Soil quality is getting a lot of attention today. We read stories about it in the media, agencies are funding initiatives, experts are giving talks on the topic, research scientists are conducting experiments, and agronomists and farmers are being trained in the subject area. Farmers want to know what steps they can take to improve soil quality, and defining it first can be helpful.

Mike Kucera, resource conservationist with the USDA-NRCS in Lincoln, NE defines soil quality as “the productivity and functioning of the soil. Features that describe quality include nutrient cycling, water infiltration, physical structure, chemical characteristics, and the biological
diversity of the soil." Charles Shapiro, CPAg and extension soil scientist with the University of Nebraska based at the Haskell Agricultural Laboratory near Concord, says that soil quality is a function of its biological, chemical, and physical properties and that it estimates the capacity of the soil to function in crop production. “Soil quality has declined because of erosion, compaction, excessive tillage, organic matter loss, declines in biological activity, salinization, and desertification,” he notes.

Healthy soils allow rainwater to penetrate, preventing excess runoff, sedimentation, erosion, and flooding. They store more water, support greater root and plant growth, and ultimately promote increased productivity. But the processes are complex, and improving soil health is an endeavor that takes effort and time.

Jill Clapperton, soil health consultant with Rhizoterra in Spokane, WA, said soil health is about the soil ecosystem and its function. “Soil is alive, supporting various organisms while recycling carbon and nutrients and holding water. You can’t have health without life, and you can’t have quality without health. You have to remember that plants drive soil health. Their roots feed the soil and drive microbial activity. And soil nutrients are important to microbial metabolism.”

Measuring soil quality

Improving soil quality requires monitoring and measurements. Shapiro believes monitoring soil quality begins with
identifying the parameters, establishing baseline values, and then monitoring change while making improvements. “Growers can’t manage what they can’t measure, and they need to be able to evaluate a similar set of soil parameters to determine the quality of their soil before making decisions on how to improve it.”

First, get out the spade and dig. Compare a cropped soil to a fence line soil that has been undisturbed. How easily can you push the spade in the soil? What is the color? How easily does the soil break apart? Does it smell earthy? An undisturbed grassland soil can be easily dug, has a darker color reflective of higher organic matter levels, easily breaks apart in your fingers, has an abundance of worms, and has a natural earthy smell. Kucera added “Look for compaction layers and evaluate rooting depth and if the roots are moving laterally. Are earthworms present, and do you see casts? Break the soil apart and evaluate structure and tilth. There is a lot you can learn from an initial physical assessment, and this is the place to start.”

Kucera has been working on soil quality assessment as part of his role with the NRCS and has helped identify the appropriate soil indicators and techniques for doing the assessments quickly in the field. “We look for parameters that change and are influenced by the environment and management. These include physical, chemical, and biological parameters as they are all indicators of quality. However, the biological assessment is more difficult and often takes laboratory tests. I look for direct evidence of fungi mycelium, earthworm casts, and the smell.”

According to Shapiro, the most important indicators of soil quality include: organic matter or soil organic carbon, aggregate stability, bulk density, water infiltration, available water-holding capacity, soil pH, nutrient availability, cation exchange capacity, and soil respiration.

Interpreting the data can be a challenge. “There are numerous tests growers can run, and they generate data, but that is not enough,” Kucera says. “Always look at numbers first based on their agronomic interpretation and then compare it to other fields with similar soils but different histories to understand what is causing changes in quality.”

Indicators of soil quality need to be evaluated and interpreted in terms of the soil texture since many of the soil quality measurement values are based on a particular texture. Since soil texture can vary across a field, it is important to know what is the texture of the soil for each area of the field being evaluated.

Shapiro believes growers can make corrections, but they need to understand what the health of their soil is first. “When it comes to improving soil quality, there are four goals to address: increasing soil carbon, increasing soil aggregation and water infiltration, increasing water and nutrient holding capacity, and increasing biological activity.”

**Chemical measurements**

Soil chemistry is complex, but there are a few measurements that can be made in the field that relate to soil quality, including pH, conductivity, soil organic matter, and nitrogen and phosphorus levels.

**Soil tests**

Routine soil tests measure soil pH, organic matter, nutrient levels, and CEC (cation exchange capacity). These are all indicators of soil quality, and most of these tests can be done in the field with kits. Soils low in phosphorus limit crop growth and residue production. Phosphorus is an indicator of P cycling in the soil and is an index of potential crop response as well as soil microbial activity and P mineralization. However, P can easily be fixed in the soil, particu-
larly at low and high soil pH and is not readily available. Water soluble P levels should be in the medium or moderate range. Strategies to better manage P and keep it available include applying organic manures, liming soils to raise pH to 6.5 to 7.0, fertilizing often in smaller amounts and in season or just before the season starts, and banding P in the soil instead of broadcasting over the surface to reduce tie-up.

Kucera also likes to measure soil nitrogen and says it can be an indicator of what is going on with the nitrogen cycle. “Nitrogen is an indicator of the level of mineralization or if you have overfertilized and is useful for fertilization recommendations. Measurements are only valid for the first crop year and should be taken as close to planting time as possible.”

