ORGANIC FARMING RESEARCH FOUNDATION

fostering the improvement and widespread adoption of organic farming

Research Summary for Cooperative Agreement on Conservation Benefits of Organic Management

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Refinement of the Short-term Carbon Mineralization Soil Health Assessment

NRCS Resource Concerns (RCs) Addressed:

- Soil RCs: Organic matter depletion.
- Water RCs: Naturally available moisture use (water holding capacity).

Soil test biological activity (STBA), a short-term measurement of soil carbon mineralization (microbial respiration over a 3-day period) has been recommended as a soil health parameter reflecting general microbial activity (Franzluebbers, 2018; Stott, 2019). Aerobic soil microbial activity reaches an optimum level at about 50% water-filled pore space (WFPS) and decreases in wetter soil conditions (Franzluebbers, 2022). Accurate assessments of STBA require a reliable means to bring soil to 50% WFPS before measurements are taken.

Franzluebbers (2022) documented the water relations of 266 agricultural soils representing a wide range of climates and soil types. Relationships between soil texture, % soil organic matter (SOM), and moisture content at near-saturation[1], at water holding capacity after gravitational water has drained out (WHC), and at 50% WFPS were determined. Soil water contents at near-saturation, WHC, and 50% WFPS showed strong curvilinear responses to %SOM and to a lesser degree, clay content. This finding shows that building SOM is especially important for improving WHC in sandy, low-SOM soils.

Drying soil samples at 55°C (a temperature that does not disrupt soil biochemical processes or microbial communities) rather than 105°C (lethal to most microbes) provided a reliable estimate of gravimetric water content. Soil water content at 50% WFPS for the 266 samples was 58% (±3) of water content at near-saturation. **These results provide practical guidelines for adjusting soil to 50% WFPS for an accurate assessment and brings the STBA one important step closer to utilization as a practical tool for routine soil health assessment.**

[1] *refers to a method where water is allowed to wick up into soil in cylinders with the soil surface 25 mm above the water surface*

Effects of Organic Nutrient Sources, Tillage, Cover Crops, and Crop Cultivars on Soil Microbial Communities

NRCS Resource Concerns (RCs) Addressed:

- Soil RCs: Soil organism habitat loss or degradation, Aggregate instability, Compaction, Organic matter depletion.
- Water RCs: Naturally available moisture use (available water holding capacity), Nutrients transported to surface water and groundwater.
- Plant RCs: Plant productivity and health, Plant pest pressure

NRCS Soil Health Principles Addressed:

- Minimize soil disturbance.
- Keep soil covered.
- Maintain living roots.

A growing body of research has shown that:

- organic nutrient sources support a greater functional diversity of soil microbes than conventional soluble fertilizers;
- fertility practices have a greater impact on soil microbial communities than tillage practices; and
- organic farming systems with reduced tillage can enhance the biological activity and health of cropland soils.

In a meta-analysis of 46 studies, organic fertilizers enhanced the abundance of soil bacteria involved in carbon (C) and nitrogen (N) cycling, while conservation tillage reduced the abundance of microbes involved in residue decomposition, and both practices slightly increased arbuscular mycorrhizal fungi (AMF) abundance (Mondaca et al., 2024). In the long-term farming systems trial established in 1981 at Rodale Institute in Kutztown, PA, fertility source (legumes, manure, or conventional soluble fertilizer) strongly influenced the species composition of microbial communities (bacteria, archaea, fungi). Legumes or manure enhanced N-cycling microbial guilds while conventional fertilizer promoted microbes that compete with plants for soluble N and phosphorus (P) and reduced the activity of plant-symbiotic and organic residue-decomposing microbes (Bier et al., 2024). Tillage practices and cover crops affected microbial community structure to a lesser degree. Other trials have shown little effect of tillage on soil organic carbon (SOC) sequestration by cover crops (Peng et al., 2023).

