Why "Organic" Matters for Soil Health in Virginia
Soil Organic Matter and Organic Farming

A Webinar for the Virginia Soil Health Coalition
August 8, 2023

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February 22, 2022

Presentation Notes

Slides 1 and 2 – Title and acknowledgements.

Soil Organic Matter and the Organic Farming Method: a Brief History (Slides 3-11)

Slide 4 – *What does the "organic" in organic farming mean?*

Organic farming utilizes plants, animals, their residues, and natural ecological processes to provide for soil maintenance and crop and livestock nutrition, protection, health, and productivity. In chemistry, "organic" refers to any carbon compounds that contain covalent carbon-carbon or carbon-hydrogen bonds. However, organic agriculture generally limits the use of organic substances to those that occur in nature and that benefit soil, plant, animal, human, and environmental health, or at worst pose minimal risks thereto.

From its beginnings, the organic method has emphasized the importance of soil organic matter (SOM) in soil health, fertility, and successful farming.

Slide 5 - *George Washington Carver, Tuskegee University, 1896-1943*

When Africans were enslaved and brought to Jamestown and other colonial settlements within what became the United States, they carried with them their food crop seeds and agricultural traditions, which include diversified permaculture systems and soil stewardship practices that pre-date yet exemplify organic farming. In 1896, Tuskegee Institute founder Booker T. Washington hired Iowa State College agricultural scientist George Washington Carver to educate and empower Black farmers to launch sustainable and successful enterprises. Carver promoted composting and application of organic "wastes," crop rotations, cover cropping, and diversified systems to restore Alabama soils worn out and eroded from decades of extractive cotton and corn production and poor management (White, 2018; Wikipedia).

Slide 6 – *Hugh Hammond Bennett, father of soil conservation in the US.*

Hugh Hammond Bennett graduated from U North Carolina in 1903 and worked as a soil surveyor. During a 1905 survey of soils in Louisa, Virginia, he first identified the link between soil quality and prevention of soil erosion. Soil erosion selectively "steals" soil organic matter, and exactly a century later, Lal (2003) identified soil organic carbon losses via erosion as the source of 6% of human-caused GHG emissions worldwide.

In the 1920s, when Hugh Hammond Bennett warned that soil erosion threatened US agriculture and food security, many agriculturists dismissed his concerns in the belief that soil is an inexhaustible and indestructible resource. Yet, he persuaded Congress to fund several soil erosion experiment stations in 1930, and his advocacy, including a Congressional hearing during which Washington DC experienced a heavy dust cloud blowing in from the Great Plains, led to his appointment to head the newly established Soil Conservation Service in 1935.

In his astute analysis of soil erosion and the best practices to minimize soil losses, Bennett clearly recognized the importance of SOM (which he called "humus") in soil fertility, as well as its disproportionate vulnerability to the impacts of soil erosion (Bennett, 1933; USDA NRCS, undated).

Slide 7 – *Virginia's "Dust Bowl": red clay at the surface*

The "red clay" for which the southeastern US is known consists of an argillic (clay-enriched) B horizon located underneath the topsoil or A horizon of old, highly weathered soils of the orders Ultisol and Alfisol. Millennia of leaching in warm, rainy climates has moved some or most of the clays out of the A horizon into the B horizon, where they are deposited. Some of the clays consist of iron oxides, which give these argillic B horizons a brick-red, orange, or yellow color.

In rolling and hilly regions throughout the southeast, including the Southern Piedmont and the Ridge and Valley (Appalachian) regions of the Southeast from Virginia through the Carolinas into Georgia, Alabama, and Mississippi, one to two centuries of continuous production of cotton and other annual row crops with regular plowing and no cover cropping or green fallow have led to severe erosion. As much as five to ten inches of soil, often the entire A horizon, have been lost, leaving the red clay B horizon exposed and visible at the surface (Bergtold & Sailus, 2020). Despite this severe degree of degradation, these soils can be restored through good organic practices, diligent cover cropping, diverse rotations that maintain year-round living roots, and conservation tillage.

Slides 8 and 9 – *Other early leaders in organic farming*

Drawing on the work of George Washington Carver, German philosopher Rudolf Steiner, and others, early proponents of organic agriculture including Ehrenfried Pfeiffer (1943), Sir Albert Howard (1947), Jerome Irving Rodale, and Lady Eve Balfour (Wikipedia) focused on soil organic matter ("humus"), soil health, and caring for soil as a living system as the foundation of sustainable farming and healthy food. "Feed the soil" became a key guideline for organic farmers, and they did so with compost, farm-generated manure and other residues, green manures, and diverse crop rotations. Most, especially Pfeiffer (1943), emphasized the importance of integrating crops and livestock for a more complete and balanced farm ecosystem.

