

Soil Health and Organic Farming

Building Organic Matter for Healthy Soils: An Overview



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**ORGANIC
FARMING**
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SOIL HEALTH AND ORGANIC FARMING

BUILDING ORGANIC MATTER FOR HEALTHY SOILS: AN OVERVIEW

**An Analysis of USDA Organic Research and
Extension Initiative (OREI) and Organic
Transitions (ORG) Funded Research from 2002-2016**

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Introduction

Throughout the history of organic agriculture, practitioners have emphasized healthy, living soil as the foundation of sustainable and successful farming (Howard, 1947; Pfeiffer, 1938), and have often assessed soil health in terms of soil organic matter (SOM) content. As the organic movement grew during the mid-late 20th century, its leaders urged farmers and gardeners to “build soil organic matter,” or humus, and to “feed the soil.” Recommended practices included:

- Return manure and crop residues to the soil.
- Compost materials to stabilize nutrients and develop humus before applying to the soil.
- Use organic mulches.
- Grow and plow-down green manure crops.
- Diversify the crop rotation.
- Integrate crop and livestock production.

Popular writings on organic agriculture promoted SOM and humus as the remedy for all that ails the garden or field, from difficult-to-work soil and low crop yields or quality to pests, weeds, and diseases. This led new or transitioning organic growers to round up as much organic material as they could—manure, leaves, straw, kitchen scraps, and more—and add them directly to the soil or after composting. Sometimes this approach worked well. However, pitfalls were often encountered, such as nitrogen (N) tie-up after plowing down a lot of straw or other high-carbon residues, slugs and other pests attracted by organic mulch, and plant-growth-inhibiting (allelopathic) substances or plant pathogens in crop residues or immature compost.

Initially, Extension and other mainstream agricultural professionals cautioned farmers that, because of these issues, the organic approach would not make sufficient economic returns. However, as concerns about soil degradation and erosion mounted, farmers, Extension agents, and conservationists began to recognize the importance of SOM and soil life, and scientists began to unpack the “black box” of SOM in order to better understand how to manage it for optimum production and long-term sustainability.

Growing recognition of the importance of healthy living soil has led to substantial research endeavors to define and measure soil health, and to develop practical guidelines for improving and maintaining soil health

Over the past 30 years, research has documented some of the myriad organisms and functions of the “soil food web,” and characterized several distinct components of SOM. Today, most Extension, Natural Resource Conservation Service (NRCS) and other agricultural professionals understand the soil as a living system that must be “fed” and protected with living vegetation and suitable organic inputs in order to sustain agricultural production in the long run.

in farming and ranching. Expanded understanding of soil dynamics, SOM, and soil health has both validated and refined the soil health principles and practices advanced by early leaders of the organic agriculture movement.

This report summarizes research findings on SOM and soil health in organic farming systems, and outlines some practical applications for organic producers. Companion reports explore soil health-enhancing approaches to fertility and nutrient management, tillage, and weed control; cover crops and crop rotation, and the role of plant genetics in soil health and organic production.

Soil Quality, Soil Health, and the Role of Soil Organic Matter

For many years, land managers and soil scientists have sought to optimize “soil quality,” or the capacity of a given soil to perform certain functions (Brady and Weil, 2008). To a farmer, a “high quality soil” is one that has sufficient fertility to support profitable production of the farm’s chosen mix of crops and livestock, and sufficient stability to sustain production over the long term. For a conservationist, fertility *per se* may be less important than the soil’s capacity to intercept runoff, filter out nutrients and pathogens, deactivate toxins, and resist erosion. A housing developer may seek entirely different soil qualities: sufficiently compactible to make a stable foundation, and with enough but not too much porosity for septic leach fields.

With the agricultural community’s growing understanding of soil as a *living system* with many vital functions in relation to crops, livestock, natural ecosystems, and global climate, the term *soil health* has come into widespread use. NRCS has defined soil health as “*capacity of the soil*

to function as a vital living ecosystem that sustains plants, animals, and humans” (Kucera, 2015; Figure 1). Key soil functions (Moebius-Clune et al. 2016; Kucera, 2015) include:

- Providing physical, chemical (nutrients, pH), and biological support for plant growth.
- Supporting production of food, feed, fiber, and fuel.
- Providing food and habitat for a diversity of beneficial micro- and macro-organisms.
- Cycling, retaining, storing, and transforming carbon (C), N, P, and other nutrients.
- Sequestering C, thus helping to mitigate and regulate climate.
- Regulating water, allowing infiltration and storage of plant-available water.
- Maintaining adequate aeration for soil life and plant roots.
- Filtering, buffering, degrading, immobilizing, and detoxifying organic residues and inorganic materials (nutrients, potentially harmful chemicals).
- Protecting ground and surface water quality from nutrients, pathogens, sediment, and other contaminants.
- Suppressing pests, diseases, and weeds.

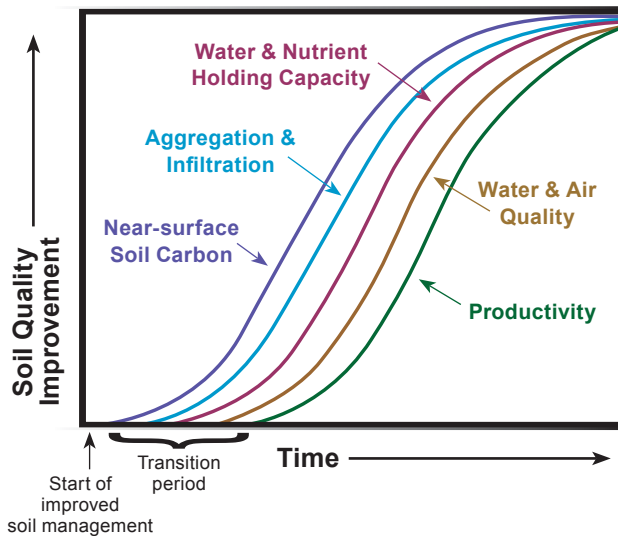


Figure 1. Benefits of soil quality improvement for agricultural production and the environment, USDA NRCS.