In paddy rice production in Asia, fields converted to ‘natural farming’ (no nutrient inputs from off-farm sources and synthetic pesticides and herbicides) two to five years prior to sampling supported a higher diversity of C and N cycling microbes and saprotrophic fungi and greater structural complexity of soil microbial communities than fields remaining under conventional management (Tatsumi et al., 2023). However, conventional inputs maintained substantially higher yields, crop biomass, and crop root exudation, which supported a greater abundance of C-cycling bacteria.

Field trials established near Zurich, Switzerland in 2009 evaluated a six-year rotation of winter wheat, grain corn, dry pea or bean, winter wheat and two years grass-clover under four systems: conventional with moldboard plowing (8 in), conventional no-till, organic with moldboard plowing (8 in), and organic reduced till (non-inversion to 4 in) (Oliveira et al., 2024). After eight years, both organic systems had higher SOM at 0-4 in, higher water holding capacity (WHC), and less subsurface compaction than the conventional plowed system; and greater mesopore space (10-30 μM) than conventional no-till. Plowing increased macropore space (>30 μM), aeration, and root growth, while the greater WHC and mesopore space in organic systems were correlated with enhanced microbial biomass and diversity (Oliveira et al., 2024). None of the four systems included cover crops and organic systems were fertilized with liquid manure. The authors recommended additional research at multiple sites and with organic systems that utilize legume cover crops and maximize soil coverage, living roots, and biomass inputs.

In organic vegetable production in south Texas, summer cover crops of sorghum-sudangrass, southern pea, or sunn hemp grown before vegetable planting enhanced rhizosphere arbuscular mycorrhizal fungal (AMF) spore counts by 2-3 fold (Soti et al., 2023). Treating crop roots with an on-farm inoculum of indigenous AMF enhanced earliness (maturation timing) in peppers and yield in bunching onions, and root AMF colonization in both, while a commercial AMF product was less effective.

Urban farmers and gardeners often face tough challenges with degraded, compacted soils, and can utilize locally available resources such as municipal leaves, yard trimmings, and food waste to restore soil health. **In a trial in West Lafayette, IN, mixing a 4-inch depth (~67 tons/ac) of municipal leaf compost into the top 2-3 inches of soil effectively restored SOM and fertility in a degraded silt-loam soil, improved tomato yields by 58%, and delayed the onset of foliar diseases** (Richardville et al., 2022). Inoculation with the beneficial fungus *Trichoderma harzianum* improved seedling vigor and the compost enhanced *T. harzianum* populations in the rhizosphere.

Two experimental carrot genotypes that demonstrated high N use efficiency in field trials were shown to support qualitatively different rhizosphere microbial communities compared to three commercial cultivars (Triviño et al., 2023). In greenhouse trials, the experimental lines showed higher rates of rhizodeposition (root exudates and fine root sloughing) which "primed" microbial breakdown of organic residues and enhanced crop N uptake. **These findings indicate a potential for breeding carrots for enhanced capacity to utilize N from organic sources, which could reduce the need for concentrated N and thereby protect water quality and reduce GHG emissions.**

Conservation Benefits of Cropping System Diversity

NRCS Resource Concerns (RCs) Addressed:

- Soil RCs: Organic matter depletion.
- Plant RCs: Plant productivity and health, Plant pest pressure, Plant structure and composition.

NRCS Soil Health Principles Addressed:

- Diversify the system.
- Keep soil covered.
- Maintain living roots.

Intercropping – planting two or more crop species together within a field or production area – is practiced by many organic farmers to build soil health and fertility. Based on survey responses from over 1,100 organic or transitioning to organic farmers in the US, 31% utilize intercropping in their operations (Snyder et al., 2022). This practice is now offered as a CSP crop rotation Enhancement, E328N - Intercropping to improve soil health. Several recent meta-analyses show that intercropping can perform multiple ecosystem services.