Slides 10 and 11 – *Soil organic matter and soil health in the USDA Organic Standards*

In 2002, the USDA National Organic Program (NOP) Standards codified the central role of soil health and soil organic matter in the organic farming method.

<u>The Nature of Soil Organic Matter: SOM is a process as well as a substance</u> (Slides 12-17)

Slide 13 – *What is soil organic matter?*

Soil organisms (the "living" fraction of SOM) continually digest fresh residues to form active organic matter (the "dead" fraction), which in turn is further processed into more stable forms of organic matter (the "very dead" fraction). Soil test labs usually screen out the fresh residues and macro-organisms and report the sum of living microbial biomass, active SOM, and stable SOM as % SOM on a dry weight basis. The relative proportions of active and stable SOM will vary considerably with climate, soil type, and texture, with larger amounts of stable SOM in finer-textured soils (higher clay and silt content) and in cooler climates. Thus, while a 2% total SOM may indicate healthy soil conditions in a southeast coastal plain sandy loam, a healthy silt loam in the upper Midwest should contain at least 5% SOM.

Slide 14 – *Does "stable" soil organic matter = humus?*

The term "humus" is sometimes used generally to mean "stable soil organic matter" and sometimes specifically to mean humic and fulvic acids, complex macromolecular carbon compounds thought to be inherently recalcitrant (decay-resistant) and thus permanently sequestered carbon. Research over the past 20 years indicates that such molecules occur only in trace amounts in natural or agricultural soils. These "humic substances" are mostly formed during the alkaline extraction procedures historically used to analyze for stable SOM (Grandy & Kallenbach, 2015; Lehmann & Kleber, 2015).

Most stable SOM – what was once thought to be humic substances, - is in fact *mineral-associated organic matter* (MAOM), organic materials that have undergone microbial processing and subsequently became bound to soil clays and silt particles (Dynarski et al., 2020). Microbial metabolites and intermediate breakdown products from organic residues can be sufficiently mobile to leach down into subsurface soil horizons (E, B, or C) before becoming adsorbed to minerals. In deep soils, 50% or more of total SOM may occur at depths below 12 inches.

"Active" and "stable" SOM are relative terms used to describe a spectrum of rates of turnover. They are not inherently separate categories, and "stable" SOM can become more active if the environment changes. Aggregate-protected SOM is readily lost upon tillage, while MAOM is more stable, though its decomposition can also accelerate under certain conditions.

Slide 15 – *Soil microbes convert organic inputs into SOM*

Soil organic matter is as much a process as it is a substance. It exists in dynamic equilibrium with the soil life, inherent and dynamic soil properties, climate, and management practices.

Essentially all organic materials added to the soil – exudates and tissue sloughing from living roots (rhizodeposition), plant residues, manure, etc – become food for soil organisms. Part of this organic input is respired and released as carbon dioxide and plant-available nitrogen (N) and other nutrients (process of mineralization), part is converted into active soil organic matter (SOM) which undergoes further processing by the soil life, and part is converted into long-lasting SOM that is tightly bound to soil minerals as MAOM or protected within soil aggregates (stabilization). In wetlands and in colder climates, some fresh residues can become stabilized without microbial processing. In agricultural soils, microbes do most of the SOM stabilization, and this will become even more true as soil temperatures increase with climate change

Both processes are essential to the health of agricultural and natural ecosystems, as plants depend on mineralization for nutrients, while stabilization sequesters carbon and thereby helps stabilize the climate, maintains soil structure, and adds moisture and nutrient holding capacity.

An ingenious study by Kallenbach et al. (2016) demonstrated the central role of soil life in processing organic inputs into SOM. Researchers created "mesocosms" of pure mineral sand + clay devoid of organic matter, added a small inoculum of organisms from field soil, and "fed" the system with sugar, a simple phenolic compound called syringol, or a water extract of switchgrass (a mixture of soluble organic compounds), along with NPK and other mineral nutrients essential for microbial growth. After 16 months, the initially dead-looking sand-clay mixture looked like topsoil (dark brown, well aggregated), and contained about 1.5 – 2.5% SOM whose chemical composition was highly complex (~80 compounds) and fairly similar to the SOM of field soil – regardless of the form of organic carbon that the organisms received.

In a recent review of 197 research publications, Bhattacharyya et al. (2022) concluded that, given the central role of soil life in soil carbon cycling, agricultural practices must restore the soil microbial community in order to enhance and stabilize SOC sequestration. This was further confirmed by Franzluebbers (2018a) who found that total SOC and soil microbial biomass C are both highly correlated with "soil test biological activity" (STBA), a three-day soil respiration measurement under controlled laboratory conditions.

