Why “Organic” Matters: Soil Organic Matter, Soil Health, and USDA-Certified Organic Farming

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Presentation Notes

Soil Organic Matter and the Organic Farming Method: a Brief History (Slides 2-9)

Slide 3 – *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 4 - *History of Organic Farming: 1896 – early 1900s*

When Africans were enslaved and brought to the Americas, 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.

References:

- White, Monica M. 2018. *Freedom Farmers: agricultural resistance and the Black freedom movement.* The University of North Carolina Press, 189 pp. Life and work of George Washington Carver discussed on pp 38-48.
- Wikipedia entry on George Washington Carver, https://en.wikipedia.org/wiki/George_Washington_Carver.

Slide 5 – *Soil Conservation and the 1930s Dust Bowl*

In the 1920s, when Hugh Hammond Bennett first 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.

References:

- Hugh Hammond Bennet biographical summary, NRCS https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/about/history/?cid=nrcs143_021410.
- Quotes from HHB speech, January 31, 1933, NRCS https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/about/history/?cid=nrcs143_021397.

Slides 6 and 7 – *History of Organic Farming – 1940s*

Drawing on the work of George Washington Carver, German philosopher Rudolf Steiner, and others, early proponents of organic agriculture 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.

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- Howard, Sir Albert. 1947. *The Soil and Health: a Study of Organic Agriculture*. University of Kentucky Press (re-published 2006). Pages 26-32.
- Wikipedia entry for Lady Eve Balfour, https://en.wikipedia.org/wiki/Lady_Eve_Balfour.

Slides 8 and 9 – *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.

Reference:

- USDA Organic Regulations, https://www.ams.usda.gov/rules-regulations/organic.

The Nature of Soil Organic Matter: SOM is a process as well as a substance (Slides 10-15)

Slide 11 – *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 indicates 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 12 – *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 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, and are mostly formed during the alkaline extraction procedures historically used to analyze for stable SOM (Grandy & Kallenback, 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 adsorbing 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, and decomposition of MAOM can also accelerate under certain circumstances.

References

- Dynarski, K. A., D. A., Bossio, and K. Scow. 2020. *Dynamic stability of soil carbon: reassessing the "permanence" of soil carbon sequestration*. Frontiers in Environmental Science. Vol 8 (November 2020). https://doi.org/10.3389/fenvs.2020.514701.
- Grandy, S., and C. Kallenbach. 2015. *Microbes drive soil organic matter accumulation in organic cropping systems*. Recording from the Organic Agriculture Research Symposium, LaCrosse, WI February 25-26, 2015, http://eorganic.info/node/12972.
- Lehmann, J., and M. Kleber. 2015. *The Contentions Nature of Soil Organic Matter*. Nature 528:60-68.

Slide 13 – *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. 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 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.

References:

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Slide 14 – *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.

Reference:

- Weil R. R., and N. C. Brady. 2017. *The Nature and Properties of Soils*. 15th Edition.

Slide 15 - *How to Enhance Root Exudation and Build MAOM*

Going just a little "lean" on water and fertilizer, especially plant-available N and P, will somewhat slow aboveground growth without adversely affecting photosynthetic rate and with little effect on yield or quality. This results in a surplus of organic carbon, which the plant sends into the root system, stimulating both root growth and root exudation, which in turn feeds soil microbes and enhances MAOM formation and long-term soil carbon sequestration.

Unlike soluble N from synthetic fertilizer or 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.

In rotational grazing, allowing the forage to recover completely and go through most of its rapid growth phase (during which root exudation is greatest) before grazing again 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.

Reference:

- Prescott, C. E., Yi. Rui, M. F. Cotrufo, and S. J. Grayston. 2021. *Managing plant surplus carbon to generate soil organic matter in regenerative agriculture*. J. Soil & Water Conservation 76(6): 99A-104A.

<u>Organic Farming Practices and Soil Organic Matter</u> (Slides 16-24).