Soil health—the capacity to perform these functions—comprises physical, chemical, and biological properties, which are often measured separately, yet must be considered as an integrated whole in order to accurately assess soil condition. Characteristics of a healthy agricultural soil (Magdoff and Van Es, 2009; Moebius-Clune et al, 2016) include:

- A sufficient but not excessive supply of plant nutrients:
 - Optimum plant nutrition, good crop yield and quality.
 - No or minimal nutrient losses through leaching, runoff, or denitrification.
- Good structure and aggregation (tilth) with a network of large, medium, and small pores that provide:
 - Easy infiltration of rainfall and irrigation water.
 - Good capacity to hold plant-available moisture.
 - Optimum drainage and aeration.
 - Sufficient depth through which plant roots easily penetrate and grow.
 - Reduced need for tillage.
 - Improved field access during wet periods.
- Resistance to erosion, compaction, nutrient losses, and other forms of degradation.
- Resilience (ability to recover) following an episode of degradation.
- Crop resistance or resilience to pests, pathogens, drought, heat, cold, and other stresses:
 - Reduced risk of yield loss during periods of environmental stress.
 - Reduced input costs related to efficient nutrient and water cycles and fewer pests.
- Low populations of weeds, plant pathogens, and parasitic organisms.
- Large and diverse population of beneficial organisms that enhance plant nutrition, suppress pathogens and pests, transform fresh residues into SOM, and maintain tilth.
- Freedom from or ability to bind and detoxify substances that can harm plant growth.

Soil quality consists of the summation of inherent and dynamic soil properties. Inherent properties are what nature has given the producer: soil type (series), texture (proportions of sand, silt, and clay), stoniness, depth to bedrock or other parent material, mineralogy, and any naturally occurring hardpans or other features that limit drainage or root penetration. Dynamic properties are those that respond to management practices, and include organic matter percentage and quality, tilth (structure, aggregation), nutrient levels, biological activ-

ity and biodiversity. Soil health is the degree to which dynamic properties have been managed for optimum function within the constraints of the soil's inherent properties (Moebius-Clune et al., 2006).

Soil texture is one inherent soil property that has an important bearing on soil health monitoring and management. The soil's ability to retain stable SOM is directly related to its clay and silt content (Brady and Weil, 2008; Magdoff and van Es, 2009). Thus, sandy soils require extra care to conserve SOM, and will maintain lower total SOM levels even under best management than loamy or clay soils. Sandy soils generally drain and warm up faster and are easier to work than heavy soils, while the latter have greater nutrient and water holding capacity. Notably, soils rich in silt (e.g., silt loams) are more prone to erosion than either sandy or clayey soils (Moncada and Sheaffer, 2010).

Organic matter and soil life play central roles in soil health and fertility. In natural plant communities, the daily consumption and assimilation of organic residues by soil organisms provides the primary source of plant nutrition. In both natural and agricultural ecosystems, the continual processing of organic residues by the soil food web supports each of the soil functions listed above. Without regular inputs of organic (carbon-based) materials derived from photosynthesis and other life processes, soil organisms go hungry and the soil's capacity to support agriculture and provide ecosystem services degrades.

The soil organic matter (SOM) is comprised of multiple components, including:

- Plant and animal residues recently incorporated into the soil by field operations or by earthworms and other macro-organisms.
- The soil life itself.
- Active organic matter, including recently-dead soil organisms, root exudates, and partially decomposed materials that remain available for further utilization by soil life.
- Stable organic matter, which is protected from further decomposition because it is physically integrated into soil aggregates or it has become chemically resistant.

Each of these SOM components contributes to soil health (Moebius-Clune et al., 2016). For example, tilth (structure, aggregation), and its associated benefits of drainage, aeration, moisture holding capacity, rooting depth, and resistance to erosion and compaction are maintained and enhanced by fungal hyphae, earthworms, and the glue-like metabolites of microbes feeding on fresh residues. Stable SOM also contributes



Figure 2. Crops residue that is conserving moisture and protecting the soil from erosion, NRCS

to till by helping to hold aggregates together. Fresh residues on the soil surface reduce erosion, conserve moisture, and protect aggregates (Figure 2).

The active SOM serves as a storehouse of slow-release nutrients, especially nitrogen (N), phosphorus (P), sulfur (S), and boron (B) (Brady and Weil, 2008). Stable SOM contributes substantially to the soil's cation exchange capacity (CEC), the ability to hold potassium (K), calcium (Ca), magnesium (Mg) and several micronutrients in a plant available yet not readily-leachable form. SOM also helps buffer micronutrient levels, ameliorating both deficiency and toxicity (Brady and Weil, 2008).

Beneficial soil organisms outcompete, suppress, or consume plant and human pathogens as they feed on manure and other fresh residues. Heavy metals and other toxic contaminants are either degraded by the soil food web or bound and inactivated by SOM. Finally, any net increase in total SOM represents net C sequestration and contributes to climate change mitigation.

The SOM percentage shown on a soil test report is a dynamic quantity that reflects the balance between organic inputs and their consumption by the soil life. Since both stable SOM and the processing of active SOM by the soil food web make vital contributions to soil function, “soil organic matter” is as much a process as a substance—indeed, it is the process in natural ecosystems that supports all terrestrial life on Earth. Sustainable and organic farming systems seek to simulate nature by maintaining vegetative cover year round, returning organic residues to the soil, and applying compost and other organic amendments.

Challenges in Assessing and Managing Soil Organic Matter and Soil Health in Organic Systems

The USDA National Organic Standards require certified producers to implement crop rotation, cover cropping, tillage, nutrient management, and other practices that improve and maintain the physical, chemical, and biological condition of the soil (USDA-National Organic Program). Organic farmers need improved tools for monitoring the health of their soils, and research-based practical information to help them optimize SOM quality and quantity and develop the best suite of soil management practices for their particular operations.

Research has verified strong positive correlations between total SOM and many aspects of soil health (Chen et al., 2015; Cogger et al., 2013; Delate et al., 2015b; Reeve, 2014; Reinbott, 2015). However, total SOM as reported by soil test labs can be difficult to measure and interpret accurately enough to track soil health trends of a given field for several reasons:

- Random error in measured SOM (unavoidable sample variability) can be large.
- SOM fluctuates over time and is affected by temperature and moisture, tillage, organic amendments and other inputs, vegetative cover, and phase of the crop rotation.
- Target SOM for a healthy soil varies widely with soil type and texture, region, and climate. For example, a 2% total SOM might reflect excellent soil health in a sandy loam in southern Georgia, but indicate severe soil degradation in a silt loam in Iowa.

Other indicators of soil health include field measurements of soil permeability to moisture, compaction, soil respiration, and earthworm counts; and laboratory assays of active SOM, active or total organic N, aggregate stability (a measure of soil structure or tilth), microbial biomass, functional groups of soil organisms (soil food web), and specific soil enzymes related to nutrient and carbon cycling. These tests entail labor costs, fees for the lab analyses, and a learning curve in conducting measurements and interpreting results.

While organic methods generally enhance SOM and soil health, organic producers commonly encounter several challenges. These include:

- Tillage and cultivation required for weed control can accelerate SOM oxidation or degrade soil aggregates (tilth).