Slide 16 – *An ancient partnership: how to feed the soil*

Plant nutrition is a two-way exchange, in which photosynthesis provides nourishment for the soil life, in the form of root exudates. In addition to the "bread and butter" of sugars and amino acids, the roots of each plant species secrete other substances that act as specific chemical signals to stimulate and host those soil organisms most beneficial to that plant. In turn, the resulting root zone microbiome facilitates uptake of the nutrients the plant needs to thrive. This relationship evolved some 450 million years ago when plants and their mycorrhizal fungal symbionts first colonized the land and began converting gravel, sand, silt, and clay into living soil.

Thus, the best practices for feeding the soil life exemplify or mimic this ancient partnership by providing a diversity of living plant roots to support a diverse and fully functional soil food web.

Slide 17 - *How to enhance root exudation and build MAOM*

Plant root exudates provide the "raw materials" for microbial processes to build MAOM. Prescott et al. (2021) identified three key strategies for optimizing root exudate production. First, providing water and nutrients, especially N and P, at rates *slightly below the optimum for aboveground growth* will not slow photosynthesis itself; rather, it creates a surplus of organic carbon, which the plant sends into the root system to enhance root growth and root exudation. This, in turn, feeds soil microbes and supports MAOM formation and long-term soil carbon sequestration. Yields are usually not affected, and reduced inputs may improve net returns.

Second, include legumes in the rotation or pasture mix. Unlike soluble N from synthetic fertilizer, fresh manure, or poultry litter, legumes supply N in organic forms (amino acids), which, combined with sugars, provide a particularly nourishing root exudate for optimum microbial growth and function.

Third, in rotational grazing, allow the forage to recover completely and go through most of its rapid growth phase (during which root exudation is greatest) before grazing again. This can optimize the SOM accrual benefits of livestock grazing systems. Grazing too soon (incomplete recovery) or too late (overmature forage) reduces net annual exudation and MAOM formation.

Organic Farming Practices and Soil Organic Matter (Slides 18-25).

Slide 19 – *Does organic farming build soil organic matter?*

The slide shows three meta-analyses that found higher levels of soil organic matter (SOM) or soil organic carbon (SOC ~ SOM X 0.5) under organic versus conventional management.

While the "humic substances" reported by Ghabbour et al. (2017) are likely an artifact of the alkaline extraction method, the fact that they were 53% higher for organic fields while the difference in total SOM was only 13% suggests a qualitative difference between the SOM in conventional versus organic fields. This might be related to the differential impact of conventional versus NOP-compliant inputs on the soil microbiome.

Total SOM accrual lags behind microbial biomass, microbial enzyme activity, and active SOM (Lori et al., 2017) because MAOM formation is a gradual process supported by microbial activity over a long period of time.

Other reviews and meta-analyses conducted since the Ghabbour et al and Lori et al studies have also shown significantly higher SOM in organic than in conventional systems (Mandal et all, 2020; Smith et al., 2019).

Although part of the SOM accrual in organically managed fields can be attributed to the application of organic amendments from off-farm sources rather than in-situ C sequestration (Gattinger et al., 2012), diversion of organic residues (manure, food waste, yard waste, leaves) from lagoons or landfills to field application (either directly or after well-managed composting) represents a substantial reduction in net GHG emissions. Composting converts about half of feedstock into stable organic matter and half into CO_2, while organic materials in landfills and lagoons emit considerable amounts of methane (CH_4), a potent greenhouse gas (25 X CO_2).

Slide 20 – *Long-term farming systems trials*

Organic systems have accrued more SOM than conventional corn-soy rotations in six long-term farming systems trials (Delate et al., 2015b). The organic rotations included cover crops and often a perennial legume or legume-grass sod phase, which increases the depth, biomass, and seasonal duration of living roots, and thus plays a major role in building SOM (Wander et al., 1994). The NOP Crop Rotation standard requires cover or sod crops for good reason. Researchers at University of Minnesota found that a two-year "organic" corn-soy rotation can degrade soil health and invite weed problems, while a four-year organic corn-soy-cereal-alfalfa rotation improves soil conditions and reduces weed populations (Moncada and Sheaffer, 2010).

After 13 years, organic rotations in the Beltsville, MD long term trial had substantially higher total SOC levels (surface to 39-inches) than no-till corn-soy with conventional inputs (Cavigelli et al., 2013). The organic rotations included cover crops, light applications of poultry litter (0.7 – 1.3 t/ac annually), and routine tillage, which shows that some tillage in conjunction with tight rotations, cover crops, organic amendments, and sound organic nutrient management can be compatible with significant gains in SOM and soil health.

Slide 21 – *Four NRCS principles of soil health*

The NRCS principles of soil health provide a roadmap for cropland soil management and for building and maintaining desirable SOM levels. Research has abundantly validated these four principles as guidelines for building SOM, sequestering carbon, and developing healthy, resilient soils for long term system sustainability and risk reduction.