Brassica vegetables (kale, broccoli, cauliflower, Brussels sprouts, cabbage) are weak competitors and showed an average of 17% yield reduction when intercropped in conventional production, but no yield loss in organic systems (Carrillo-Reche et al., 2023). **Intercropped brassicas sustained much less pest damage than monocultures, showing that this practice may be especially valuable for organic producers, who do not use synthetic pesticides**. Field trials in the Netherlands confirmed that strip intercropping of cabbage with wheat increased arthropod diversity and reduced abundance of diamondback moth and other cabbage pests. Intercropping cabbage with a diverse crop mix that included wheat further enhanced these benefits (Cuperus et al., 2023).

In US organic strawberry production, semi-natural habitat planting such as conservation buffers enhanced wild bird diversity and increased the abundance of bird species that consume lygus bugs, a major pest of strawberries (Garcia et al., 2023).

Planting mixtures of cultivars of a single crop such as corn, soybean, or wheat can enhance yield stability and resilience to pest, weeds, diseases, and adverse weather, especially when cultivars with contrasting rooting depth, growth habit, or pest resistances are combined (Krekel, 2022; unpublished manuscript).

Optimizing Cover Crops for Soil Health, Carbon Sequestration, and Weed Suppression

<u>NRCS Resource Concerns (RCs) Addressed</u>:

- Soil RCs: Organic matter depletion, Soil organism habitat loss or degradation, Aggregate instability, Compaction, Erosion.
- Air RCs: Emissions of greenhouse gasses.
- Plant RCs: Plant productivity and health, Plant pest pressure (weeds).

<u>NRCS Soil Health Principles Addressed</u>:

- Keep soil covered.
- Maintain living roots.
- Diversify the system.
- Minimize soil disturbance.

Cover cropping is a central practice in organic cropping systems, practiced regularly by 75% of organic field crop producers compared to less than 10% of conventional corn and soybean farmers in the Midwest (Gustafson, 2024; Snyder et al., 2022). **Recent research has contributed to better understanding of cover crop species, soil texture, and management factors in soil organic carbon (SOC) sequestration, weed suppression, and other agro-ecosystem services.**

In a Pennsylvania organic farming systems trial, soil samples were collected after seven years under a corn-cover crop-soybean-wheat-cover crop rotation with cover crops of triticale, crimson clover, canola, a mix of all three, or no cover (fallow). All treatments were fertilized with manure. Soil organic matter (SOM) fractions were analyzed, including free particulate organic matter (fPOM; plant-derived and readily decomposed), occluded particulate organic matter (oPOM; protected in soil aggregates, short-term sequestration), and mineral-associated organic matter (MAOM; microbially derived, long-term sequestration). All cover crops enhanced total SOM and POM fractions compared to fallow, and the legume and three-way mix enhanced MAOM (Kaye et al., 2022). **The mixture combined high biomass (grass, brassica), extensive fibrous root systems (grass), and enhanced microbial activity (legume) to build all SOM fractions and thereby produce a broader spectrum of soil health benefits.**

In an analysis of cover crop versus no cover comparisons in 19 long term farming systems trials across North America, cover cropped treatments sequestered C at an average rate of 240 kg/ha (214 lb/ac) annually, had 8% higher SOC and total soil N concentrations, 15% higher water stable aggregates, and 34% higher microbial activity (Peng et al., 2023). SOC accrual rates under cover crops increased with soil clay content, soil pH, annual rainfall, duration of cover cropping practice, and cropping system diversity. **Tillage had a non-significant effect on SOC accrual under cover crops, which reflects the protective effects of cover crops against adverse effects of tillage such as SOC oxidation and increased erosion.**

Researchers at Colorado State University are refining the COMET Farm and Cool Farm Tool models for estimating net greenhouse gas (GHG) emissions to better account for integrated soil health practices on organic farms, especially cover cropping (Schipanski et al., 2024). In a meta-analysis of 40 studies in temperate climates, cover cropping enhanced SOC by an average of

12%, or 980 lb/ac. SOC accrual was directly related to cover crop biomass, cover crop growing duration, and soil clay content, with a minimum biomass of 890 lb/ac required for SOC sequestration to occur. **Cover crops that attained at least 6,250 lb/ac and provided nearly continuous ground cover between successive cash crops enhanced SOC stocks by 30%.**

Livestock grazing can maintain or enhance the agro-ecosystem services of cover crops. In trials at three sites in western Kansas, cover crop grazing by cattle did not adversely affect soil physical properties (bulk density, aggregate stability, wind-erodibility, etc) and enhanced total soil organic carbon (SOC) stocks and soil test potassium (K) (Simon et al., 2024).