Nitrogen can also assess quality, Kucera notes. “After tillage, you can have a spike in nitrates because it speeds mineralization of organic matter, which can be a bad thing for soil health because you are breaking down organic matter and soil structure. We prefer to have nitrogen in the organic form to avoid leaching and volatilization losses.”

**Soil pH**

The pH is a measure of acidity and alkalinity and is an indicator of soil health and soil’s ability to sustain plant growth. Soil pH values below 6.0 and above 7.5 affect root growth, nutrient availability, mineral toxicity, and microbial activity. Soils are either acidic by nature, or the routine addition of nitrogen and sulfur fertilizers can lower pH. Acidic soil pH can be managed by liming, managing nitrogen fertilizer, diversifying crop rotations to reduce the use of nitrogen, and increasing organic matter to build buffering capacity. Alkaline soils are managed by increasing organic matter, applying organic materials, and banding nutrients in the soil to prevent tie-up. However, lowering soil pH is usually not economical, and if soils are calcareous and contain free lime, it is not feasible to correct.

**Electroconductivity**

Conductivity is a measure of amounts of soluble salt in the soil and a reflection of salinity. Soluble salt readings are a direct measure of soluble ions in soil solution, not on the cation exchange complex. Electroconductivity (EC) is a direct indicator of soil health and affects plant growth, nutrient and water availability, and microbial processes such as respiration, decomposition, nitrification, and denitrification. Management practices that reduce organic matter or drainage increase EC and the soil’s ability to buffer it. Soils with EC readings less than 1 dS/m aren’t saline, so they won’t impact crops or microbial processes while readings greater than 1 will. In humid regions, salts are flushed below the root zone while in arid regions, salts regularly are brought to the surface by capillary action. High EC readings can

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be controlled by managing fertilizer programs, improving drainage, managing compaction, adding gypsum and using irrigation water to flush salts below the root zone, adopting no-till to keep soil more moist and limit capillary movement, and increasing organic matter.

**Soil organic matter**

The soil organic component of the soil consists of plant residues, living soil organisms, decaying materials and stable humic compounds. Crop residue on the soil surface is not considered part of the SOM fraction. SOM provides nutrients, organic carbon, and its decay by-products; improves soil aggregation and CEC; and increases nutrient- and water-holding capacity and water infiltration while reducing compaction and crusting. SOM is an indicator of soil health as higher levels generally mean healthier soils that are more biologically active and mineralize more nutrients.

Organic matter decomposes faster in warmer soils and humid conditions and slower in cooler and drier conditions. Tillage increases decomposition while compacted or dense clay soils have slower decomposition due to less aeration. SOM levels less than 2% are considered low and should be increased. Growers can increase organic matter by producing more plant biomass, adding organic materials such as manure or organic materials with a high C:N ratios that decomposes slowly (think cornstalks and wheat stubble), reducing or eliminating tillage, planting cover crops, or including perennial forages into the rotation.

**Physical measurements**

When it comes to soil quality, the measurements that describe the physical conditions of the soil include compaction, density, porosity, infiltration, and aggregate stability.

**Bulk density**

Soil bulk density is an indicator of compaction and denseness and impacts soil structure, porosity, aeration, water-holding capacity, drainage, and nutrient availability, which in turn affect root growth and microbial activity. Bulk density is the mass of soil in a known volume. Rocks have densities around 2.65 g/cm³ while a silt loam with 50% pore space will have a density of 1.3 to 1.35 g/cm³. The finer the soil (clays), the lower the bulk density. Ideal bulk densities range from 1.1 (clays) to 1.6 (sands) g/cm³. As densities begin to exceed the ideal, root growth and microbial activity are affected. Soil cores can be pulled by pushing an aluminum cylinder ring of known volume in the soil and then dry-
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**Soil porosity**

Porosity is the amount of pore space in the soil. As bulk density increases, porosity decreases. If compaction increases bulk density from 1.3 to 1.5 g/cm³, porosity decreases from 50 to 43%. When determining bulk density, porosity and water-filled pore can be calculated. An ideal soil has 50% solids and 50% pore space, with half the pore space filled with air and half with water. When water-filled pore space reaches 50 to 60%, soil process are impacted positively, and when it exceeds 80%, it is impacted negatively. Soil respiration, nitrification, and ammonification increase with increasing soil moisture. When soils are saturated and aerobic respiration declines, soils denitrify, releasing nitrogen gas into the atmosphere.

**Infiltration rate**

Water infiltration reflects bulk density and soil structure and is an indicator of how fast soils can absorb water (less runoff) as well as how much water the soils can hold. Reduced infiltration can result in ponding and reduced aeration, resulting in poorer root functions, less plant growth, reduced nutrient availability, lower microbial activity, and less nutrient cycling. Infiltration rates are measured with an infiltration ring in inches per hour. There is an initial infiltration rate that reflects filling up the soil pores followed by steady-state infiltration rates that reflect true water movement through the soil. Ideal infiltration rates range from 0.8 (sands) to 0.2 (clays) inches per hour. The infiltration rate can be improved temporarily with tillage that breaks the compaction layer, fractures dense soil profiles, and improves soil physical quality.