Organic farmers minimize soil disturbance by avoiding synthetic inputs, using NOP-allowed pesticides only as a last resort when other NOP-allowed strategies fail, and tilling with care and only when needed. No-till conservation farmers minimize soil disturbance by eliminating most physical disturbance and through judicious and conservative use of synthetic fertilizers and pesticides. Both approaches can support substantial gains in the quantity and quality of SOM.

Slide 22 – *Organic farmers use more cover crops*

In a survey of specialty crop (vegetables and/or fruit) producers in Michigan and Ohio, USDA certified organic producers were significantly more likely than non-organic producers to plant cover crops and were *much* more likely to plant legumes to provide N, to plant buckwheat, and to use complex multi-species cover cropping systems (Schoolman & Arbuckle, 2022). Non-organic growers who used cover crops most often chose a grass cover crop, usually rye. Farmers who described themselves as "organic in practice" though not certified reported a frequency and complexity of cover cropping intermediate between conventional and certified organic. This suggests that both farmer commitment to soil stewardship and NOP requirements impel certified organic vegetable growers to adopt high-level cover cropping practices.

In a nationwide survey of certified organic producers, Organic Farming Research Foundation found that 78% of organic vegetable farmers and 76% of organic field crop farmers grow cover crops "often" or "very often" (Snyder et al. 2022). In contrast, only about 10% of conventional field crop producers use cover crops regularly, and while cover crop acreages rose 50% between 2012 and 2017, only 4% of US cropland was cover cropped in 2017 (Hellerstein et al., 2019).

Slide 23 – *Diversified crop rotations on organic farms*

One of the main differences between the organic systems and the conventional systems in LTAR trials (slide 19) is that the organic systems include longer, more diverse rotations with greater continuity of living vegetative cover. These systems reflect common conventional and organic practices in the regions of each LTAR. Greater crop diversity and enhanced continuity and depth of living root in organic rotations that include a perennial forage phase contribute to the higher SOM levels in the organic systems (Wander et al., 1994).

Slide 24 – *Soil health challenges in organic farming*

Tillage alters soil environments and can harm key soil organisms. Organic farmers are generally cognizant of the soil health costs of tillage and seek to minimize these impacts. Ever since no-till research and practice took hold in the conventional agricultural sector in the 1970s, organic farmers have likewise sought to reduce the intensity and frequency of tillage and thereby conserve SOM and soil life. Although continuous no-till is not practical in organic annual cropping systems, many organic farmers use shallow non-inversion tillage or rotational no-till (roll-crimping cover crops for no-till cash crop planting). Integrated weed IPM can reduce the need for frequent cultivation, and prompt planting after tillage minimized bare fallow.

In addition to improving crop nutrition, health, and stress-resilience, root-symbiotic mycorrhizal fungi can substantially enhance the formation and stabilization of SOM. However, when soil phosphorus levels rise above the optimum range for crop production, mycorrhizal fungi tend to go dormant and root colonization by these fungi declines or ceases. Intensive organic production systems that rely on compost or manure for fertility often accrue excessive soil test P levels and may thereby lose the vital functions of mycorrhizae (Douds, 2009; Rillig, 2004; Van Geel et al., 2017). However, improved organic nutrient budgeting and management strategies, including legume cover crops, low-P organic N sources, and compost / manure rates based on soil test P, show considerable promise for overcoming this soil health challenge (Cavigelli, 2020).

Because the release of plant-available N from organic sources depends on biological processes, the amount and timing of N provision is harder to predict and manage than N from soluble inorganic fertilizers. Historically, organic farmers, often on the recommendation of crop consultants, have applied organic N sources at “agronomic rates” based on estimates of N availability, such as 50% for manure or poultry litter, and as little as 10-25% for finished compost. This has resulted in applications of *total* N as high as 300 – 1,000 lb/ac, often along with excesses of P, other nutrients, and soluble salts. After several years’ application of these high total N rates, biological N mineralization can lead to heavy leaching or denitrification, as well as soil imbalances that compromise marketable yield or quality. Excess soluble N also alters the soil-plant microbiome in ways that reduce its capacity to build and stabilize SOM or to deliver N to crops efficiently, thereby perpetuating reliance on heavy nutrient inputs.

A recent global meta-analysis has shown that using organic N sources at rates based on their *total* N content rather than estimated "plant-available N" reduced N leaching substantially without compromising yield (Wei et al., 2021).

Recent research has shown that healthy, biologically active soils under best organic management practices can develop an enhanced capacity to deliver N from cover crop residues and SOM to growing crops, thereby reducing the need for N inputs and the risk of N leaching or denitrification (Bowles et al., 2015; Kloot, 2018; Robb & Zehnder,2016). In multi-site studies in the southeastern US, one-third of sites had sufficiently high soil biological activity and N mineralization capacity to reduce the economic optimum nitrogen rate (EONR) to *zero* for corn grain, corn silage, or fescue forage (Franzluebbers, 2018b, Franzluebbers et al.,2018a). Again, organic practices enhanced both SOM and soil biological capacity to supply crop-available N without external inputs (Franzluebbers et al., 2018b, 2020).