Soil health is an assessment of how well soil performs all of its functions now and how those functions are being preserved for future use. Soil health cannot be determined by measuring only crop yield, water quality, or any other single outcome. Soil health cannot be measured directly, so we evaluate indicators.”
(USDA Natural Resources Conservation Service, Soil Health Assessment)

- Some crops require N more quickly than soil life can mineralize it. Concentrated organic N sources (e.g., poultry litter) enhance yield but can leach N or accelerate SOM losses.
- Frequent compost applications sustain yields in intensive production, but can accumulate excessive soil phosphorus (P) or (in high tunnels) soluble salts.
- Practices that maximize SOM and soil health (e.g., minimum till, high biomass cover crops) sometimes entail yield tradeoffs that present farmers with difficult choices.
- Modern crop cultivars, bred for input-intensive conventional production, may not perform optimally in organic systems designed to optimize soil health.

Monitoring Soil Organic Matter and Soil Health in Organically Managed Fields

The first step in monitoring soil health is to get to know your soil, including inherent properties and recent management history. Use the NRCS Web Soil Survey (Table 1, pg. 14, item 1) to identify soil type (soil series), texture and other inherent properties for each field. This information, combined with direct observation and soil test reports, provides a starting point or baseline against which to track future changes and responses to management practices.

The second step is to conduct annual assessments of soil health at the same time of year in successive seasons. Maintain good multi-season records for each field to track long term trends. Several approaches to soil health assessment, from simple to complex, include:

- Observe soil and crop condition in each field.

- Obtain a standard soil test from a reputable lab that includes total SOM analysis.
- Use a soil health scorecard for your region (Table 1, pg. 14, item 3) to estimate overall soil condition and identify areas of concern.
- Conduct quantitative field measurements of dynamic soil properties, using simple protocols or a soil quality test kit (Table 1, pg. 14, items 2a and 2b).
- Obtain a comprehensive analysis such as the Cornell Assessment of Soil Health (CASH, Table 1, pg. 14 item 4).

Direct field observations can provide a lot of valuable information, and may be sufficient for some producers (Figure 3). A few tips for field observation include:

- Is the topsoil soft and crumbly, with visible aggregates, or hard, cloddy, or crusted?
- Is the topsoil a dark, rich brown (high SOM), or a lighter tan or reddish (lower SOM)?
- Is there a subsurface hardpan that could restrict root penetration? Does rainfall or irrigation water soak in quickly, or does water tend to pond or run off?
- Are crops thriving and resilient, or prone to drought, disease, or other stresses?
- Dig up some plants – are the roots deep, abundantly branched, and a healthy white color, or is root growth restricted or affected by disease (dark, discolored)?
- Are earthworms and other macroscopic soil organisms abundant? Numerous worm casts and burrows, and several worms per shovelful indicate a healthy soil food web.



Figure 3. Land users inspecting soil and crop residues, USDA NRCS

Some of the soil health cards and test kits offer simple protocols for more quantitative in field measurements, including water infiltration, bulk density, earthworm counts, and soil respiration. One useful tool is the penetrometer, which measures surface and subsurface hardness. Take penetrometer readings when soil is at field capacity (moist but not waterlogged); readings above 300 psi indicate soil conditions that restrict root penetration. For additional guidelines for field observation, see Table 1, pg. 14, items 2, 3, 4, 5, and 8.

A standard soil test that includes total SOM, nutrient levels, and pH can help in tracking soil health trends, provided that sampling methods are consistent year to year, and the short term impacts of crop rotation and field operations are taken into account. For example, SOM in soil samples taken before *versus* after tillage, or from a planting of spring salad greens *versus* a winter cover crop nearing maturity may differ substantially. Some tips for getting the most out of total SOM and basic soil test data include:

- Take samples at the same time of year each season.
- Take samples before tillage, as it is harder to get uniform samples from disturbed soil.
- Use consistent and precise sampling depth and method. Clear surface residue, take cores from surface to 6 inch depth, and combine 10 or more cores from spots evenly scattered over the field to obtain a representative sample.
- Submit samples to the same lab year to year.
- Track total SOM over a long period of time, at least 10 years or several crop rotation cycles.
- Consider soil type, soil texture, and climate in using total SOM to gauge soil health.
- Track P, K, and other nutrients, manage for optimum but not surplus levels.
- Compare SOM and nutrient data from the same phase of successive crop rotations. For example, in a 4-year corn-soy-wheat-clover rotation, data collected before corn planting in 2010, 2014, and 2018 are more meaningful than year to year fluctuations.

Soil health score cards integrate field observations with some elements from standard lab tests to obtain an overall soil health score and highlight areas of concern, such as compaction, low biological activity, or nutrient imbalances. Developed by farmers working with university scientists the score cards rate each of ten or more parameters of soil condition on a simple scale (poor, average, or excellent; or 1 – 10 scale) and totaled to obtain an overall score (Moebius-Clune et al., 2016; see Table 1, pg. 14, items 3 and 4 for more).

Additional lab procedures have been developed to estimate the active component of the SOM, active soil organic N, microbial biomass and activity, and levels of specific soil enzymes. These parameters provide a more sensitive indicator of soil health effects, and respond more rapidly to changes in management practices such as cover cropping, reduced tillage, and organic amendments.

The Cornell Soil Health Team has developed a Comprehensive Assessment of Soil Health (CASH) that includes quantitative measures of plant-available moisture holding capacity, surface and subsurface hardness, aggregate stability, permanganate oxidizable soil organic C (a measure of active SOM), soil protein index (indicator of plant available organic N), and soil respiration as well as total SOM and standard nutrient analysis (Moebius-Clune et al., 2016). This package is offered for \$95 per sample. An extended test that also includes a root health bioassay, heavy metals, and salinity costs \$150. Both assessments include a soil texture analysis, which is utilized in interpreting the other measurements. The CASH manual, which offers much valuable information on assessing and managing soil health is available on-line at no charge (Table 1, pg. 14, item 4).

Best Soil Health Management Practices in Organic Systems

Since 2002, over 100 USDA funded organic agriculture research projects have addressed soil health and soil management (Schonbeck et al., 2016). Findings largely validate the four NRCS management principles for soil health (Kucera, 2015):

- Keep the soil covered as much as possible.
- Grow living roots throughout the year.
- Use diversity of plants to enhance soil microbial diversity
- Manage more by disturbing soil less.

The central theme here is that *living plants are the farmer's primary soil health management tool*. Thus, cover crops play a pivotal role in maintaining the health of cropland soils. Integrating perennial sod crops (two or more years) can be especially effective in building active and total SOM and other attributes of a healthy soil (Barbercheck, 2016; Borrelli et al., 2011; Briar et al., 2011; Delate et al., 2014; Eastman et al., 2008), and rotationally grazed livestock can further enhance soil benefits and economic returns from the sod phase (Menalled, 2016).