Creeping perennial weeds, especially field bindweed (*Convolvulus arvensis*) and Canada thistle (*Cirsium arvense*), severely constrain organic dryland grain production in the Great Plains and Intermountain West. Intensive tillage or a multiyear alfalfa forage crop can control these weeds but also degrade soil structure (tillage) or deplete soil moisture (alfalfa). Two diversified crop rotations were evaluated as alternative strategies: a lentil-spring wheat-sweet clover (cover crop) rotation and a 9-species cover crop cocktail in years 1 and 3 and wheat in year 2 (Gramig et al., 2024). All treatments were planted in spring wheat in year 4 to evaluate weed suppression. Three years in alfalfa cut twice annually suppressed Canada thistle, perennial sowthistle (*Sonchus arvensis*), and field bindweed far more effectively than the alternative rotations. **Alfalfa provided more intense and consistent competition against the weeds, and forage harvests coincided with the most vulnerable stages of the Canada thistle life cycle.**

Two years of field trials were conducted in upstate New York to determine whether cover crops alter weed species composition or selectively suppress certain weed species. Winter cover crops of rye, hairy vetch, or rye + vetch shifted weed flora by suppressing closely related weeds, while neither canola nor warm season cover crops significantly altered weed flora (Menalled et al., 2023). **High biomass cover crops reduced weed biomass by 95-99%, including rye + vetch or rye alone at 6,250 lb/ac, canola at 4,460 lb/ac, and sorghum-sudangrass at 4,910 lb/ac. While sunn hemp biomass reached just 2,500 lb/ac and reduced weed biomass by two-thirds, buckwheat was an outlier, providing 99% weed suppression despite biomass of only 1,790 lb/ac**.

Orchard Floor Vegetative Cover and Organic Orchard Practices

NRCS Resource Concerns (RCs) Addressed:

- Soil RCs: Organic matter depletion, Soil organism habitat loss or degradation, Aggregate instability, Erosion
- Water RCs: Naturally available moisture use, Nutrients transported to surface water and groundwater.
- Plant RCs: Plant productivity and health.

NRCS Soil Health Principles Addressed:

- Keep soil covered.
- Maintain living roots.
- Minimize soil disturbance.
- Diversify the system.

Recent research documents the ecosystem services provided by organic orchard management systems that include living cover and organic amendments. In multiple studies, orchard and vineyard floor soils under living vegetative cover maintained twice the SOM and substantially better water holding capacity and nutrient cycling compared to bare fallow (Azarenko et al., 2009; Lorenz and Lal, 2016; Rowley et al., 2012; Vicenti-Vicenti et al., 2017). NRCS offers a CSP enhancement, E340D Intensive Cover Cropping for Orchard/Vineyard Floor that can directly operationalize this research's findings.

Conventional management with bare orchard floor maintained by herbicides and tillage has severely degraded and eroded olive grove soils in Andalusia (southern Spain) and has depleted soil organic carbon (SOC) stocks to 30% of levels found under natural vegetation. **In a study conducted in an olive grove under conventional bare soil management, conversion to organic practices including no-till, sheep manure as fertilizer, and natural orchard floor vegetation managed by mowing improved soil aggregation and allowed SOC to recover to 46% of natural levels within four years** (González-Rosado et al., 2023). Without manure, the organic no-till system yielded more gradual increases in SOC and aggregation.