Slide 25 – *Organic practices, microbial biomass, and SOM*

A global meta-analysis showed that the use of organic fertilizers and soil amendments in lieu of soluble NPK fertilizers more than doubled total microbial biomass, with increases in both fungal and bacterial components, while simply omitting fertilizer of any kind reduced microbial biomass by 14% (Morugán-Coronado et al., 2022). A review of multiple meta-analyses showed that organic N sources also enhanced SOM over conventional N (Young et al., 2021).

Reduced tillage – non-inversion tillage to 4-6 inches in lieu of inversion plowing to 8-10 inches – nearly doubled fungal, bacterial, and total microbial biomass, while strict no-till only enhanced fungal biomass by about 28%. The authors attributed this finding to reduced soil porosity and aeration in the no-till systems (Morugán-Coronado et al., 2022). Many organic farmers use some form of reduced-intensity tillage including newer tools such as the high-speed disk, rotary harrow, or vertical tillage implements, or simply by operating rototillers at reduced PTO speeds (Kuepper & Schahczenski, 2020; Shade, 2021).

Crop diversification practices like rotation and intercropping enhanced microbial biomass by about 20%. Given the central role of the soil microbiome in processing organic materials into SOM and building stable MAOM, this analysis suggests that integrated systems that include organic fertilizers and amendments, diverse cropping systems, and judicious, shallow, non-inversion tillage may be especially effective in building SOM and soil health.

In another global meta-analysis, Crystal-Ornelas et al (2021) showed that organic systems that used organic amendments or reduced tillage had 24% and 14% higher total SOM, respectively, than organic systems that did not implement these practices. Cover cropping improved SOM gradually over time, showing significant differences after 5 or more successive years of using cover crops. Conversely, the SOM benefit from conservation tillage by itself decreased somewhat over time. The authors cited a need for more research into the benefits of combining multiple organic practices – reduced tillage, cover cropping, and organic amendments – to long term SOM accrual and soil health.

<u>Functions of Soil Organic Matter</u> (Slides 26-34)

Slide 27 – *SOM function: crop nutrition*
Slide 28 – *SOM components and crop nutrient cycling*

As soil life converts plant residues, manure, and other organic inputs into active and stable organic matter, most of the nitrogen (N), phosphorus (P), and sulfur (S) in the residues become integral parts of the organic matter and are gradually released to plants through further action of soil organisms on the active fraction. Potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), and some micronutrients are released from residues into the soil as soluble cations. Negative charges on stable mineral-associated organic matter (MAOM) contribute to the soil's *cation exchange capacity* – its ability to adsorb and hold cations in a plant-available form.

Soil organic matter can also hold micronutrients through chelation, a process that can make scarce trace elements more plant-available yet reduce solubility of potentially toxic excesses of aluminum (Al) or iron (Fe), thereby protecting plant health.

In addition, soil minerals hold large nutrient reserves, particularly potassium (K), other cations, and micronutrients, which are gradually converted into plant available forms through the action of soil life and plant roots on the mineral component of the soil (biological weathering).

The capacity of SOM and soil life to provide for crop nutrition through these processes is a key attribute of healthy agricultural soils. One notable aspect of soil health and plant nutrition is the depth of soil profile that is accessible to plant roots. While biological activity is slower at depths below 6 – 12 inches, plant roots with their associated microbiomes can grow as deep as five feet or more, retrieving leached nutrients (N, S, sometimes others), and accessing K and other nutrients from soil mineral reserves.

The plant root zone or rhizosphere – those parts of the soil within a millimeter or so of the surfaces of living roots – hosts much higher microbial populations than bulk soil. In healthy soils under optimum organic management, this soil-plant microbiome facilitates the conversion of organic N, P, and other nutrients to plant available forms at or near the root surface for efficient uptake with minimal losses via leaching or denitrification. For example, organic tomato crops in California have thrived and given top yields in soils with nitrate-N concentrations as low as 5 ppm, a level normally associated with crop N deficiency (Bowles et al., 2015).

Slides 29 and 30 – *SOM function: structure, porosity, water, and air*

The creation and maintenance of good soil structure (aggregation or "tilth") requires the ongoing activities of a diverse community of soil life including earthworms, plant roots, and other macro-organisms which create macropores and channels; bacteria whose metabolites include carbohydrate "glues" that hold mineral soil particles together in micro-aggregates, and fungi whose mycelia further assemble the micro-aggregates into macro-aggregates.

Note that the soil surface should remain covered by crop canopy, crop residues, or organic mulch as much as possible to protect it from raindrop impacts. Even the healthiest soil will begin to crust over or wash away under the impacts of severe downpours, which are becoming more common with climate change. The cover breaks the force of falling raindrops and allows the water to trickle gently into the soil surface.