A healthy, balanced soil ecosystem provides a habitat for crops to grow without the need for interventions such as soil fumigants and drench pesticides. Replacing and building soil organic matter enables sustainable cycling of nutrients, like nitrogen.”
(Baker et al., 2016)

Inputs such as compost, manure, organic mulching materials, and organic and natural mineral fertilizers play a supplementary role, and can enhance soil health outcomes of crop rotation and cover cropping (Delate, et al., 2015a; Hooks et al., 2015; Tavantzis et al, 2012). Finished compost adds both active and stable SOM and a diversity of beneficial organisms, and can improve soil health over uncomposted manure (Cogger et al, 2013; Sheaffer et al., 2007). However, relying on compost alone to maintain SOM, tilth, and crop yields in intensive production such as vegetables, can lead to nutrient excesses, especially P (Heinrich et al., 2017), and salt accumulation in drier climates or in high tunnels.

The carbon to nitrogen (C:N) ratio of organic inputs can impact soil health. Materials with very low C:N (e.g. poultry litter ~ 7:1) or very high C:N (e.g. corn residues >35:1) are less beneficial than materials with moderate C:N (e.g. dairy manure-straw bedding compost, C:N ~20) (Baas et al., 2015; Cates et al, 2015; Cogger et al., 2013; Grandy and Kallenbach, 2015; Reeve and Creech, 2015). A diverse mix of organic inputs (cover crops, compost, other amendments) that include both high- and low- C:N materials can be especially effective in building SOM and enhancing N use efficiency (Cogger et al., 2013; Jackson and Bowles, 2013).

Although excessive tillage degrades soil, sound organic management systems that include judicious routine tillage can build SOM and soil health (Cogger et al, 2013; Delate et al., 2015a; Dimitri et al., 2012). Integrated organic weed management practices can reduce the need for tillage and cultivation in organic crop rotations (Michigan State University, 2008).

Crop genetics can also play a role in soil health. Breeding and selecting crop for organic systems – emphasizing traits like weed weed com-

petitiveness, disease resistance, nutrient use efficiency, and enhanced association with beneficial soil organisms – would enhance both soil health outcomes and economic viability of organic production (Hubbard and Zystro, 2016).

Based on these findings, some guidelines for building and maintaining optimum soil health in organic farming systems might include:

- Develop a diverse crop rotation that maintains soil coverage and living root biomass, and provides sufficient organic residues to feed soil life and maintain SOM.
- Include high-biomass, multispecies cover crops in annual crop rotations.
- Integrate a sod phase in the rotation where practical.
- Integrate crop and livestock production.
- Manage for sufficient but not surplus plant-available N, P, K, and other nutrients.
- Use compost, manure, other amendments, and microbial inoculants to complement crop rotation and cover crops. Adjust amendment rates according to soil nutrient status.
- Feed the soil a diverse mix of high- and low-C:N inputs; balance nutrient rich inputs like poultry litter or legume green manure with C sources like straw or rye cover crop.
- Till with care; reduce tillage frequency and intensity when practical.
- Implement an integrated weed management strategy that reduces the need for cultivation.
- Choose locally-adapted crop cultivars that have been developed for or are well suited to organic systems (weed tolerance, nutrient efficiency, etc.).

Additional Resources

See Table 1, pg. 14, for additional resources on best soil health management practices.

For more in-depth treatment of soil health topics and management strategies, see the following additional *Soil Health and Organic Farming Guides*:

- *Nutrient Management for Crops, Soil, and Environment.*
- *Weed Management: An Ecological Approach.*
- *Cover Crops: Selection and Management*
- *Practical Conservation Tillage*
- *Plant Genetics: Plant Breeding and Variety Selection*
- *Water quality and Management*
- *Soil Carbon Sequestration, Greenhouse Gas Mitigation, and Climate Change*

Table 1. Resources on Soil Organic Matter and Assessing and Managing Soil Health in Organic Systems

1. **NRCS Web Soil Survey** – soil series, texture, and any inherent constraints such as naturally occurring hardpans, limited or excessive drainage, stoniness, limited depth to bedrock, and erodibility. <https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm>.
2. **NRCS Soil Health** web page, <https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/soils/health/>.
 - a. *Soil Health Assessment, with link to soil quality indicators (measurements)*. <https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/assessment/>.
 - b. *NRCS soil quality test kit – equipment, supplies and instructions for 12 in-field measurements*. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/home/?cid=nrcs142p2_053873.
 - c. *The science behind healthy soil, webinar by Mike Kucera (2015), available at* <https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/health/mgnt/?cid=stelprdb1257753>.
 - d. *Soil Health Management (four principles)*: <https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/mgnt/>
 - e. *Grow With It – Farmer profiles in soil health management*: <https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/soils/health/?cid=stelprdb1048860>.
3. **Soil Health Assessment Score Cards** provide a framework for evaluating soil health using field observations, sometimes supplemented with simple lab procedures such as a standard soil test.
 - a. *Iowa State University Extension* <https://store.extension.iastate.edu/Product/Iowa-Soil-Health-Assessment-Card>.
 - b. *University of Wisconsin Extension* <https://www.cias.wisc.edu/wisconsin-soil-health-scorecard/>, click on “read the full report (pdf file)”

- c. *Links to soil health cards for several states in the Northeast (CT, MD, PA), North Central (IN, NE, OH), Western (ID, MT, ND, OR), and Southern (GA) regions at: https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/health/assessment/?cid=nrcs142p2_053871.*

4. Comprehensive Assessment of Soil Health (Cornell) <http://soilhealth.cals.cornell.edu/>.

- a. *Comprehensive Assessment of Soil Health – The Cornell Framework Manual (3rd edition 2016). Available free at <http://soilhealth.cals.cornell.edu/training-manual/> Comprehensive resource on soil health, soil functions, and soil health assessment for Northeast, North-central and Appalachian regions.*
- b. *Testing Services* <http://soilhealth.cals.cornell.edu/testing-services/>

5. National Sustainable Agriculture Information Service (aka ATTRA)

- a. *Soils and Compost – info sheets and videos at <https://attra.ncat.org/soils.html>.*
- b. *Tipsheet: Assessing the Soil Resource for Beginning Organic Farmers, <https://attra.ncat.org/attra-pub/summaries/summary.php?pub=529>.*

6. Soil and Fertility Management in Organic Farming Systems, <http://articles.extension.org/pages/59460/soil-and-fertility-management-in-organic-farming-systems>. Links to many articles and videos, including:

- a. *Managing for Soil Organic Matter (Seglinde Snapp and Emily May, Michigan State U, 2011). Includes discussion of active, slow, and passive SOM.*
- b. *Soil Fertility in Organic Farming Systems: Much More than Plant Nutrition (Michelle Wander, U. Illinois, 2015).*
- c. *Soil Management for Better Fertility on Organic Livestock Farms (Wendy Sue Harper, Ken Mills, and Fred Magdoff, 2012). Discusses the physical, chemical, and biological aspects of soil health; relevant to all farming systems.*

- d. *Use of Tillage in Organic Farming Systems: The Basics* (Joel Gruver, Western Illinois U; and Michelle Wander, Illinois State U, 2015). Thorough discussion of a wide range of tillage options in organic systems, and their soil health impacts.
7. **What's Cropping Up Newsletter** (Cornell) frequently runs articles on soil health, not specifically organic, but relevant thereto. <https://scs.cals.cornell.edu/extension-outreach/whats-cropping-up>. A few examples include:
- a. *Comparing Soil Health Test Results from Northeast, Midwest and Mid-Atlantic Regions* (Aubrey K. Fine, Aaron Ristow, Robert Schindelbeck and Harold van Es, Vol. 26, No. 6, Nov-Dec 2016).
- b. *Impact of manure and compost management on soil organic matter and nitrate dynamics* (Amir Sadeghpour, Sarah Hetrick, Karl Czymmek, Gregory Godwin, and Quirine Ketterings; Vol. 26, No. 5, Sept-Oct, 2016)
8. **Building Soils for Better Crops: sustainable soil management** (Fred Magdoff and Harold Van Es, 2009, 294 pp). <http://www.sare.org/Learning-Center/Books>.
9. **Soil Microbial Interactions and Organic Farming** (Organic Farming Research Foundation, 8 pp). Overview of the roles of soil microbial communities and the soil food web in soil and plant health. http://ofrf.org/sites/ofrf.org/files/staff/OFRF.Soil_.brochure.4.16.v4.Web_.pdf.
10. **Risk Management Guide for Organic Producers** (K. Moncada and C. Sheaffer, 2010, U. Minnesota, 300 pp) Chapters on soil health, soil fertility, crop rotation, and cover cropping for organic corn-soy-forage production in the North Central region. <http://organicriskmanagement.umn.edu/>
11. **Rodale Institute Farming Systems Trial**. Reports and summaries of soil health and fertility, crop yield and net economic returns in long term (since 1981) comparison of organic crop-livestock, organic crop, and conventional cash grain systems. <https://rodaleinstitute.org/our-work/farming-systems-trial/>.

12. Organic Agriculture Research Symposium, 2015, Lacrosse, WI, Feb 25-26, 2015 – <http://eorganic.info/node/12972> Soil health presentations, including:

- a. *Long term tillage, rotation, and perennialization effects on particulate and aggregate organic matter. (A. Cates, M. D. Ruark, and J. Hedtke)*
- b. *Microbes drive soil organic matter accumulation in organic cropping systems. (S. Grandy and C. Kallenbach)*



Soil quality is the main driver of optimal organic crop yields. Management of soil organic matter (SOM) to enhance soil quality and supply nutrients is a key determinant of successful organic farming, which involves balancing two ecological processes: mineralization of carbon (C) and nitrogen (N) in SOM for short-term crop uptake, and sequestering C and N in SOM pools for long-term maintenance of soil quality. The latter has important implications for regional and global C and N budgets, including water quality and C storage in soils.”
(Delate et al., 2015b)

Soil Organic Matter and Soil Health in Organic Systems: An Analysis of USDA OREI and ORG Funded Research from 2002-2016

Soil organic matter and soil health have become a major priority in agricultural research, extension, and conservation assistance programs conducted by USDA in partnership with land grant university researchers, non-governmental organizations, and producers. For example, nearly half of all USDA funded organic agriculture research projects between 2002 and 2014 addressed one or more aspects of soil health (Schonbeck et al., 2016), and NRCS working lands conservation programs now emphasize soil health management (USDA Natural Resources Conservation Service, Financial Assistance Programs). Some key findings include:

- Total SOM is a fairly good index of soil health, but “baseline” values vary widely with climate and soil type, and total SOM values respond slowly to management changes.
- Other measures of soil health that respond more readily to management practices include active SOM, total and active organic N, microbial biomass, soil enzyme levels, and some tillage-related physical properties such as aggregate stability and water-permeability.
- Building SOM enhances resilience of crops and livestock to weather extremes and other stresses, and sequesters carbon (C), thus helping to mitigate climate change.
- The most practical and sustainable way to build SOM at a field scale is to *grow it in place* with living plants; thus cover crops are vital in annual crop rotations.

- Including a perennial sod phase in the rotation significantly enhances SOM, fertility, and soil health. Rotational livestock grazing of the sod phase can further improve outcomes.
- Living plants “donate” 10-30% of their photosynthetic product to the soil life via root exudates and fine root sloughing (rhizodeposition), and thus constitute a primary food source for soil life as well as active and stable SOM.
- Soil microbes, especially those proliferating in the plant root zone (rhizosphere) build soil and plant health by cycling and delivering N and other nutrients to plant roots, enhancing tilth, and building active and stable SOM.
- Aboveground biodiversity (crops, livestock, etc) can contribute to soil food web function and soil health. Interactions can be complex and species-specific; thus simply increasing number of crops does not guarantee a proportional increase in SOM or soil health.
- Excessive tillage, prolonged bare fallow, excessive soluble N, or inadequate plant biomass (especially living roots) can lead to loss of SOM and net CO₂ emissions.
- Reduced tillage systems, including but not limited to no-till cover crop termination, enhance SOM and other soil health benefits of organic practices.
- It is not necessary to eliminate all tillage to realize net gains in SOM and soil health.

Soil Organic Matter and Humus: Some Research Findings

Soil organic matter (SOM) is comprised of living and recently-dead soil organisms, organic substances readily consumed by soil life, including recently-incorporated and partially decomposed residues (“active” or “labile” SOM), and materials that are much less available to microbial attack (“stable” SOM) with half-lives measured in decades (“slow” fraction) or centuries to millennia (“passive” fraction) (Brady and Weil, 2008). When root exudates, plant litter, animal dung, and other organic residues are returned to the soil, virtually all of this fresh organic matter is consumed by soil microbes (Figure 4). Roughly half is respired as CO₂ and the other half becoming microbial biomass and active SOM (Grandy and Kallenbach, 2015). As soil organisms grow, multiply, feed on one another, and die, more CO₂ is evolved, plant nutrients are released, and a fraction of the original organic input remains in the soil as stable SOM.

