology: Double Ring Infiltrometer (Saturated)

Double ring-infiltrometer is inserted into the soil, lined with plastic, and filled with a known volume of water. The plastic is removed, and the water is allowed to infiltrate through both rings. Fifteen minutes after the water has completely infiltrated the soil, the process is repeated, using a timer to measure the rate at which the water enters the soil.

Bulk Density

Bulk density is an indicator of soil compaction. It is calculated as the dry weight of soil divided by its volume. This volume includes both soil particles and the volume of pores among soil particles. Bulk density is typically expressed in g/cm3.

Methodology: A 3-inch diameter aluminum ring is hammered into the soil in the middle of a given sampling depth, and then excavated with the core intact. All contents of the core are transferred to a plastic bag and subsequently dried and weighed. The total mass of the dry sample is divided by the known volume of the core to obtain bulk density.

Aggregate Stability

Aggregate stability is the ability of aggregated soil particles to resist disintegration when exposed to a rain or irrigation event. This ability to maintain structure has a major impact on porosity and thus, the flow of water, air, and nutrients. Changes in aggregate stability are one of few early indicators of soil degradation. Decreases in stability often indicate a greater occurrence of clogged pores and surface crusts that reduce infiltration and aeration, and can lead to increased runoff and erosion, decreased drainage, heightened plant stress, and changes to microbial community composition.

Methodology: Agricultural Research Service (ARS) Wet Aggregate Stability

Air-dried soil aggregates (<2mm) of a known weight are placed on a sieve and repeatedly submerged in water. Soil remaining on sieve is dried and reweighed to calculate the percentage of water stable aggregates.

Surface and Subsurface Hardness

Hardness is an indicator of soil compaction, measured in pounds per square inch (psi) of resistance using a penetrometer. Surface compaction results in increased runoff and erosion and decreased infiltration and water storage. Subsurface compaction contributes to poor drainage and aeration, as well as limited rooting depths (especially at 300+ psi) and mobility of soil organisms. This can lead to reduced root growth, declines in yield and crop quality, and increased weed pressure.

Methodology: Penetrometer is inserted into saturated soil at two specific depths (surface: 0-15 cm, sub-surface: 15-45 cm) and reading on the gauge is recorded.

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SOIL SAMPLING PROTOCOL

1. Locate sampling locations using SoilWeb (USDA-NCSS Soil Survey data). Collect information on unique soil types and properties (i.e. mineralogy, slope, climate, etc.).
2. Upon arrival at location, walk the landscape with the grower. Ask questions about management history, challenges/areas of concern, and future goals.
3. Select 3-4 sampling sites that control as much as possible for variability in landscape, soils, and historic/current management practices. Try to identify side by side comparisons, where only one factor varies (i.e. same soil, vegetation, slope, etc. but managed differently -- no-till vs. conventional tillage or high vs. low density stocking OR fields that are/have been managed the same, but clayey vs. sandy or loamy soils or different positions on a hillslope)
4. At each site, select a location at least 25 m from field edges (and sufficient distance from unique landscape features (i.e. gopher holes; cattle trails) to start a transect. Flag the location.
5. From the initial flag, walk 75 ft. at a 90° angle. Insert another flag. Continue in a zigzag pattern until you have established six sites for subsampling.
6. Consult SoilWeb for sampling depths; consider relevant agricultural practices (i.e. tillage, grazing, etc.). Dig a pit to 1 meter or maximum potential depth and identify horizons.
7. Using a hori hori or trowel, collect soil from the face of the pit, from the bottom up. Be sure to collect a uniform amount of soil across the entire depth being sampled (i.e. 10-20 cm).
8. If required, use an auger to collect samples from deeper horizons. Use a ruler to measure from the soil surface to the desired sampling depth.
9. Place the sample from each unique depth into a separate bucket. Composite (combine and mix) subsamples from all six sites by individual depth.
10. At the second and the fifth flag, using a 3-inch core, collect samples from the center of each sampling depth for bulk density determination.
11. At the central flag and the two outermost flags, hammer an 8-inch double ring infiltrometer into the ground, line with plastic, and fill with 440 mL (or 1 inch) of water. Remove plastic and measure unsaturated infiltration rate.
12. Wait 15 minutes and repeat to measure saturated infiltration rate.
13. After both infiltration tests are complete, use a penetrometer to measure surface (usually 15 cm) and subsurface hardness (30 cm).
14. Put on gloves. Using a soil probe (sterilized with ethanol), collect samples for PLFA from two surface depths (typically 0-5 and 5-15 cm, or 0-10 and 10-20 cm) at all six flags and composite by depth in plastic bags.
15. Immediately place samples on ice in a cooler. Be sure the bagged sample is touching ice on both sides. Keep the cooler in the shade throughout the day.
16. Use ethanol and change gloves between samples to avoid contamination.
17. Ship microbial samples overnight on ice to Ward Labs.
18. All other samples will be kept in a refrigerator until they can be air-dried and/or sent out for lab analyses. Current funding supports analysis of the surface two sampling depths. The remaining depths will be air dried and maintained as an archive for potential future analysis.

SUMMARY		
Metric	**Indicator**	**Methodology**
Carbon Storage	Soil Organic Matter	Loss on Ignition
	Total C	Dry Combustion
Acidity	pH	1:2 Soil:Water Solution
Salinity	Soluble Salts	Electrical Conductivity
Structure	Texture	Hydrometer Method
	Bulk Density	3-inch Diameter Core
	Surface Hardness	Penetrometer
	Aggregate Stability	ARS Wet Aggregate. Stability
Nutrient Cycling	Cation Exchange Capacity (CEC)	NH_4^+ acetate extraction; Spectrophotometer
	N, P, K	KCl and other chemical extractions
	Ca, Mg, S, Micronutrients	Assorted chemical extractions
Microbial Activity	Biomass & Diversity	PLFA
	Respiration	Potentially Mineralizable C
	Available C	Permanganate Oxidizable C
	Available N	ACE Protein Index
Water Dynamics	Infiltration Rate	Double Ring Infiltrometer

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