The more water the soil can absorb and store in it pore space during rainfall, and the deeper the profile of unrestricted soil, the better crops can obtain the moisture they need and withstand the dry spells which are also becoming more frequent with climate change.

Porous soils with high water holding capacity also play a role in protecting the Chesapeake Bay as reduced runoff means less nutrients and sediment into streams flowing into the Bay.

Slides 31 and 32 – *SOM function: habitat for soil organisms*

The soil life continually reproduces itself and recreates habitat, building SOM in the process. Fresh residues provide food and habitat for soil organisms that live near the surface and need protection against desiccation and temperature extremes. Additional habitat is created throughout the soil profile by the activities of soil organisms, plant roots, and their exudates.

Healthy soils with sufficient SOM generally reduce crop disease problems by breaking or weakening the "plant disease triangle" in several ways. Soils rich in SOM and biological activity have better structure and drainage, making the environment (E) less conducive to most pathogens. Biologically active soils often have higher populations of beneficial organisms that consume or suppress pathogens (P). Plant disease mitigation is an especially important function in warm, rainy regions such as Virginia.

Organic management has been shown to support beneficial soil organisms while agrichemicals may suppress them, leaving the soil more friendly to certain pathogens (Abdelrazek, 2018; Ariena et al., 2015). Some rhizosphere microbes supported by healthy soil with sufficient SOM induce systemic resistance (ISR) to foliar pathogens (Abdelrazek and Hoagland, 2017; Zubieta and Hoagland, 2017), making the crop a less favorable host (H).

Slide 33 – *SOM function: Climate stabilization and resilience*

Building SOM generally improves crop and livestock resilience to weather extremes, climate disruption, and biotic stresses such as pests and diseases. In addition, since SOM is about 50% carbon, an increase in SOM from 2% to 3% in the top 7 inches of the soil profile (roughly 1000 tons per acre) might represent sequestration of 5 tons of carbon per acre, or removal of 18.3 tons of CO_2 from the atmosphere. Carbon in composted materials from off-farm sources represents GHG mitigation if their alternative fate is landfills, manure lagoons, or incineration.

Managing soil N to mitigate nitrous oxide (N_2O) emissions poses a challenge for organic producers, since this potent greenhouse gas (global warming potential 300 X CO_2) is formed in N-fertilized soils whenever high moisture levels (80% water filled pore space) coincide with high biological activity, ample digestible organic materials (residues + active SOM), and soluble N (nitrate and ammonium). When organic nutrient management provides a lot of N at once to support a heavy feeder like corn or broccoli, for example, by plowing-down an all-legume green manure, a large burst of N_2O emissions may follow the next heavy rain. On the other hand, organic systems managed to maximize tight N cycling and minimize reliance on concentrated N sources can curb N_2O emissions. More research on this topic is needed.

Slide 34 – *SOM function: waste management*

The waste management function includes decomposition or de-activation of toxic substances from unintended introduction of industrial pollutants, chemical contaminants in compost or manure, and residues from pesticide applications. Stable SOM can bind up many toxins, especially heavy metals, and soil microbes have shown considerable capacity to evolve and "learn" to consume some petrochemicals, converting them to less-harmful substances.

Polyfluoro- and perfluoro-alkyl substances (PFAS, aka "forever chemicals") have emerged as a potentially serious contamination problem for agricultural soils and water resources. More research is needed on the efficacy of building SOM and soil biological activity in reducing the health and environmental hazard posed by PFAS.

When it comes to everyday "garbage," soil organisms are the world's greatest waste managers. In this time of soil loss and degradation, all organic residues from manure to food scraps, yard trimmings, and autumn leaves can and must be returned to agricultural soils with a priority for those that have become degraded or worn-out. With the possible exception of severely contaminated materials, there is no such thing as "organic waste" unless we waste it.

Building Soil Organic Matter in Agricultural Soils – Best Organic Practices and Farm Stories (Slides 35-47)

Slide 36 – *The living plant is the farmer's #1 tool for building soil organic matter*

Design crop rotations to maximize vegetative cover, diversity, and living root. Cover crops, sod crops, and crop rotations are emphasized in the NOP standards and NRCS working lands conservation programs because living plants are the ultimate source of SOM. Photosynthesis creates the raw materials for plant growth, crop yield, and sustaining soil life. Plant cover protects the soil surface from overheating, desiccation, crusting, and erosion. Living roots work with the soil life to build and maintain SOM and support all the functions of a healthy soil, including resilience to extreme and erratic weather related to climate changes.