In a study of 19 olive groves in the same region, organic operations that maintained vegetated orchard floor with mowing and grazing, utilized organic fertilizers, and returned olive milling residues (pomace and leaves) as well as prunings to the soil showed much better N use efficiency than conventional operations with bare orchard floor and only prunings returned to the soil (Domouso et al., 2024). **While organic yields were lower, the living cover and residue recycling greatly enhanced SOC and N cycling, reduced N input needs by half and water use by 70%**.

During the first two years of establishment of a table grape vineyard in the Central Valley of California, planting a winter cover crop of phacelia (a native plant species) in alleys enhanced soil microbial biomass, aggregation, water content, and vine vigor (Fernando et al., 2024). Cereal rye generated less biomass and provided the same benefits to a lesser degree.

Organic Nutrient Management, Manure, Green Manures, and N_2O Emissions

NRCS Resource Concerns (RCs) Addressed:

- Soil RCs: Organic matter depletion
- Water RCs: Nutrients transported to surface water and groundwater.
- Air RCs: Emissions of greenhouse gasses.
- Plant RCs: Plant productivity and health.

NRCS Soil Health Principles Addressed:

- Keep soil covered (CGM as N source)
- Minimize soil disturbance (tillage, concentrated N sources).

Carr et al. (2020) reviewed 130 research articles on the use of animal manures, cover crops, and green manures for fertility in organic field crops (corn, soybean, cereal grains, forages) and analyzed findings to identify both nationwide and region-specific trends. Their findings include:

- Cover crops and green manures (CGM) can meet N needs in organic field crops in warm, humid climates (Mid-Atlantic and Southeast) but only part of N needs in colder (Midwest, southern Canada) or drier (Intermountain West) regions.
- No-till cover crop termination often reduces grain yields through N limitation; however, organic soybean (a strong N fixer) planted no-till into roll-crimped rye can achieve high yields.
- Relying entirely on manure for N builds excess soil P and has caused water quality degradation in all humid regions studied.
- Using both manure and CGM builds more SOM than CGM alone. Combining CGM with manure at P-based rates and supplementing with oilseed meals or feather meal if more N is needed can realize this benefit without accruing excess soil P.
- In the semiarid Great Plains and intermountain West, manure is not readily available and can entail prohibitive long-distance hauling costs. As a result, only 15% of organic producers use manure and soil nutrient deficiencies often limit production.
- Recent research has shown that a single application of composted manure (22 tons/ac) greatly improves soil structure, water holding capacity, SOM, nutrient levels, and dryland organic wheat yields for at least 16 years in Utah (Reeve et al., 2012, cited in Carr et al., 2020).
- Crop-livestock integration with grazed forages in the rotation can enhance on-farm nutrient cycling, reduce N input needs, build SOM and soil organic N, reduce N leaching and weed pressure, and improve yields and net returns.

Research is needed to improve synchrony of N release from CGM with cash crop needs, evaluate costs and benefits of a single large manure or compost application for dryland grains, support adoption of crop-livestock integrated systems, and breeding CGM species for enhanced N release and weed control (Carr et al., 2020).

The European Union (EU) has set goals of decreasing nutrient surpluses in agriculture by 50% and fertilizer use by 20% by the year 2030 to address environmental and climate concerns. A central pillar of their strategy is to increase the percentage of agricultural land in organic agriculture (OA) from the current 10% to 25% by 2030. France currently leads the EU in organic acreage and a study was conducted to evaluate N flows, treating the nation's 6.2 million acres of organic land as a single operation (Vergely et al., 2024).

The researchers found that French organic farming is about 80% self-sufficient for N, that N use efficiency is higher than for the nation's conventional farming, and net N surplus (N inputs minus N exports in farm products) is about half that of conventional (Vergely et al., 2024). Livestock-crop integration within or among farms contributes to nutrient cycling and N use efficiency. Remaining vulnerabilities include the need for manure from conventional farms and for imported organic livestock feed to fully meet N requirements. Because the analysis did not account for changes in soil organic N, it could not determine what proportions of the N surplus were leached, denitrified, or immobilized in soil microorganisms and SOM. Recommendations for increasing N efficiency and self-sufficiency of the organic sector include increased use of legumes for biological N fixation and for livestock feed.