Often described as “humus,” the stable SOM has long been thought to consist of highly complex macromolecules derived from polymerization of recalcitrant (decay-resistant) plant lignins. However, recent

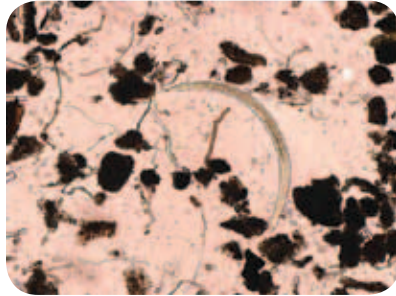


Figure 4. Soil Microbes, USDA ARS, 2016

research indicates that these “humic” substances may be an artifact of extraction techniques, and that the soil food web consumes much of the lignin as well as the protein, carbohydrate, and lipid components of plant residues (Grandy and Kallenbach, 2015; Petit, 2012). Stable SOM forms as some of the active SOM becomes physically protected from further decomposition, either in the interior of soil aggregates or firmly adsorbed to their surfaces (Cates et al., 2015; Grandy and Kallenbach, 2015), or is simply deposited deeper in the soil profile (by deep rooted plants) where decomposition takes place much more slowly (Petit, 2012). Medium to fine textured soils with substantial amounts of silt and/or clay stabilize more SOM in this way than very sandy soils.

Both active and stable SOM play important roles in soil function, and a deficit of either can indicate a need for better management. For example, when excessive tillage breaks up soil aggregates, some of the physically protected stable SOM becomes exposed to microbial attack (Grandy and Kallenbach, 2015). Inadequate plant cover and root biomass can cause a decline in active SOM levels regardless of tillage (Cates et al., 2015). Total SOM over the entire soil profile is a key part of the global carbon cycle; net increases or decreases in total SOM represent net C sequestration or CO₂ emissions, respectively. For more on the soil health—SOM—climate connection, see the companion guide, *Carbon Sequestration, Greenhouse Gas Mitigation, and Climate Change*.

Assessing Soil Health: Active and Total SOM, and Other Parameters

Organic agriculture researchers continue to track total SOM, often expressed as *total soil organic carbon* (SOC ~ SOM X 0.58), especially in long term farming systems trials, because of its central role in the global carbon cycle as well as its approximate correlation with soil

health and fertility. Because total SOM changes slowly in response to management practices; scientists also measure “active” fractions of the SOM in order to monitor shorter term system responses to specific inputs or management practices. For example, perennial wheat cultivars grown for two years did not significantly impact total SOM, yet enhanced labile SOM by 20% compared to standard annual wheat cultivars (Snapp and Swinton, 2013).

Various laboratory procedures have been developed to measure particulate organic matter (POM) (Moore-Kucera et al., 2008) or particulate organic carbon (POM-C) (Delate et al., 2015b), potentially mineralizable organic C (Sheaffer et al., 2007), and permanganate-oxidizable organic C (Culman et al., 2012; Moebius-Clune et al., 2016). Fourier transform infrared (FTIR) spectroscopy has been used to distinguish fractions of SOM and elucidate relationships among active and total SOM, N dynamics, and crop nutrition (Margenot et al., 2015)

POM is defined as sand-sized (0.05 – 2.0 mm) particles of organic debris and fine plant roots, and may comprise 10-35% of total SOM (USDA Natural Resources Conservation Service, 2011; Moore-Kucera et al., 2008). The POM provides food for micro-organisms, holds intermediately-available plant nutrients (released as needed, not readily leached), improves soil aggregation and porosity, and may suppress plant diseases. Soil POM levels respond readily to the dynamic balance between organic inputs and decomposition by soil microbes. POM can be measured by a reliable lab procedure and provides a robust index of active SOM, soil fertility, and plant-available organic N.

Permanganate-oxidizable carbon (POX-C) is a more processed yet still dynamic fraction that provides a useful index of management-related changes in active SOM (Culman et al., 2012). The POX-C corresponds roughly to a fine, dense (“heavy”) subfraction of the POM itself (Ibid.). The Cornell Assessment of Soil Health (CASH) utilizes POX-C because the lab procedure is simpler and more economical than POM (Moebius-Clune et al., 2016).

Other parameters of soil condition include soil microbial biomass, total organic N, potentially mineralizable N (PMN), the N component of POM (POM-N), and soil enzymes involved in C, N, and other nutrient cycles (Moore-Kucera et al., 2008). PMN has been replaced by Autoclaved Citrate Extractable Protein as an estimate of plant-available N from organic matter in the CASH (Moebius-Clune et al., 2016).

The Cornell Soil Health Assessment (CASH) (Moebius-Clune et al., 2016) provides an excellent protocol for evaluating overall soil health and identifying specific areas of concern, and is applicable to the Northeast, eastern parts of the North Central, and the Appalachian region within the upper South.

Soil respiration provides an index of microbial activity, yet it also represents carbon loss from the soil as well as a greenhouse gas (GHG) emission. Microbial growth efficiency (defined as the increase in microbial biomass C divided by the sum of increase in microbial biomass C and respiratory CO₂-C) and measured through a ¹³C isotope labeling method (Reeve, 2014; Grandy and Kallenbach, 2015), helps in the interpretation of soil respiration rates in relation to soil health and carbon balance.

Soil respiration has been measured in the field using static (Hatfield et al., 2015; Cogger et al., 2014) or vented (Menalled, 2016) chambers enclosing a small area of the undisturbed soil profile to measure CO₂ accumulation over a short time interval). Micrometeorological measurements allow continuous real-time monitoring of net CO₂ fluxes from the soil, but this method is more expensive and can be challenging to interpret (Cogger et al., 2014). These field methods have also been used to monitor greenhouse gas (GHG) emissions, including methane (CH₄) and nitrous oxide (N₂O) as well as CO₂ (Hatfield et al., 2015, Fortuna et al., 2014, Cogger et al., 2014). A simple laboratory procedure for estimating microbial activity based on respiratory CO₂ from a moistened soil sample over a four day period is used in the CASH (Moebius-Clune et al, 2016).

Soil enzyme assays include key enzymes involved in cycling of soil C (beta-glucosidase, which degrades cellulose), N [N-acetyl-beta-D-glucosaminidase, which degrades chitin into amino-sugars whose N is readily mineralized], S (arylsulfatase, a fungal enzyme that converts organically bound S to sulfate-S), and P (acid and alkaline phosphomonoesterases, which convert organically bound P to inorganic phosphate) (Moore-Kucera et al., 2008).

How Well do SOM Values Reflect Soil Function and Soil Health?