Slide 37 – *Organic amendments play a complementary role*

Organic amendments, especially finished compost, can work in a complementary and synergistic manner with living plants to build SOM and soil health (Delate et al., 2015a; Hooks et al., 2015; Hurisso et al., 2016). The compost adds stable SOM and may help stabilize the SOM deposited by crop roots. Brennan and Acosta-Martinez (2017) found that cover crops support microbial activity while compost builds stable SOM, which together promote soil health and fertility. Other studies have shown that compost and cover crops work together better than either alone (Hurisso et al., 2016), and biochar builds SOM and boosts crop yields while curbing N_2O emissions (Young et al., 2021).

In a long-term study of organic farming systems in Washington State, Bhowmik et al. (2016, 2017) showed that organic vegetable rotations fertilized with a finished compost based on dairy manure, bedding, and yard waste (C:N ~20:1) resulted in substantially higher levels of active and total SOM and soil microbial activity than the same rotation fertilized with poultry litter (C:N ~7:1). Total N rates for the two systems were equivalent, as were crop yields.

Slide 38 – *Stack practices to build SOM and soil fertility.*

Integrated systems of practices generally yield greater benefits than single practices such as compost without cover crops or vice versa. As noted above, organic rotations that integrate multiple soil health practices have sequestered significantly more SOC than conventional rotations in long-term farming systems trials across the US (Cavigelli et al., 2013; Delate et al., 2015b). Light applications of compost that do not aggravate P surpluses may be sufficient to provide synergistic benefits, and reducing tillage can further enhance outcomes.

In a recent meta-analysis of 36 studies comparing organic systems using different practices and inputs, Crystal-Ornelas et al (2021) found statistically significant increases in SOM from organic amendments or conservation tillage. Eight of these studies compared systems with vs. without cover crops and showed a gradual increase in SOM over multiple seasons with cover cropping.

While continuous no-till is not feasible for organic producers, many other tools and techniques exist that can reduce the SOM costs of necessary tillage. These include strip tillage (photo on slide), ridge tillage, spading machine (deep, non-inversion primary tillage), rotary harrow (shallow tillage), and even a rototiller operated at low PTO speed to avoid pulverizing surface aggregates (Schonbeck et al., 2017).

Slides 39 and 40 – *Farm story: building SOM in a sandy coastal-plain soil*

Rick and Janice Felker of Mattawoman Creek Farms in Cape Charles, VA (Eastern shore) grow 11 acres of organic vegetables for a CSA, including 1/3 acre under high tunnels. Outdoor crops are grown in rotation with a winter rye + hairy vetch cover crop, which is planted over the entire field (beds and alleys) to maximize biomass. In spring, the cover crop is mowed, pulled onto bed tops with a front-mounted disk bedder and mixed in shallowly with a rear mounted tiller. After allowing the cover crop to break down for a few weeks, the farmers add organic soil amendments and till 3-4 inches deep to prepare the seedbed.

For later-planted vegetables, the cover crop is mowed to a higher (1 ft) stubble height and allowed to regrow, thereby enhancing biomass and N fixation by the vetch.

Tillage is done with a tractor-drawn rototiller with the PTO on a low gear and a forward speed of about 2.5 mph to get the job done with less damage to soil structure. Many farmers operate their tillers at maximum PTO speed with a forward speed of 1 mph, which creates a finely pulverized seedbed that crusts over and erodes easily.

Despite annual rotary tillage, soil health and fertility have improved steadily over the farm's 20+ years of operation. The sandy topsoil has developed visible crumb structure, SOM has climbed to 2.0-2.2%, and crops no longer need midseason fish fertigation. Rick attributes this success to several management factors:

- Lower-intensity rototilling.
- Controlled traffic with permanently positioned beds.
- Subsurface (3-4 inches) drip irrigation to encourage deeper rooting.
- Tight, diverse rotations with same-day bed flips.
- Returning all crop residues to the soil.

Slide 41 – *Animals help build SOM.*

Early leaders in the organic movement, including George Washington Carver, Ehrenfried Pfeiffer, and Sir Albert Howard, emphasized the importance of crop-livestock integration for building soil fertility and ecological balance. More recently, research has shown that manure (fresh or composted) can work in a complementary manner with cover crops and other plant-based inputs to build soil microbial diversity and enhance quantity and quality of SOM.

Slides 42 and 43 – *Farm story: soil and watershed stewardship in a crop-livestock system.*

CJ Isbell manages 340 acres in a crop-livestock integrated operation in the Chesapeake Bay watershed. His innovative and effective stewardship practices have restored Piedmont soils with a history of erosion and protected the Chesapeake while making a good living marketing pastured beef, pork, poultry, and eggs. He grows mixed annual cover crops for warm and cool season forages, which are rotationally grazed to provide the bulk of nourishment for the beef cattle. Steeper land remains in perennial sod to provide forage when cover crops are not ready for grazing.