Slide 17 – *Does organic farming build soil organic matter?*

The slide shows three examples of meta-analyses that show higher levels of soil organic matter (SOM) or soil organic carbon (SOC) 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 the organic carbon 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).

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Slide 18 – *Long-term farming systems trials*

The organic systems that accrued more soil organic matter (SOM ~ SOC X 2) than conventional corn-soy rotations in six long-term farming systems trials included cover crops and often a perennial sod crop. The perennial legume or legume-grass sod phase in the organic rotations increases the depth, biomass, and duration / continuity of living roots, and thus plays a major role in SOC accrual in these systems (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 corn-soy rotation with NOP-allowed inputs can degrade soil health and invite weed problems, while a four-year organic corn-soy-cereal-alfalfa rotation improves soil conditions.

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.

References:

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Slide 19 – *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 20 – *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).

References:

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Slide 21 – *National Organic Standards limit chemical disturbance*

The NOP Regulations prohibit the use of most synthetic materials in organic crop and livestock production and allow certain synthetics within strict guidelines for specific purposes, as stipulated in the "National List." Conventional fertilizers, pesticides, herbicides, fungicides, and soil fumigants are not allowed in USDA certified organic production. Furthermore, organic farmers must first implement cultural, physical, and biological controls, and then use NOP-allowed pesticides (botanical, microbial, natural mineral, or National List materials) only when cultural, physical, and biological tactics fail to provide adequate control of the target pest.

Slide 22 – *Synthetic inputs can hurt soil life and reduce SOM*

Relatively little research has been conducted on the impacts of pesticides, herbicides, fungicides, and soluble fertilizers on soil organisms and soil biotic community function. However, several recent reviews indicate that their impacts, while sometimes subtle, may be significant. In a review of nearly 400 studies, Gunstone et al. (2021) identified negative impacts of all classes of pesticides on earthworms, micro-arthropods, and other soil invertebrates, with 70% of comparisons showing adverse effects on lifespan,mortality, reproduction, biomass, or biotic functions of the organisms studied. The greatest number of comparisons were conducted for earthworms, with nearly 79% of comparisons showing negative impacts.

A meta-analysis of earthworm studies in organic versus conventional systems showed 18% higher earthworm populations and 46% higher earthworm biomass in organic crop production systems with tillage than in the conventional systems (Pelosi et al., 2014)

Since these macroscopic organisms greatly facilitate microbial processing of organic residues into SOM, the impacts of pesticides on SOM development, SOM quality, and soil biological functions, and the benefits of excluding synthetic inputs, merit further study.

Another review identified significant negative effects of agrochemicals on the soil microbiome, including a reduction in mycorrhizal activity and root colonization from glyphosate applied at normal field use rates (Klein, 2019). Since the mycorrhizal symbiosis plays vital roles in SOM stabilization as well as crop nutrition and resilience, glyphosate could hinder SOM formation and carbon sequestration in no-till systems that rely heavily on this herbicide.

A global review conducted at University of Illinois showed that moderate to high rates of synthetic NPK that stimulated crop biomass formation failed to increase SOM and were sometimes correlated with significant SOM losses (Khan et al., 2007).

References:

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Slide 23 – *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 in order to better conserve SOM and soil life. Although continuous no-till is not practical in annual cropping systems that do not use herbicides, organic farmers often use shallow non-inversion tillage or rotational no-till (roll-crimping cover crops for no-till cash crop planting). Integrated weed IPM that reduces the need for frequent cultivation, and tight crop rotations and interplanting to maximize year-round living roots and minimize bare fallow further enhance SOM development and conservation.

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% 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).

References

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Slide 24 – *Organic practices, microbial biomass, and SOM*

A global meta-analysis showed that the use of organic fertilizers and soil amendments in lieu of conventional 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% (Morugan-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 inches or more – nearly doubled fungal, bacterial, and total microbial biomass, while strict no-till only enhanced fungal biomass by about 28%, while bacterial and total microbial biomass showed little change. The authors attributed this finding to reduced soil porosity and aeration in the no-till systems.