While total SOM may not be as sensitive an indicator of improved soil stewardship as other parameters such as POM and PMN (Wander et al, 2014), it generally moves in parallel with these other indicators. In multi-site studies in Maryland, Pennsylvania, Ohio, Iowa, Michigan, Wisconsin, and California, organic practices enhanced total SOM by an average of 14%, while POM and POM-N increased by 30 – 40% (Carpenter-Boggs et al., 2016). Suites of soil health parameters that have increased with increasing total SOM include:

- Active SOM, microbial biomass, reduced N leaching, less SOM and total sediment in runoff (Osmond et al., 2014).
- N availability, aggregation, soil food web structure, and reduced N₂O emission (Chen et al., 2015)
- Active SOM, microbial biomass, and enzyme activity (Reinbott, 2015)
- POM, total and available N, microbial biomass and activity, C sequestration, aggregation, and reduced N leaching (Delate et al., 2015a, 2015b)
- Lower soil bulk-density, faster moisture infiltration, total and mineralizable organic N, and soil enzyme activity (Cogger et al., 2013; Fortuna et al., 2014)
- Total organic N, microbial biomass, and microbial growth efficiency (Reeve, 2014)

Although Hatfield et al. (2015) measured CO₂ as part of the GHG footprint of different crop and crop-live-stock systems, the treatment with the greatest CO₂ emissions (organic winter wheat with sheep grazing) also showed the highest total SOM in the top six inches of the soil profile. This suggests that the organic wheat / grazing treatment received larger organic inputs (root exudates, plant residues, sheep dung), and/or maintained higher microbial growth efficiency, resulting in a net sequestration of C. Similarly, winter cover crops plowed down prior to planting rice tripled the CO₂ component of annual GHG emissions yet enhanced total SOM in organic paddy rice production (Dou et al., 2016).

Impacts of Crop Rotation, Cover Crops, Tillage Intensity, and Compost, Manure, and Other Organic Inputs on Soil Organic Carbon and Soil Health

Cover crops, organic soil amendments, reduced or conservation tillage, and perennial sod breaks in the rotation can each contribute to enhancing total SOM and other measures of soil health (Baas et al, 2014; Chen et al, 2015, Delate et al 2015b; Reinbott, 2015). Regular use of cover crops resulted in significant increases in total SOM within the plow layer over an 18 year period in long term farming system trials in Maryland (Yarwood, 2016), and winter cover crops enhanced total SOM in organic paddy rice production in Texas (Dou et al., 2016). In dryland organic wheat production in Utah, a single application of a dairy manure-straw bedding compost (C:N ~ 20:1) at 22 tons per acre in 1995 more than doubled total SOM measured 13 years later (Reeve and Creech, 2015).

Particulate organic matter (POM) levels respond readily to management, and POM losses can be accelerated by tillage, cultivation, wetting and drying cycles, and inputs of readily-decomposable, low C:N organic materials (USDA Natural Resources Conservation Service, 2011). Recommended practices to increase POM include cover cropping, crop rotations that maximize living plant cover and minimize bare fallow, reduced tillage, and pasture under rotational grazing (USDA Natural Resources Conservation Service, 2011)

The contributions of cover crops and organic amendments such as compost to soil C and N dynamics, soil life, and soil function appear different and complementary. For example, fine (<1.0 mm diameter) roots of winter annual legume cover crops (hairy vetch, crimson clover, and Austrian winter pea) comprise 70% of the total below-ground biomass, and the fine roots become readily-available microbial food upon termination of the cover crop, resulting in increased microbial biomass and release of nearly half of the fine root N within one week (Hu et al., 2015). Notably, termination by mowing resulted in greater microbial growth and N mineralization than either disking or herbicide. In contrast, finished compost contributes more stable SOM (Reeve and Creech, 2015), adding as much as 222 lb stable C per dry ton of compost applied (Carpenter-Boggs et al., 2016).

Organic Grain (Corn-Soy-Cereal) and Grain-Forage Rotations

In Minnesota, a four-year organic crop rotation of soybean-oats/alfalfa-alfalfa-corn resulted in higher total SOM and total organic N than a two-year organic corn-soy rotation, and the improvement was attributed to the presence of a perennial (alfalfa) in the longer rotation (Sheaffer et al., 2007). Organic practices increased the percent large soil aggregates over conventional systems, and the four-year organic rotation further enhanced soil aggregation and corn yields by about 25% over the two-year organic corn-soy rotation (Moncada and Sheaffer, 2010). In these studies, hairy vetch winter cover and composted manure enhanced potentially mineralizable SOM, soil aggregate size, and soil test P compared to no winter cover and uncomposted manure (Sheaffer et al., 2007).

Root biomass of perennial forages has been estimated at 3,000 – 8,000 lb/ac, compared to just 800 – 1,400 lb/ac for annual cereal grain root biomass (Carpenter-Boggs et al., 2016). Similarly, perennial strains of wheat develop three times as much root biomass as standard annual cultivars, accrued 20% higher labile SOM, and greatly reduced N leaching (Snapp and Swinton, 2013). In a comparison of six different cropping systems on a silt-loam in Wisconsin, POM (measured from surface to 10 inch depth) correlated strongly ($r^2 = 0.57$) with below-ground biomass over the rotation (Cates et al., 2015). In this study, rotationally grazed pasture maintained the highest POM levels, followed by corn-alfalfa rotations, then annual grain rotations without a perennial phase. A surprisingly low POM in an organic corn-soybean-wheat/clover rotation was attributed to low root biomass and frequent tillage and cultivation.

In New Hampshire, an organic rotation of corn-winter rye (cover crop)-soybean-wheat-clover (cover crop) accrued significantly higher total SOM than a conventional corn-soybean-wheat rotation, even though the former entailed more tillage and slightly lower average plant biomass (Grandy and Kallenbach, 2015). The organic system showed a higher microbial growth efficiency (55%) than the conventional rotation (45%), and considerably greater stabilization of SOM in clay aggregates. The investigators attributed the better performance of the organic system to more frequent organic inputs of “high quality” (C:N ratio below 35:1), which enhanced microbial growth and ultimately, formation of stable SOM. However, organic inputs with very low C:N ratio can also reduce SOM. For example, applications of poultry litter (C:N <10) maintained lower POM levels than dairy or swine manure (Cates et al, 2015), and lower total SOM than a mixed compost with higher C:N (Cogger et al., 2013).

In organic corn-legume (soy or dry bean)-cereal grain rotations at 11 sites across six northern states (North Dakota, Iowa, Minnesota, Wisconsin, Michigan, and Pennsylvania), terminating cover crops with a roller-crimper improved POM, microbial biomass and diversity, PMN, and soil structure over the same rotations with cover crops terminated by disking (Delate, 2013). However, the roll-crimp treatment reduced yields of corn and oats by 63% and soybean by 31%.