In 2020, he received recognition as the Virginia Farmer of the Year. In the farmer's words, "Keenbell Farm practices intense rotational management of all livestock raised. Most are moved daily, but at a minimum of every three days, allowing for natural distribution of manure and preventing the buildup and potential runoff of nutrients. Being in the Chesapeake Bay watershed, we decided to install exclusion fencing—at twice the minimum buffer from water—to keep livestock out of the farm's lake and streams and to stimulate wildlife refuge areas. We use precision agriculture with grid sampling and variable rate fertility application as well as planting multi-species cover crops to sustain a living cover and as a key component in our crop production cycle that has nearly eliminated the need for routine chemical applications. Through these measures we've been able to practically double soil organic matter, reducing erosion and increasing water/nutrient holding capacities and reducing runoff potential."

For the full story, see https://www.valor.alce.vt.edu/index/isbell.html.

In a 2021 conversation with the presenter of this webinar, CJ noted that the farm is always changing and adapting practices based on what works, and also depending on both random weather variability and climate change. Extreme amounts of precipitation may warrant new approaches such as drilling annuals into existing perennial sod. If soil is wet, CJ avoids drilling (heavy equipment compacts soil) and uses a light tractor to broadcast the seed, after which he either lets his cattle tramp it in or incorporates it with a light drag. In addition, a crop such as rye may be grazed, hayed, or harvested for grain depending on crop condition, and the biomass balance among rye, weeds, and undersown clovers.

Slide 44 – *Additional organic practices to build SOM*

First, stop the thief of soil erosion. Both wind and water erosion selectively remove the most fertile, SOM-rich fractions of topsoil, and is thought to be responsible for 6% of total human caused GHG emissions (Lal, 2003). Annual crop production on slopes greater than 3-5% inevitably leads to soil erosion losses, especially in a high-rainfall environment like Virginia.

Sloping land should either be devoted to perennial production systems that do not require tillage, or should be terraced, strip-cropped, or alley-cropped on contour with alternating strips or rows of perennial and annual crops.

NOP-allowed pest and weed control materials should be used with discretion and mainly as a last resort. Vinegar for weed control has suppressed mycorrhizal activity and copper based fungicides have been shown to reduce microbial biomnass (Atthowe, 2010; Merrington et al., 2002)

Crop cultivars and livestock breeds selected for regional adaptation and for organic production systems can reduce input requirements, including N applications and cultivation for weed control, both of which can save SOM as well as money.

Field observations over time can provide sound guidance on outcomes of efforts to build SOM and soil health. Watch long-term trends in total SOM on the standard soil test or use a soil health evaluation tool such as the Cornell Comprehensive Assessment of Soil Health (CASH), which includes a panel of physical, chemical, and biological parameters of soil health including active and total SOM as well as microbial activity.

Slides 45 and 46 – *Farm Story: permaculture terraces for soil conservation.*

Lee and David O'Neill established Radical Roots Farm in the year 2000, producing five acres of mixed vegetables on a south-facing hillside in central Virginia. Some of their fields are moderately sloping (5-10%) with a land capability class of 3e, indicating a need for robust conservation measures to prevent erosion. In 2005, they applied their permaculture training to plan and install a series of berm-and-swale terraces on contour, designed to retain and conserve moisture and nutrients during heavy rains, provide level areas for growing annual crops, and minimize the possibility of erosion.

Berms are planted with diverse herbaceous and woody perennial plants, and swales are maintained in sod and provide access to the growing area, which consists of a series of eight to ten raised beds within each terrace. The farmers also installed a small irrigation pond below one of the berms, supplied by roofwater catchment and occasional runoff from swales during heavy rains.

The berm plantings include coniferous trees as windbreaks and buffers along farm boundaries; apple, Asian pear, and other tree fruit; native berries including elderberry, serviceberry, and chokeberry (Aronia); and herbaceous perennials that provide medicinal herbs and habitat for pollinators and natural enemies of crop pests. Alders are coppiced periodically to provide wood chips to mulch fruit trees (which enhances beneficial fungi that help these crops thrive). In addition to planted species, black locust has come up volunteer, some of which they plan to remove to reduce shading and competition against other desired species.

The terrace system keeps the soil in place while cover crops, diverse rotation, compost tea, other organic amendments, and reduced tillage build SOM and biological activity in the vegetable beds. While the fruit trees and berries have produced well in some years, the farmers consider biodiversity – above ground and below ground – as their primary benefit from the perennial planting. "We used to see maybe 20 species of birds; now we see hundreds of species," Lee observed. "The pond has amazing biodiversity, with herons, snapping turtle, and bald eagle."

Slide 46 – *Summary – how to have more SOM: grow it, add it, save it*.

Slide 47 – Questions?

Feel free to contact me at schonbeckmark@gmail.com, and visit https://ofrf.org/research/reports/ for soil health guides and other publications on organic agriculture research and practice.

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