**Aggregate stability**

Aggregate stability is the ability of natural soil aggregates to resist disintegration when disruptive forces from water, wind, and tillage are applied. Wet aggregate stability indicates how well a soil can resist raindrop impact and water erosion, while size distribution of dry aggregates indicates how well a soil will resist wind abrasion. Changes in aggregate stability may serve as early indicators of recovery or degradation of soils. Aggregate stability tests can be done in a commercial laboratory or with simple fields tests that look at particles slaking off large aggregates as they sit in water. Soils with low stability will quickly “melt” in the water while stable aggregates remain intact longer.

Improving the physical qualities of the soil requires long-term solutions to reduce bulk density while increasing biological activity. Adopting no-till, increasing organic matter, adding cover crops to already diverse crop rotations, not trafficking when wet, using controlled trafficking and tram lines, and increasing biological activity to improve aggregate stability will improve quality.
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Biological measurements

Getting a measure of biological activity is important to understanding the health of the soil, and the simplest test is a measure of soil respiration and organic matter. There are also more comprehensive tests like the Haney test developed by Rick Haney at Texas A&M University or the PLFA (phospholipid fatty acid) test.

From a biological perspective, Clapperton says key measurements include organic carbon, organic nitrogen, and organic phosphorus and recommends a routine soil test to measure the total amount of the water soluble form of these mineral elements and the Haney test to measure the water soluble (non-particulate) carbon, nitrogen, and phosphorus. “It’s also important to look closely at the organic matter level, amount of microbial biomass, and the microbial community,” she says, recommending the PLFA test to measure this. “PLFA are constituents of membranes, and each class of organisms has different specific classes of lipids. The PLFA test provides a broad-stroke description of the microbial landscape and how it is functioning in the soil.”

Will Brinton, CEO of Woods End Laboratories in Mount Vernon, ME, developed the Solvita Respiration System to estimate respiration of the soil. “The Solvita test measures the CO₂ burst, and we are applying it to estimate nitrogen mineralization. It can also be used to give an estimate of soil health. However, soil health is more complicated than just a measurement. There is a very diverse community that interacts with its environment and each other. Respiration is an indicator of soil health since it shows how active microbes are following soil rewetting (CO₂ burst).”

Solvita provides two applications of respiration—“basal” done in the field and in vitro “CO₂ burst” in the laboratory. Brinton explains that with the basal test, you put a field moist soil sample in a jar along with the company’s patented probe and then 24 hours later read the color change on a strip. The basal test approximates microbial respiration at the temperature and moisture level of the sample. In the lab version of the test, a sample is dried, weighed, and then rewetted to standardized moisture content. The CO₂ probe is inserted with the sample and then allowed to incubate for 24 hours. The CO₂ is measured quantitatively as ppm with a hand-held spectrometer.

“CO₂ is a reliable overall indicator of soil biology,” Brinton explains. “Healthy soils will have a high CO₂ number. However, the CO₂ burst
doesn’t tell the whole story. If the carbon to nitrogen ratio is 10 or less, then the CO₂ burst corresponds to a strong nitrogen release. However, if the burst is strong, but the carbon to nitrogen ratio is greater than 10, the nitrogen release will be much less.”

Solvita measures on a scale from 0 to 5. A reading of 0 to 1 equates to a 0- to 5-ppm CO₂ burst and can’t sustain an active microbial population. A read of 1 to 2 equates to a burst of 5 to 112 pm, a reading of 2 to 3 equates to a burst of 12 to 30 ppm, a reading of 3 to 4 equates to a burst 30 to 70 ppm, and a reading of 4 to 5 equates to a burst of 70 to 160 ppm. “Really healthy soils can hit 4.2 to 4.8 but rarely exceed 5,” Brinton says. “Generally, agriculture soils under conventional management run between 2 and 3. The goal is to bring that value up. To build soil health, growers can adopt no-till and add cover crops and animal and plant manures.”

Summary

Measuring soil quality takes a little time and effort, but the value is understanding how the soil is performing. Armed with this information and knowledge of a soil’s strengths and weaknesses, steps can be planned to correct any shortcomings.

Shapiro emphasizes that the keys to good quality are keeping the soil covered with residue, disturbing the soil as little as possible, adding cover and green manure crops to add organic matter and extend the green bridge, and diversifying crop rotations.

Paul Jasa, extension agricultural engineer with the University of Nebraska, recommends that growers start out by asking what is the quality of their soil and what problems are they facing.

“Figure that out first, and then set your goals,” he advises. “If growers want to improve soil quality, the first thing they need to do is park their tillage tools. Tillage destroys soil structure and life in the soil. The second step is to increase the diversity in their soil by planting different crops and species, extending the growing season beyond the cash crop, and stimulating more microbial diversity. And he emphasizes that to build diversity in the soil requires living roots. “Roots exchange oxygen and carbon dioxide and exude sugars and nutrients that feed organisms and creates more diversity. And that is the role of cover crops in the off season.”

“When it comes to quality, we want growers to look at longer-term (soil) sustainability and productivity,” Kucera says. “We want to help growers be better stewards and be able to pass the land onto the next generation in its most productive state possible.”

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