Reliance on concentrated organic N sources with a low C:N ratio, such as liquid manure (slurry) or poultry litter has raised concerns about nitrous oxide (N_2O) emissions in organic systems. Experiments conducted in a sandy soil in a cool-temperate climate (Denmark) showed higher N_2O emissions after field applications of cattle and pig manure slurries and digestates from anaerobic methane digesters than from conventional soluble fertilizers applied at equivalent rates of plant-available N (Peterson et al., 2023). Another field trial conducted in a corn-wheat-barley-forage rotation on a silt-loam in Switzerland found similar N_2O emissions from liquid manure, anaerobic digestate, and soluble N fertilizer (Efosa et al., 2023).

Researchers in Denmark compared total GHG emissions (N_2O and CH_4) during storage and after field application of untreated liquid dairy cattle manure (CA), anaerobic digestate of liquid cattle manure (DD), and the liquid fraction after solid separation of the digestate (LF). The organic fertilizers and a conventional N fertilizer were applied at approximately 90 lb N/ac to spring barley grown on a loamy sand soil. DD and LF emitted much less CH_4 during storage than CA, and solid separation further reduced total GHG emissions (Meng et al., 2023). Both processes reduced the organic carbon content of the liquid fertilizer, which may have limited microbial denitrification and methanogenesis. The conventional N fertilizer treatment had the lowest total GHG emissions. However, the analysis did not account for GHG emissions from the solid fraction after solid separation in LF, nor the embodied energy in N fertilizer manufacturing.

Breaking sod can lead to a burst of N_2O emissions (Shrestha et al., 2019) and the vast majority of N_2O emissions in the field trial in Switzerland occurred in the corn crop, which was planted and fertilized immediately after perennial sod was broken (Efosa et al., 2023). In an organic farming system trial in southern Quebec, chisel plowing (non-inversion) and using a legume green manure (GM) to meet part or all of the crop's N requirement reduced N_2O emissions compared to moldboard plowing (inversion) and using poultry manure (PM) to meet N requirements. PM applied at planting released soluble N before crops could utilize it effectively, and labile organic carbon in the PM stimulated microbial denitrification. Significant N_2O emissions occurred when soil water filled pore space exceeded 50% and nitrate-N exceeded 5 ppm.

Organic Livestock Production

NRCS Resource Concerns (RCs) Addressed:

- Water RCs: Naturally available moisture use, irrigation water use.
- Air RCs: Climate change impacts.
- Plant RCs: Plant productivity and health, Plant structure and composition (forage species).
- Animal RCs: Feed and forage imbalance

NRCS Soil Health Principles Addressed: None directly addressed; healthy forages maintain cover and living root.

Researchers conducted a survey of 165 organic pasture-based dairy producers in the Northeast, Midwest, and West Coast regions to identify current organic forage production practices, farmer knowledge and technical assistance needs, and impacts of climate change (Hatungimana et al., 2024). A strong majority of respondents (65-80%) reported that they were somewhat or extremely satisfied with most aspects of their forage production systems and felt that it improved animal health and milk production. **Irrigation emerged as a challenge with forage production for some.** Most producers noted that they "sometimes" experience climate-related impacts including drought, reduced yield or quality, or reduced pasture availability, and half reported that severe weather was somewhat limiting to forage production. However, fewer than one in five reported difficulties in meeting NOP requirements that ruminant livestock derive at least 30% of dry matter intake from pasture during a grazing season of at least 120 days.

Technical assistance priorities reported by survey respondents included:

- Minimum-till pasture renovation and reseeding.
- Selecting and managing forage species and cultivars for climate resilience and whole-season grazing.
- Cost-effective pasture fertilization and composting.
- Optimum harvest timing and storage methods for forage quality.

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