This is a notable finding because similar percentages of organic and conventional farmers use some form of conservation tillage and, without herbicides, organic farmers use various forms of reduced-intensity, full-width tillage to manage weeds and cover crop residues (Kuepper & Schahczenski, 2020; Shade, 2021). These include modern tools like the high-speed disk, rotary harrow, or vertical tillage tools, and rototillers operated at reduced PTO speed.

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 "conservation tillage" (reduced till or rotational no-till) 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.

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Functions of Soil Organic Matter (Slides 25-33)

Slides 26 and 27 – *SOM function: crop nutrition; 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 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 brought into the exchangeable (plant available) pools 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, cited above).

Slides 28 and 29 – *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 (shown on slide 29 as yellow squiggles) 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.

Slides 30 and 31 – *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 protective cover 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). Organic management has been shown to support these beneficial organisms while agrichemicals may suppress them, leaving the soil more friendly to certain pathogens (Abdelrazek, 2018; Ariena et al., 2015). Finally, 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).

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Slide 32 – *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. While of the SOM gain may come from imported materials, this still reflects greenhouse gas mitigation if the alternative fate of those materials is wastage via 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.

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Slide 33 – *SOM function: waste management*

The waste management function includes decomposition or de-activation of toxic substances from unintended introduction of industrial pollutants, chemical contaminantss 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.

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 "wastes" 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.

Building Soil Organic Matter in Agricultural Soils – Best Organic Practices (Slides 34-38)

Slide 35 – *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 36 – *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.

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Slide 37 – *Organic amendments + living plants build more SOM*

Organic amendments, especially compost, manure, or biochar, can play a valuable complementary role with living plants in building SOM and soil health. Brennan and Acost-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, cited above).

In a long-term study of organic farming systems in Washington State, Bhowmik et al. (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. The compost-amended soil supported a microbiome that enhanced N mineralization for crop nutrition, yet immobilized excesses of soluble N thereby reducing leaching and N_2O emissions (Bhowmik et al., 2016)

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Slide 38 – *Additional organic practices to build SOM*

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 reduced microbial biomnass (Atthowe, 2010; Merrington et al., 2002)

Crop cultivars and livestock breed 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 outcome of efforts to build SOM and soil health. While lab tests for soil health such as the Soil Test Biological Activity (Franzluebbers, 2018, cited above), and the permanganate oxidizable carbon (a parameter related to active SOM) are not yet widely available through standard soil labs, Cornell University offers a Comprehensive Assessment of Soil Health (CASH) that develops a composite score based on soil physical, chemical, and biological properties.

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<u>Farm Story: Organic practices build SOM and fertility in a sandy soil</u> (Slides 39-41)

Slides 40-41 – *Mattawoman Creek Farms – the starting point, the practices, the outcome*

Working with a Bojac sandy loam (order Ultisols) on the Eastern Shore of Virginia, Rick and Janice Felker maintain a tight diverse crop rotation in fields and high tunnels that exemplifies three of the four NRCS soil health principles – soil coverage, living root, and biodiversity. Their soils remain occupied by living vegetation year-round except for short periods to allow a cover crop to decompose after tilling in. Fields are planted to high biomass cover crops whenever they are not in production, and high tunnel beds are replanted the very day the previous crop is harvested and cleared.

The farmers address the fourth principle – minimize disturbance – by gearing-down the PTO on their rototiller and increasing tractor forward speed to 2.5 mph, which subjects each foot of bed to a shorter instant of less-intense tillage than the standard practice of traveling at 1 mph with the rototiller on "high." This has not only saved SOM but also allowed visible crumb structure to develop despite the sandy texture of their soil.

Organic nutrient sources are used in moderation, carefully calibrated to meet but not exceed crop needs. Over time, the Felkers' integrated soil health practices have built inherent fertility sufficiently that mid-season fertigation is no longer needed.

Slide 42 – 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.