In six long term farming systems trials in California, Iowa, Wisconsin, Michigan, Pennsylvania, and Maryland, organic systems with routine tillage have enhanced total and active SOM, total and plant-available soil N, microbial biomass and activity, C sequestration, and water quality (less nitrate-N leaching) compared to conventional systems, and maintained competitive grain yields and net economic returns (Delate et al., 2015b). Key factors in soil quality and yield stability include cover cropping in conjunction with manure or compost application, lengthening the rotation to include one or more years in alfalfa or other perennials, and excellent weed control. In Iowa, a four-year organic corn-soy-oat-alfalfa rotation sequestered as much C over 10 years as would be expected from converting a conventional grain system from annual plowing to continuous no-till. In the Maryland trial, an organic system with some tillage has accumulated more SOM and POM-N than conventional systems under continuous no-till (Ibid.), and sequestered an estimated 475 lb additional C per acre annually (Carpenter-Boggs et al., 2016).

A farmer-participatory study that engaged 72 farmers across Illinois indicated that organic practices and conservation tillage were about equally effective in enhancing POM-C, PMN, and total SOM over conventional full-tillage systems (Wander et al., 2014). In organic corn-soy-wheat rotations in Missouri, total SOM was highest in no till with cover, intermediate in tillage with cover crops, and least in tillage without cover (Reinbott, 2015). Total and active SOM, microbial biomass, and microbial activity (enzyme assay) increased with compost applications, reaching a plateau at 1.0 – 1.5 X recommended rates for crop nutrition (Reinbott, 2015).

In Michigan, an organic corn-soybean system with cover crops sequestered an additional 1,070 lb C per acre annually compared to conventional production without cover crops. However N-rich organic inputs such as an all-legume (red clover) cover (C:N = 12:1) and/or poultry litter (C:N = 7:1) greatly increased risks of N leaching and denitrification (Baas et al., 2015).

Organic Vegetable and Vegetable-Strawberry Rotations

The use of cover crops and composted manure in organic vegetable crop rotations in Iowa and Florida enhanced total SOM by 16%, and also increased active SOM, total organic N, PMN, and soil aggregation regardless of tillage (Delate et al., 2015a). Reduced tillage (cover crops roll-crimped) further enhanced soil structure and increased microbial respiration, and somewhat reduced vegetable yields in Iowa but not in Florida. In a sweet corn study in North Carolina, active and total SOM and microbial biomass were greatest in organic no till, intermediate in organic full till or conventional no till, and lowest in conventional full till (Osmond et al., 2014).

Cover crops and reduced tillage enhanced SOM, N dynamics (less denitrification), aggregate stability, and soil food web function in Maryland and Hawaii, with good yields and economic returns for strip till vegetable production in Maryland and for no-till green onions in Hawaii (Chen et al., 2015)

In central California, a four-year rotation (three years vegetables and one year strawberry) retained more soil C than a two year strawberry/broccoli rotation, and rotations without cover crops during winter fallows showed a net loss of soil C (Shennan and Muramoto, 2016; Shennan et al, 2015, 2016).

Including a perennial sod break in vegetable rotations can benefit SOM levels and soil health. In Florida, three years in bahiagrass significantly enhanced SOM and supported improved vegetable yields for two to three seasons after the sod was broken (Andersen et al., 2014).

In organic vegetable/wheat/cover crop rotations in Oregon, the effects of two organic amendments were compared: broiler litter (low C:N) and an “on-farm mixed compost” (higher C:N). Over a five year period, the mixed C:N compost resulted in lower soil bulk-density, faster moisture infiltration, and higher total SOM, total organic N, soil enzyme activity, and capacity to provide N to production crops than the broiler litter (Cogger et al., 2013; Fortuna et al., 2014).

A study of 13 organically managed tomato fields in central CA identified several fields with high levels of active and total SOM, low bulk soil soluble N, and highly efficient N cycling in the crop root zone (rhizosphere) resulting in crop N sufficiency and high yields (Jackson and Bowles, 2013). These fields had a history of “organic matter inputs with varying N availability,” and a combination of enhanced rhizosphere microbial N cycling and plant genetic expression for N-uptake enzymes supported crop N sufficiency (Bowles et al., 2015).

Orchard Floor Management Systems and Other Fruit Production Practices

In orchard floor management studies at Oregon State University, POM levels were highest when organic amendments were used in conjunction with living cover, intermediate with organic amendments alone or landscape fabric, and lowest in herbicide-treated bare fallow (Azarenko et al., 2009). Maintaining living cover and using organic amendments enhanced orchard floor soil enzymes, especially beta-D-glucosidase and N-acetyl-beta-D-glucosaminidase.

Maintaining trefoil cover in orchard alleys and blowing clippings into tree rows enhanced total SOC, organic N, microbial biomass, and microbial growth efficiency compared to orchard floor management without living plant cover, while the tilled treatments had the lowest SOC, N, microbial biomass, and microbial growth efficiency (Reeve, 2014).

Questions for Further Research into Soil Organic Matter and Soil Health in Organic Systems

While measurements of total and active SOM, soil organic N, microbial biomass and activity, and several dynamic soil physical properties provide relevant information on the health of the soil, both measurement and interpretation remain complex and challenging. Additional research in the following areas is needed to help organic producers better understand and manage organic inputs and SOM for best soil health outcomes:

- More reliable and practical measurement protocols for active and total SOM that farmers can use to track soil health trends and impacts of management practices.
- Practical guidelines regarding optimum or target SOM levels as a function of soil type and texture, climate, and production system for different regions across the US.
- Continue to develop practical, reliable, and affordable field and/or lab methods for measuring other soil health parameters related to tilth, fertility, and soil food web function.
- Develop, test, and refine soil health assessment protocols, analogous to the Cornell Comprehensive Assessment of Soil Health (CASH), for other regions, especially the Southern, semiarid Great Plains and interior Western region, and Pacific Northwest.
- Further elucidation of the nature of “stable” organic matter, to what extent it is stabilized by physical protection within soil aggregates versus chemical properties, and management practices to protect the stability of this SOM fraction.
- The role of C:N ratio and other qualitative aspects of cover crops, green manures, and organic amendments in determining their impact on microbial activity and growth efficiency, SOM, soil fertility and crop nutrition, and other aspects of soil health.
- The role of living root biomass in maintaining active and total SOM, and practical guidelines in designing crop rotations and cropping systems to maximize root biomass.

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* For project proposal summaries, progress and final reports for USDA funded Organic Research and Extension Initiative (OREI) and Organic Transitions (ORG) projects, enter proposal number under “Grant No” and click “Search” on the CRIS Assisted Search Page at:

<http://cris.nifa.usda.gov/cgi-bin/starfinder/0?path=crisassist.txt&id=anon&pass=&OK=OK>.

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Notes



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